Protection and Restoration of Marine Life in the Inland Waters of Washington State

by
James E. West

May 1997

(Reprinted July 2004)

Puget Sound/Georgia Basin Environmental Report Series: Number 6

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Protection and Restoration of Marine Life in the Inland Waters of Washington State

by
James E. West
Washington Department of Fish and Wildlife

Prepared for the Puget Sound/Georgia Basin International Task Force
Washington Work Group on Protecting Marine Life

with support from
Puget Sound Water Quality Action Team
U.S. Environmental Protection Agency, Region 10

May 1997

(Reprinted June 2004)

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EXECUTIVE SUMMARY

Effective protection and restoration of marine life requires an understanding of the anthropogenic[1] stressors and natural limiting factors affecting those organisms. In addition, changes in the abundance or distribution of any species affects others in the ecosystem, including the types of changes in habitat that occur when abundance of plant species increases or decreases. These factors are not always considered in management schemes.

This report was commissioned by the Puget Sound Water Quality Action Team with funds from the U.S. Environmental Protection Agency, and was written to provide the Washington component of the Transboundary Protect Marine Life Work Group with

- identification of species whose populations have experienced significant declines, or are suspected of being significantly stressed in Washington's inland marine waters,
- evaluation of anthropogenic and natural factors contributing to population declines or other stress,
- evaluation and summary of current management approaches to protecting or restoring these species, and
- recommendation of ways to improve awareness of management agencies to status and trends of stressed species, as well as alternate or additional strategies to restore them and protect them from further loss.

Often resource management seeks to optimize harvest of a species or group. This report is more concerned with protecting declining populations of both harvested and non-harvested species, without discussion of ways to optimize harvest yields.

Thirteen species or groups (Resources) are identified as having undergone substantial declines in regional population abundance in recent years; they are in need of attention now to ensure successful protection or recovery. Resources include three invertebrates (Olympia oyster, pinto abalone, and a grouping of species termed "Unclassified Marine

[1] Literally, "of human origin".

Invertebrates"), six fish species or groups of species (Pacific herring, Pacific cod, Pacific hake, walleye pollock, three species of demersal rockfish, and lingcod), three seabirds (marbled murrelet, common murre, and tufted puffin), and one mammal (harbor porpoise). Although the present report discusses the status and management of the thirteen Resources only in Washington's waters, much of the analysis is applicable to British Columbian waters.

The known and surmised effects on these thirteen Resources of four major anthropogenic Stressors -- harvest, habitat loss, pollution, and disturbance -- are summarized and discussed, using best available literature, expert opinion, and common sense. The effects of Natural Limiting Factors (NLF) on these species are treated similarly. Although no attempt is made to identify the relative degree to which Stressors or NLFs have affected Resources, Stressors are grouped, qualitatively, according to whether their effects are considered major or minor. Recommendations for restoration and better protection of Resources are summarized for each Resource and for each Stressor.

Harvest (targeted harvest or bycatch) is considered a major Stressor on all species except Pacific herring and tufted puffin. Recommendations to reduce this Stressor include better, and regular, assessment of the abundance of all organisms (as a prerequisite to understanding the scope of the problem); maintaining or increasing harvest restrictions on all harvested Resources; modifying harvest gear to minimize entanglements of seabirds and harbor porpoise; quantifying better the sources of seabird and porpoise bycatch-mortality; and establishing a system of Marine Protected Areas that would provide refuge from harvest for several species.

Habitat loss and degradation are considered major Stressors for Olympia oysters and Unclassified Marine Invertebrates and minor Stressors for Pacific herring, Pacific cod, walleye pollock, demersal rockfish, and lingcod. Recommendations for reducing the negative effects of habitat loss on stressed species are detailed and extensive, focusing on protecting the function of nearshore vegetated habitats, including reducing anthropogenic turbidity, sedimentation, and eutrophication of intertidal and shallow subtidal habitats. Specific recommendations include establishing a clearly documented and formalized seagrass and seaweed policy (with a number of stipulations designed to protect the function of these habitats in the ecosystem), monitoring vegetated inter- and subtidal habitats along with the effects of anthropogenic turbidity, sedimentation, and eutrophication, encouraging basic research on the ecological function of nearshore habitats, and enhancing education and outreach programs.

Pollution is considered a minor Stressor on all Resources; however, this categorization reflects more a lack of information regarding the health effects of contaminants on marine organisms, than any meaningful comparison. Contaminant levels already detected in Puget Sound organisms are likely to have some negative effects on reproduction, however, basic research is lacking to quantify this for stressed Resources. Potential effects from episodic disasters like oil spills are beyond the scope of this report. Recommendations focus instead on a better understanding of the extent, nature, and health-effects of historic and current contamination and include (1) expanding existing monitoring efforts to evaluate effects of contaminants on the health or reproduction of Resources known or suspected to experience high exposure to contaminants; (2) continuing research on English sole, and reinstating contaminant monitoring of an invertebrate-indicator, as models of contaminant pathways and effects in Puget Sound organisms; (3) evaluating the effects of chronic, low-level sea-surface contamination on the health and reproduction of seabirds and other surface-oriented organisms; and (4) monitoring baseline contaminant conditions in Puget Sound organisms to better evaluate future changes.

Disturbance as a result of human activities or presence is considered a major Stressor for harbor porpoise and nesting tufted puffins. Substantial efforts to reduce this stressor by protecting nesting seabird colonies have already been implemented; recommendations for better protection include designating areas of low vessel traffic to protect surface-dwelling, noise-sensitive species like harbor porpoise and seabirds.

Natural Limiting Factors affect the population abundance of all organisms; recent shifts in environmental conditions (whether anthropogenic or not) are thought to be factors in recent declines in abundance of Pacific cod, walleye pollock, and Pacific hake in Puget Sound. In addition, variability in prey abundance and its effects on growth and survival of nestlings is considered a potential Natural Limiting Factor for all three seabird species. Climate-related variability in predators of Pacific herring is considered a potential cause for regional declines in adult populations of that species. The potential effects of global warming on Puget Sound's ecosystem are briefly discussed.

The effects of anthropogenic reductions or increases of any species on the overall integrity and function of the marine ecosystem are also considered. Reductions in prey abundance, combined with relative increases in abundance of predators and competitors of Resources, may contribute to the decline of stressed Resources or may prevent their recovery. Examples are provided: fishery enhancement of chinook and coho salmon (by extended-rearing programs) is considered a potential minor Stressor on a number of marine organisms, whether from increased predation by, or competitive interactions with, increased populations of resident salmon. Increased populations of pinnipeds (harbor seals and California sea lions), resulting from their protection by the Marine Mammal Protection Act, are considered a major stressor on Pacific herring, and may be inhibiting recovery of populations of Pacific hake, walleye pollock, Pacific cod, demersal rockfish, and lingcod. Aquaculture of Pacific oysters is considered a major modifier of nearshore marine habitats; however, the extent of the problem and impact on stressed Resources is poorly understood in Puget Sound. Recovery of bald eagle populations is thought to be responsible for abnormally high mortality of nestlings of already-stressed common murres at Tatoosh Island. A significant problem for management is that response of a “healthy” ecosystem to loss or reduction of one species may be an increase in another (or others). In this way, “desirable” species, such as codfishes, may be replaced by “undesirable” species, such as dogfish -- a normal, healthy response of an ecosystem under stress. Resource managers should anticipate changes in community structure and food-web dynamics from the selective removal, enhancement, or protection of any species.

Populations of all species vary substantially as a normal manifestation of the cyclic nature of ecosystem productivity. The species in this report were included in a large part because they are valuable to humans in some way. However, it is clear that all species contribute to the normal function of an ecosystem, regardless of their value to humans. Maintaining ecosystem health relies on our ability to protect the viability of all species to some degree, as well as their habitats. Successful protection and restoration of a healthy ecosystem that can provide sustainable harvests has two important prerequisites: (1) a clear mandate to managers that the ecological connectedness of all species be considered in management schemes, and (2) provision of the resources with which to accomplish this.

Preface and Acknowledgments

In this report I attempted to objectively evaluate the causes of stress in populations of marine organisms experiencing serious declines in abundance. The challenge was to distill highly complex issues into synopses amenable to feasible recommendations, without bogging down in the technical details. Many of the arguments and discussions were speculative, however, I relied on scientifically defensible logic as much as possible, and on consensus of experts or common sense where appropriate. Some recommendations could have been made without much explanation (for example, to continue harvest restrictions on overharvested species), and other ideas required extensive development (e.g., the Ecosystem Effects chapter).

Perhaps the most important, albeit most difficult, issue in protecting marine plants and animals is understanding how our manipulation of one species may affect others -- the ecosystem implications of our actions. This is a serious challenge we face; however, there are steps we can take to tackle the problem. In my interviews with the experts that contributed so valuably to this report, I heard expressed a number of times frustration at the lack of communication that exists among researchers, biologists, and managers. At the inability of "basic" and "applied" scientists to coordinate and complement activities. I challenge us to organize our research in a more directed fashion, with the support of our agencies and employers, and with excellent science, to develop solutions that address the issues raised in the Transboundary Environmental Initiative.

This report gathers information from a wide range of experts working in the Puget Sound ecosystem. I gratefully acknowledge the many experts that contributed through interviews, and the reviewers that spent time helping to make this document accurate and worthwhile. These contributors are listed at the end of the document. Without exception, those interviewed generously shared their thoughts and opinions. In addition, I thank John Armstrong, Holly Schneider-Ross, and Mary Lou Mills for providing encouragement and support. Sandie O'Neill supported my taking leave from my normal Puget Sound Ambient Monitoring Program duties to write the report and Morris Barker (Manager, WDFW Marine Resources Division) granted permission to work on the document.

Although I am an employee of the State of Washington Department of Fish and Wildlife, this report does not necessarily reflect the views, opinions, or policy of that agency. Errors in interpretation and presentation of data or in paraphrasing the thoughts of contributors are my own.

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INTRODUCTION

Alarming declines in populations of plant and animal species in the inland marine waters of British Columbia and Washington have prompted unprecedented collaboration of scientists and natural resource managers from these two regions. In 1992, an Environmental Cooperation Agreement was made between state and provincial governments, to address common concerns about declining environmental conditions and depressed populations of biota in shared marine waters. The Environmental Cooperation Council (ECC) assembled a Marine Science Panel (MSP) of US and Canadian scientists, and in 1994 convened the British Columbia/Washington Symposium on the Marine Environment (Transboundary Symposium). This symposium was designed to evaluate the status of the marine environment and biota of shared waters [Wilson et al. 1994]. The MSP subsequently summarized the Transboundary Symposium proceedings, producing an independent report on the current conditions of, and trends in, shared marine waters [MSP 1994]. The Panel recommended to the ECC twelve specific management actions, addressing priority issues, that should be addressed by combined, coordinated efforts.

Work Groups have been assembled on both sides of the border to address eight of the twelve MSP recommendations. Three Work Groups, focusing on: preventing estuarine habitat losses (Habitat Loss), minimizing introduction of exotic species (Exotics), and controlling toxic wastes (Toxics), have been assembled to investigate the negative effects of those stressors on living marine resources (hereafter referred to as "Resources"). One Work Group (Marine Protected Areas) is focused on evaluating and creating marine reserves as a tool for protecting and restoring stressed Resources, and three others address transboundary Research and Monitoring needs, Strategic Opportunities, and Communications and Outreach.

The Protect Marine Life Work Group is charged with addressing ways to protect and restore depressed populations of marine plants and animals. Effective protection of marine life, however, requires a thorough understanding and treatment of all anthropogenic[1] stressors (hereafter referred to as Stressors) and natural limiting factors as well as methods to mitigate Stressors and restore Resources. Many Resources that have experienced significant declines in shared waters were discussed in the

[1] Literally, "of human origin". This term is used throughout the report to distinguish effects of human activities from non-human, or "natural" effects.

Transboundary Symposium proceedings [Wilson et al. 1994], and in most cases, some natural or anthropogenic factors contributing to declines were identified.

The present report was prepared for the Washington Protect Marine Life Work Group and builds upon information presented in the Transboundary Symposium and other previously published reports [Armstrong and Copping 1990; Nasser 1992; BCRTEE 1993; PSR95 1995; Hay et al. 1996; Palsson et al. 1996; Newton et al. *in prep*]. The objective of this report is to provide the Work Group with a comprehensive, detailed evaluation of the Stressors contributing to Resource declines in Washington's waters, and provide recommendations for protecting and restoring stressed Resources. Specifically, it:

- identifies Resources whose populations have experienced significant declines, or are suspected of being significantly stressed,
- identifies and evaluates anthropogenic and natural factors contributing to population declines or other indicators of stress for each Resource,
- summarizes and evaluates current management approaches to protecting or restoring depressed Resource populations, and
- recommends ways to improve awareness of management agencies to status and trends of Resources, as well as alternate or additional strategies to restore Resources and protect them from further loss.

Management histories for many of the Resources discussed in this document reflect a desire to maximize harvest, and sustain yields at some optimum level. Strategies presented here are based more on protecting and rebuilding dwindling populations than on exploiting remaining stocks. In some cases, this means continuing or enhancing existing conservative strategies, and in others, proposing new courses of action. The rationale for recommendations is simple; where a stressor is shown to impact a Resource negatively, recommendations are made to reduce the negative interaction. Where stressor-Resource interaction are likely but unsubstantiated, recommendations are based on weight-of-evidence, opinions of experts, and common sense. In some cases, appropriate research is proposed to answer critical questions. Implicit in all recommendations is that adequate funding be provided for their implementation.

INTRODUCTION

A number of recommendations presented in this report have been made previously, in Transboundary reports [MSP 1994; Wilson et al. 1994] or other similar documents [Armstrong and Copping 1990; PSR95 1995]. However, this report discusses management strategies for the stressed Resources of Washington's inland marine waters in an ecosystem context, where the ecological connectedness among managed species is highlighted.

The report consists of six chapters:

(I) a rationale for selecting Resources to be considered,

(II) a description of each Resource and reasons for concern in Washington's waters,

(III) an analysis of major Stressors and natural limiting factors affecting Resources,

(IV) an analysis of potential ecosystem-effects resulting from Resource declines and management actions,

(V) a summary of Stressors and management recommendations for each Resource,

(VI) conclusions and a summary of management recommendations grouped according to Stressors.

These chapters are presented in a linear fashion, with each building on information presented in previous chapters. Most importantly, the two summary chapters are based on information and arguments developed in the previous four chapters.

Chapter I. Resource List

The species or species groups included in this report were assembled primarily from a perusal of the Transboundary Symposium [Wilson et al. 1994]. Scientists from the Transboundary Symposium identified at least thirteen species or species groups thought to be in serious decline and in need of some protection. Three more Resources were added for this report, and a few were omitted, resulting in a total of thirteen (Table 1). Pacific salmon are key components of the Puget Sound/Georgia Basin ecosystem, and many stocks are in serious decline; however, they are the focus of major international research, protection, management and conservation efforts [National Research Council 1996]. Steller sea lions *(Eumetopias jubatus*) have been listed under the U.S. federal Endangered Species Act as a threatened species, and Washington has a comprehensive recovery plan for the species [Washington Department of Wildlife 1993b]. Harlequin ducks (*Histrionicus histrionicus*) were mentioned in Mahaffy et al. [1994] as a species of concern; however, WDFW wildlife biologists do not consider this species in decline in Washington [Tom Juelson, Washington Department of Fish and Wildlife, personal communication]. Harlequin ducks may require some special consideration (aside from this report), because wintering populations of this species are highly concentrated in small areas of inland waters, apparently increasing the risk that an oil spill or other environmental disaster in an overwintering area would affect populations region-wide [Mary Mahaffy, US Fish and Wildlife Service, personal communication].

Migratory species were not included in this report. Of special note here are scoters *(Melanitta* spp), which have experienced population declines along the west coast of North America (Dave Nysewander, Washington Department of Fish and Wildlife, personal communication). These species are found in shared waters in winter, migrating to and from Arctic breeding grounds in spring and fall.

Finally, these thirteen Resources represent stressed species for which we have some information, or which we suspect are stressed; there may be others experiencing significant stress for which we have no information to make such a determination. In addition, information we have for any species describes only recent history; data are usually available for only the past one or two decades. We have no way of quantitatively assessing, for instance, ecosystem conditions that existed prior to immigration by Europeans in the 19th century.

Table 1. Species or species groups identified as having suffered significant anthropogenic stress and in need of special consideration for their protection.

SPECIES	SOURCE
pinto abalone (*Haliotis kamtschatkana*)	[Bourne and Chew 1994]
Olympia oyster (*Ostrea lurida*)	[Dumbauld *in press*]
unclassified marine invertebrates	[Cummins and Kyte 1990; Carney and Kvitek 1991]
Pacific herring (*Clupea harengus pallasi*)	[Schmitt et al. 1994]
Pacific cod (*Gadus macrocephalus*)	[Schmitt et al. 1994]
Pacific hake (*Merluccius productus*)	[Schmitt et al. 1994]
walleye pollock (*Theragra chalcogramma*)	[Schmitt et al. 1994]
demersal rockfish (*3* spp) quillback rockfish (*Sebastes maliger*) copper rockfish (*S. caurinus*) brown rockfish (*S. auriculatus*)	[Schmitt et al. 1994]
lingcod (*Ophiodon elongatus*)	[Schmitt et al. 1994]
marbled murrelet (*Brachyramphus marmoratus*)	[Mahaffy et al. 1994]
common murre (*Uria aalge*)	[Mahaffy et al. 1994]
tufted puffin (*Fratercula cirrhata)*	[Mahaffy et al. 1994]
harbor porpoise (*Phocoena phocoena*)	[Calambokidis and Baird 1994]

All stressed fish and shellfish Resources identified in the Transboundary Symposium report support or have supported important commercial or recreational fisheries. Of eight important species or groups of finfish discussed by Schmitt et al. [1994], population abundance of six were described as "low", or "very low": lingcod (*Ophiodon elongatus)* rockfish, *(Sebastes* spp), Pacific hake *(Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock *(Theragra chalcogramma*), and certain stocks of Pacific herring (*Clupea harengus pallasi*). Bourne and Chew [1994] identified one shellfish, the northern abalone *(Haliotis kamtschatkana*), as requiring some form of protection from further over-harvest. Populations of three species of marine birds were identified as being depressed in Washington; marbled murrelet (*Brachyramphus* *marmoratus*), tufted puffin (*Fratercula cirrhata*), and common murre (*Uria aalge*) [Mahaffy et al. 1994]. Populations of one marine mammal, harbor porpoise (*Phocoena phocoena*) were also considered depressed by Calambokidis and Baird [1994] and in need of some protection in shared waters.

Some species were not represented at the Transboundary Symposium, even though there is fairly clear evidence that we should be concerned about their status in Washington. The Washington Department of Fish and Wildlife (WDFW) has recognized that populations of the native Olympia oyster (*Ostrea lurida*) are in decline and in need of attention [Dumbauld *in press*].

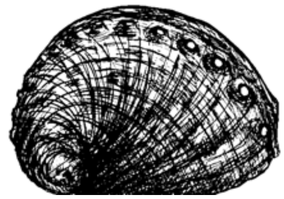
Harvest of unclassified[1] marine invertebrates (UMI) has risen dramatically in recent years. This group consists primarily of intertidal invertebrates which are harvested by a wide array of users. The most commonly harvested UMI in Puget Sound include marine snails *(Nucella* spp), shore crabs, polychaete worms, and moon snails (*Polinices lewisii*) [Carney and Kvitek 1991]. In many cases, little is known about their abundance, distribution, life history or ecology. UMI are considered in this report because many of these species are thought to be sensitive to overharvest and other anthropogenic stressors [Kyte 1989], are important components of intertidal and subtidal communities, and receive little or no monitoring [Cummins and Kyte 1990; Carney and Kvitek 1991].

[1]Unclassified means that the species has not been designated by the WDFW as a foodfish or shellfish. Most, if not all, are currently unmanaged by the WDFW

Chapter II. Resource Descriptions

In order to orient readers unfamiliar with all the species in Table 1, brief, one- or two-page descriptions of each are offered. The distribution, habitat requirements, and life history parameters pertinent to the following discussions are presented, along with more detailed reasons why the species were included in the report.

Pinto Abalone (*Haliotis kamtschatkana*)



RESOURCE

The pinto[1] abalone (*Haliotis kamtschatkana*) is a large (up to 15 cm), benthic marine snail, occurring from Point Conception, California, to Sitka, Alaska. In Washington waters its distribution appears to be limited to the Strait of Juan de Fuca and San Juan Islands.

HABITAT REQUIREMENTS

This species occurs on shallow (<20m) rocky substrate, where it feeds almost exclusively on various seaweeds [Mottet 1978]. Adults attach to rocks and live primarily in kelp forests, where they forage for algae over a relatively small home range, or remain stationary, catching detached algae as it drifts past the animal's extended foot and tentacles. Abalone are broadcast spawners, with planktonic egg and larval stages; however, their planktonic stage is extremely short (a few days). Juvenile abalone apparently settle directly to their ultimate benthic habitat, possibly using chemical cues secreted by algae to find suitable habitat [Quayle 1971].

REASONS FOR CONCERN

The primary cause for concern in protecting Pinto abalone is overharvest. Abalone are easily harvested by SCUBA divers and because its habitat is well within the safe depth range for divers, there is no deep refuge for the species. In addition, the species is relatively long lived (up to 10 years [Quayle 1971]), resulting in a slow recovery from overharvest. Population abundance and trends have not been adequately monitored for this species, so perceived effects have not been verified. The Washington

[1] Also known as "northern" or "Japanese" abalone.

Department of Fish and Wildlife closed all recreational harvest of this species in Washington’s waters by regulation in 1994; however, intensive, illegal, commercial harvest of this species is thought to have depleted pinto abalone populations in the San Juan Islands [Alex Bradbury, Washington Department of Fish and Wildlife, personal communication]. All harvest of pinto abalone in British Columbia was closed in 1991 [Bourne and Chew 1994].

Olympia Oyster (*Ostrea lurida*[1])

RESOURCE

The Olympia oyster (*Ostrea lurida*) is a small (<6 cm) native oyster species occurring in inland marine waters and coastal estuaries of Washington. Its full range includes the Pacific Coast from Baja, California, to Sitka Alaska. This is a common species which was once abundant and commercially harvested throughout its range. Its fishery-importance has been replaced by the much larger, non-native giant Pacific oyster (*Crassostrea gigas*). However, Olympia oysters are raised commercially in Puget Sound, in dike-impoundments. A system of oyster reserves was constructed by the Washington Department of Fisheries from 1890-1910 [Westley et al. 1985], designed to enhance commercial production of Olympia oyster through the construction of diked tidal areas. The effort was abandoned later because of failures in culture or a shift in focus to Pacific oyster in these areas.

HABITAT REQUIREMENTS

Olympia oysters are usually found along the lower intertidal line, from +1.0 ft. To -2.0 ft., elevation, or in tidal channels where they are continuously covered with water. The species is sensitive to temperature extremes and is often found on substrates near groundwater intrusion, which prevents them from freezing and overheating. Olympia oysters produce planktonic larvae which require a firm substratum upon which to settle -- typically rock or shell. The species is intolerant of siltation, typically growing best on firm substrata and in areas with substantial water flow (Couch and Hassler 1989; Dumbauld [*in press*]; Duane Fagergren, Washington Department of Ecology, personal communication).

REASONS FOR CONCERN

In the past 100 years the Olympia oyster has suffered from a number of stressors which have severely depleted populations in Puget Sound. Pollution from pulp mills decimated Olympia oyster populations in south Puget Sound in the early part of this

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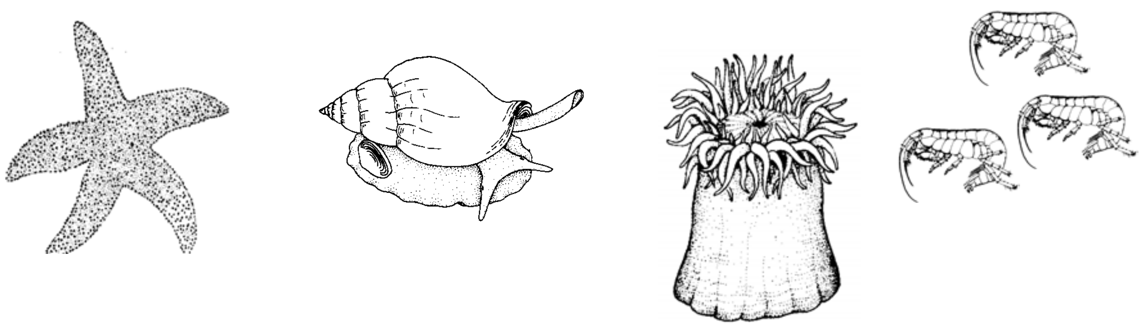
[1] Also known as the Native Pacific Oyster. There is some disagreement among taxonomists regarding the correct scientific name for this species. Other acceptable names include *Ostreola conchaphila* and *Ostrea lurida conchaphila*.

century. Japanese oyster drills and flatworms, inadvertently introduced into Washington's waters with non-native Pacific oysters, prevented later recovery of Olympia oyster populations (Couch and Hassler 1989; Duane Fagergren, Washington Department of Ecology, personal communication). Current populations in Puget Sound[1] are patchily distributed, and deteriorating water quality, increased shoreline siltation, and overharvest potentially threaten their health [Dumbauld *in press*].

[1]Some commercial culture of Olympia oyster continues in Puget Sound

Unclassified Marine Invertebrates[1]



RESOURCE

This Resource presents an unusual case simply in its description. Whereas all other species or groups presented in this report are named using their taxonomy, this group is distinguished based on its status in the agency that manages it. Unclassified marine invertebrates (UMI) comprise all invertebrate species currently not considered as foodfish or shellfish by the Washington Department of Fish and Wildlife -- over 2,900 species -- or 98% of all invertebrates occurring in Washington's waters [Cummins and Kyte 1990]. Dethier et al. [1989], Kyte [1989], Cummins and Kyte [1990], and Carney and Kvitek [1991] have reviewed the management, status, and harvest of UMI in Washington. UMI cover a huge expanse of taxonomic groupings, including amphipods, sea anemones, barnacles, crabs, chitons, worms, seastars, nudibranchs, seapens, sand dollars, and shelled snails.

It is impossible to succinctly summarize the normal distribution range of the species in this group; individual species range from ubiquitous to rare, on spatial scales from the whole Pacific Coast to the Puget Sound. It is likely that, upon closer inspection, some species will be shown to be more sensitive to harvest than others, and may require special management considerations.

HABITAT REQUIREMENTS

The habitat requirements of this diverse group are equally diverse, and like many marine species, vary according to life stage. However, a unifying aspect of UMI is that

[1]For this report, "unclassified" means that the species has not been designated by the WDFW as a foodfish or shellfish, and is not managed by the WDFW.

most of the protection needed for these species is in the intertidal zone, where shoreline harvesters can glean organisms depending on the state of the tide. Habitats used by UMI include mud and sand flats, cobble or sand beaches, eelgrass and algae meadows, rocky shorelines, tidepools, and any other intertidal habitat.

REASONS FOR CONCERN

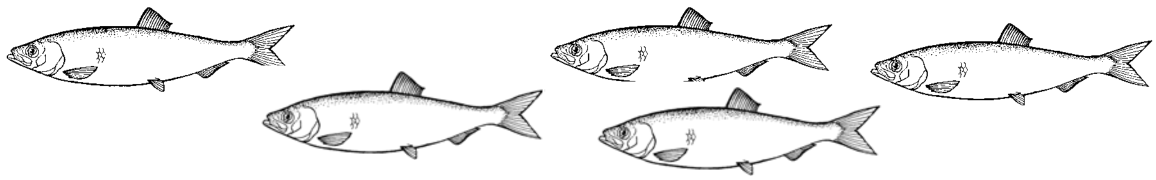
Cause for concern regarding the status of UMI has arisen from a recent increase in harvesting these species. UMI have been harvested historically by a number of users including consulting, research or education organizations, biological supply houses, aquaria, subsistence fishers, bait-fishers, and curio-collectors; however, the intensity of harvest has increased sharply in the past decade as a result of subsistence fishing by recent immigrants (who harvest species not traditionally taken by the local populace). Harvest of UMI has never been monitored, so the cumulative effects of these harvesters on the Resource is unknown.

The WDFW has received a number of inquiries and comments from citizens, environmental groups, public aquaria, and other advocates concerned with the health of UMI populations in the State [Mary Lou Mills, Washington Department of Fish and Wildlife, personal communication]. These groups perceive the harvest described above as a threat to the ecological integrity of intertidal plant and animal communities. They have identified a problem based not on a desire to protect these species for their own consumption, but on a value they place on maintaining healthy, diverse biological shoreline communities. The WDFW has been interested in the problem as well (see Cummins and Kyte [1990] and Carney and Kvitek [1991]), and is now investigating the issue further.

An additional cause for concern here is the potential change in diversity of intertidal communities, especially on small, local scales, where heavy harvesting occurs or has occurred. Many of these organisms are important in the intertidal (and other) food web(s), as keystone species[1], or as significant modifiers of the biological or physical nature of the habitat. When removed in large numbers, their removal can result in substantial changes in the community structure.

[1]Species which, by their numbers or activity, determine community structure, integrity, and stability (Paine, 1969).

Pacific Herring (*Clupea harengus pallasi*)



RESOURCE

Pacific herring (along with Pacific sandlance, *Ammodytes hexapterus*) are the most abundant forage fish in shared waters, providing a source of food for many fish, bird, and marine mammal populations. In its adult or juvenile form, Pacific herring is an important prey for Pacific salmon, Pacific cod, Pacific hake, walleye pollock, lingcod, spiny dogfish, halibut, rockfishes, common murres, tufted puffins, marbled murrelets, cormorants, gulls, harbor porpoise, California sea lions, harbor seals and others. Pacific herring are found from California, to the Bering Sea and along the Asian coast to central Japan. In Washington, this species is ubiquitous in marine waters, including the coastal estuaries.

HABITAT REQUIREMENTS

Pacific herring is a pelagic, schooling species that preys primarily on zooplankton. In Puget Sound they spawn from January until June, depositing adhesive eggs on blades of eelgrass (*Zostera marina*) and a variety of other marine vegetation. Eggs hatch in approximately two weeks, after which pelagic larvae are found in nearshore plankton. Larvae aggregate in protected bays, and after their first year they mix with adults in more pelagic habitats.

REASONS FOR CONCERN

Overall, populations of Pacific herring appear to be relatively healthy in Puget Sound. However, four recent conditions have caused concern for WDFW Forage Fish Unit biologists: (1) four stocks[1] of herring, those centered around Cherry Point, Port Susan, Port Orchard, and Discovery Bay, are considered either "depressed" or "critical" [WDFW Forage Fish Unit *in press*], based on decreasing trends in estimated spawning biomass (Figure 1), (2) estimated natural (non-fishery) mortality of this species in Puget Sound has increased from about 30-40% (considered normal for healthy herring populations world-wide) before 1982 to 60-70% (Figure 2), (3) the number of age classes comprising the bulk of the populations in Puget Sound has decreased from five to two or three (as illustrated by the Cherry Point herring stock -- Figure 3), and (4) increased night-time sightings by WDFW herring-survey biologists of harbor seals near schools of herring, and concurrent changes in the schooling behavior of herring, supporting the perception that predation by harbor seals on Pacific herring has risen in recent years [Norm Lemberg, Washington Department of Fish and Wildlife, personal communication].

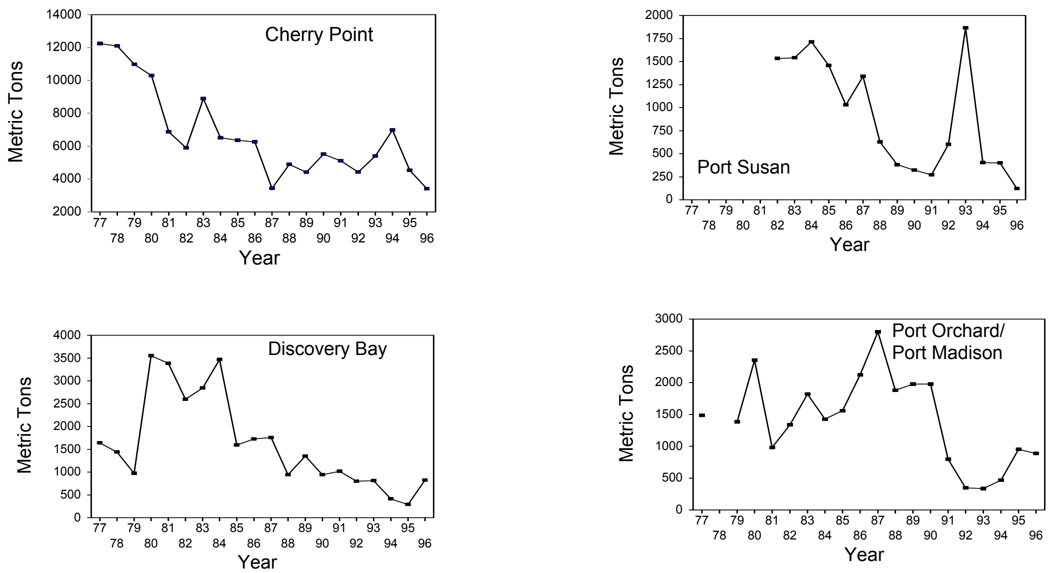


Figure 1. Estimated spawning biomass of four stocks of Pacific herring considered "depressed" or "critical" by the WDFW Forage Fish Unit. Graphs created from data from WDFW Forage Fish Unit (*in press*).

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[1] Eighteen herring stocks are recognized in Puget Sound and the Strait of Juan de Fuca by the WDFW Forage Fish Unit. The quality of data used to estimate spawning biomass, annual survival, age composition, and stock assessments of ten stocks were rated "fair" or "good", and eight were rated "poor". (WDFW Forage Fish Unit, *in press*).

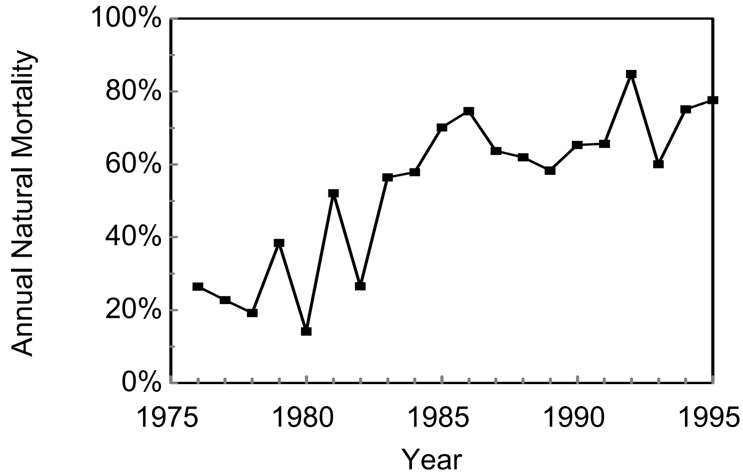


Figure 2. Estimate annual natural (non –fishery) mortality rates of adult Pacific herring from Puget Sound. Graph constructed from data supplied by the WDFW Forage Fish Unit.

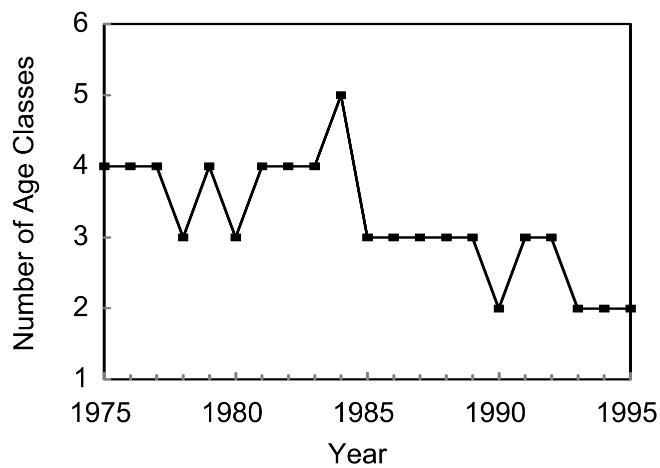
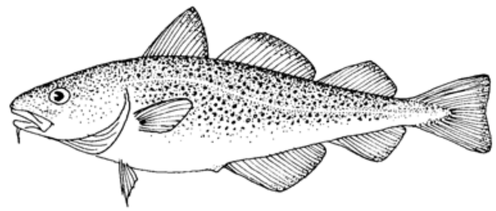


Figure 3. Number of age classes comprising a significant portion (>10%) of one of the eighteen Pacific herring stocks in Puget Sound. Reduction in number of age classes results primarily from loss of older individuals. Graph created from unpublished data supplied by the WDFW Forage Fish Unit.

Pacific Cod (*Gadus macrocephalus*)



RESOURCE

The Pacific cod (*Gadus macrocephalus*) is widely distributed in relatively shallow marine waters (50-200m) along the shoreline of the northern arc of the Pacific Ocean, from Japan to western North America. Cape Flattery, Washington (the mouth of the Strait of Juan de Fuca), and the inland marine waters of Washington State are considered the southern limit of fishery-exploitable populations [Ketchen 1961]. This species is a large demersal[1] carnivore (exceeding 140 cm in its northern range, but less than 100 cm in Puget Sound), consuming primarily fish and crustaceans. Pacific cod support substantial commercial fisheries throughout its range, except in Puget Sound, where abundances have recently declined precipitously [Palsson 1990; Schmitt et al. 1994; Palsson et al. 1996]. Three, apparently separate stocks, or populations, of Pacific cod existed historically in Puget Sound; a stock in the northern region, in the Gulf of Georgia, a stock resident in the eastern Strait of Juan de Fuca, and a stock in the South Sound, centered around Agate Pass.

HABITAT REQUIREMENTS

Habitat requirements of Pacific cod vary according to life stage. Adult Pacific cod are demersal, occurring over unconsolidated substrate such as mixed-fine and mixed-coarse sand, and soft bottom, primarily at depths ranging from 50 to 200 m [Matthews 1987]. Palsson [1990] and Matthews [1987] have recently reviewed the life history and habitat requirements of Pacific cod. This species apparently prefers cool waters (6-7°C) with spawning occurring in shallow waters during the winter [Westrheim and Tagart 1984]. Pacific cod are highly fecund broadcast spawners, with largest females producing millions of eggs. Unlike most broadcast spawners, eggs of Pacific cod sink to the sea floor where they adhere to substrate particles. After hatching, cod larvae are 3-4 mm in length, and rise in the water column to a depth of 15 to 30 m. However, in

[1] Associated with the sea floor

Puget Sound, Pacific cod larvae have been found nearer to the bottom [Karp and Miller 1977]. Larvae spend several months in the water column, during which they metamorphose into the juvenile form. Juvenile Pacific cod settle to relatively shallow, demersal habitats in late summer, when they are commonly found in sand-eelgrass habitats (see Matthews [1987]).

Adult Pacific cod feed in the water column and on the sea floor, consuming primarily Pacific sandlance (*Ammodytes hexapterus*), Pacific herring *(Clupea harengus pallasi*), flatfishes, rockfishes (*Sebastes* spp), other fishes and crustaceans. Euphausiid shrimps and other crustaceans dominate the diet of subadult Pacific cod [Westrheim and Harling 1983; Walters et al. 1986; Westrheim et al. 1989], and juvenile Pacific cod prey mainly upon copepods, amphipods, and mysids [Walters 1984].

REASONS FOR CONCERN

The main cause for concern regarding the health of Pacific cod in Puget Sound relates to recent declines in catch per unit effort (ie. the number of fish caught per trip, or lbs caught per hour -- Figures 4 a-b). Palsson et al. [1996] described the population of Pacific cod in South Puget Sound as “critical or near extinct levels”, and the population in North Puget Sound “depressed”, based on most recent in fishery catches.

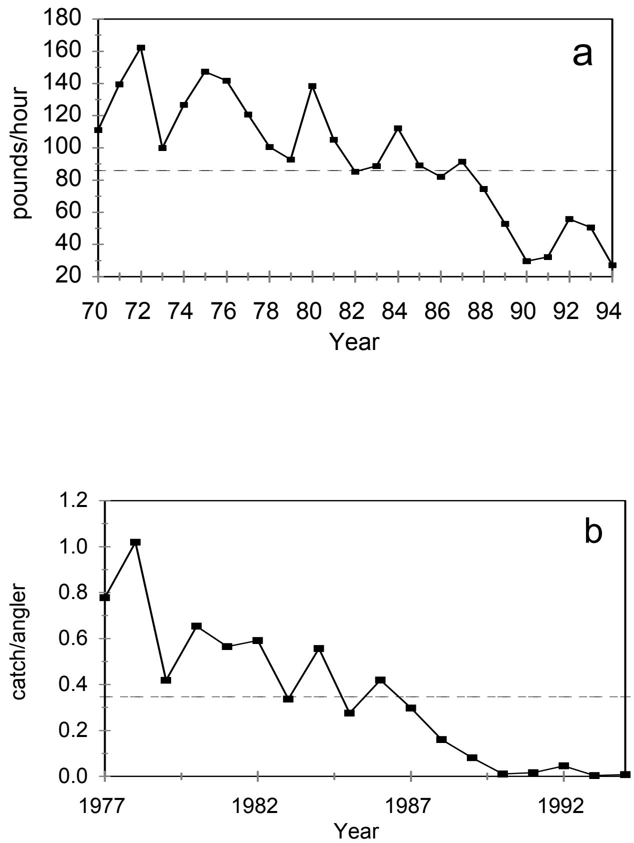


Figure 4a-b. Primary stock indicators (catch per unit effort) for Pacific cod from the North Puget Sound trawl fishery (a) and South Puget Sound recreational fishery (b). Dashed line represents long-term average (from Palsson et al. 1996).

Pacific Hake[1] (*Merluccius productus*) and
Walleye Pollock (*Theragra chalcogramma*)

RESOURCE

Pacific hake and walleye pollock are carnivorous, midwater, schooling codfishes, both occurring in Puget Sound and the Georgia Basin. Because of similarities in their life history, fisheries, and management, they are presented together here. Pacific hake are considered a southern, or warm-water species, with abundant populations occurring off the coasts of California and Baja. These populations undergo feeding migrations northward in the summer to as far as Washington and British Columbia, returning to spawn in southerly waters in the winter. A small, genetically distinct, resident population occurs in Puget Sound which migrates seasonally between Port Susan and Saratoga Passage. It is this population whose numbers have experienced severe decline in recent years, and which is assessed in this report.

Walleye pollock is a northern, colder-water species, occurring along the shoreline of the northern arc of the Pacific Ocean, from Japan to western North America. Like Pacific cod, Puget Sound represents the southern extent of fishery-exploitable populations. Walleye pollock occur year-round in Puget Sound as well.

HABITAT REQUIREMENTS

Pacific hake and walleye pollock both occur in pelagic mid-waters throughout Puget Sound and Georgia Basin. Both produce pelagic eggs and larvae. Juvenile pollock migrate to inshore, shallow habitats in their first year, moving back to deeper waters in their second year [Ray Buckley, Washington Department of Fish and Wildlife, personal communication; Simenstad et al. 1979].

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[1] also commonly known as Pacific whiting

REASONS FOR CONCERN

At one time, Pacific hake comprised the largest fishery (by weight) in Central Puget Sound. The commercial fishery is now closed by regulation of the Washington Department of Fish and Wildlife because of low abundance. Palsson et al. [1996] described the stock status of Pacific Hake in South Puget Sound as “critical” because of the sharp decline in abundance of the species observed in the WDFW hydro-acoustic hake survey conducted annually at Port Susan (Figure 5).

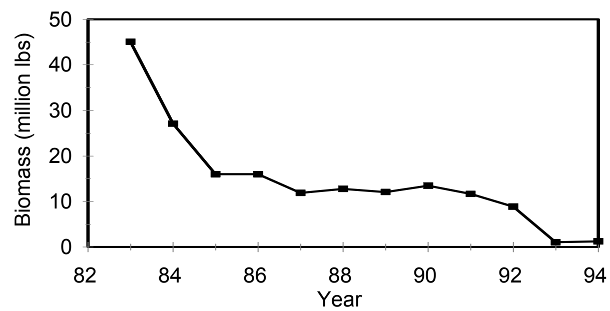


Figure 5. Biomass of Pacific hake in South Puget Sound estimated from the WDFW hydro-acoustic trawl survey, 1983-1994 (from Palsson et al. 1996)

Walleye pollock in South Puget Sound were once the most common species taken in the recreational fishery. This population experienced a sharp decline in its abundance during the 1980s (Figure 6) and is “at a critical status” in the area [Palsson et al. 1996]

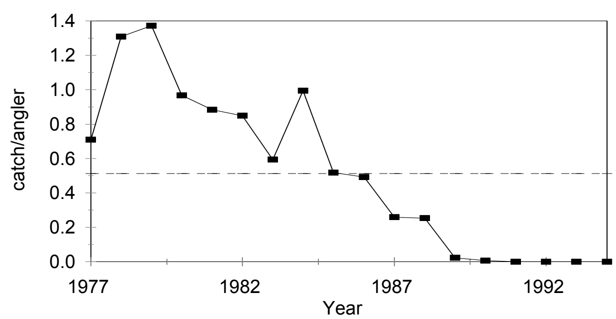
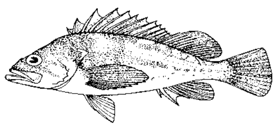
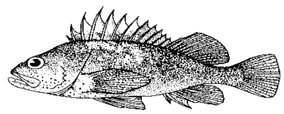
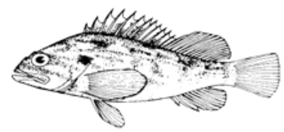


Figure 6. Catch per unit of walleye pollock from the South Puget Sound recreational fishery. Dashed line represents long-term average (from Palsson et al. 1996)

Demersal Rockfish (*Sebastes caurinus, S. maliger*, and *S. auriculatus*)

RESOURCE

Demersal[1] rockfish is a group of closely related rockfishes (family Scorpaenidae), consisting of copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), and brown rockfish (*S. auriculatus*). Copper rockfish are found in shallow coastal and inland marine waters from Monterey, California to the Gulf of Alaska. They are common in the Georgia Basin and Puget Sound. Quillback rockfish are found from central California to southeast Alaska, and are common in the Georgia Basin and Puget Sound (north of the Tacoma Narrows). Brown rockfish are found from Baja, California, to southeast Alaska. They are uncommon in the Georgia Basin, and common in central and south Puget Sound.

HABITAT REQUIREMENTS

Habitat requirements for these species include three distinct types -- pelagic waters, nearshore vegetated substrate, and rocky-reefs -- each associated with a different phase in their life history. Demersal rockfish are born around April as free-swimming pelagic (open water) larvae and spend approximately 4 months in the pelagic habitat [DeLacey et al. 1964]. Larval ecology of *Sebastes* in oceanic waters was reviewed in detail by Moser and Boehlert [1991]. Oceanic rockfish larvae occur above the thermocline in mid- and surface waters [Moser and Boehlert 1991]. Doyle [1992] categorized *Sebastes* larvae as facultative neuston, indicating that they spend some substantial portion of their time in surface waters. She documented nocturnal migrations of *Sebastes* larvae to surface waters, and suggested that such migrations are made to take advantage of the rich, nocturnal biotope of surface waters. In Puget Sound, *Sebastes* larvae have been found commonly in surface waters [Miller et al. 1977] and can readily be collected within a few centimeters of the surface [Morgan

[1] associated with the sea floor

Busby, National Marine Fisheries Service, personal communication]. *Sebastes* were the most abundant larvae collected during a spring survey in Puget Sound [Waldron 1972].

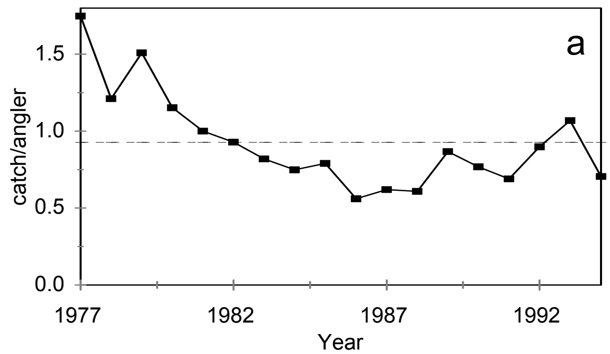
At some point during their pelagic phase, rockfish larvae metamorphose into the juvenile form, acquiring a morphology more closely resembling their final adult form. After metamorphosis, juveniles of a number of *Sebastes* continue their pelagic existence for a short period; some pelagic juveniles subsequently associate with drifting mats of detached, floating macroalgae, eelgrass, other plants, and debris [Lamb and Edgell 1986; Larsen 1993; Buckley et al. 1995; Shaffer et al. 1995], using the drift-algae habitat as a source of food and refuge [Buckley et al. 1995; Shaffer et al. 1995].

After some months in the pelagic habitat, juvenile rockfish move to, and become permanently associated with, the sea floor in a process known as "settlement". It is during the settlement process, and during their first year of demersal existence, that rockfish juveniles are commonly found in nearshore vegetated habitats. These habitats include beds of eelgrass (*Zostera marina*), bull kelp (*Nereocystis luetkeana*), and understory kelps and other algae (e.g., *Laminaria* spp, *Agarum* spp, and *Costaria costatum*), and are thought to be important as an intermediate, "nursery" habitat, between the pelagic larval/juvenile and the final, rocky reef adult habitat [Haldorson and Richards 1987; Love et al. 1991; Norris 1991; West et al. 1994; Doty et al. 1995; West et al. 1995]. Nursery habitats provide food and refuge for the first year of demersal existence during a period when juvenile rockfishes undergo substantial changes, including switching diets from pelagic to benthic prey, becoming oriented to solid substrate, and learning to avoid a new suite of predators.

Adult demersal rockfish typically require habitat with complex, high-relief substrate. Hence, they are usually found on rocky reefs, slopes, or pinnacles, around pilings, artificial reefs, or associated with submerged debris [Matthews 1988]. Home range of demersal rockfish on these habitats is small (approximately $30m^2$ for high-relief reefs), suggesting that once these species encounter suitable habitat, they subsequently migrate little [Matthews 1990].

REASONS FOR CONCERN

Catch rates for these species since have declined since the 1970s (Figures 7a-b), and these (and other rockfish) species were described as either "fully utilized" or "overutilized" by Palsson et al. [1996].



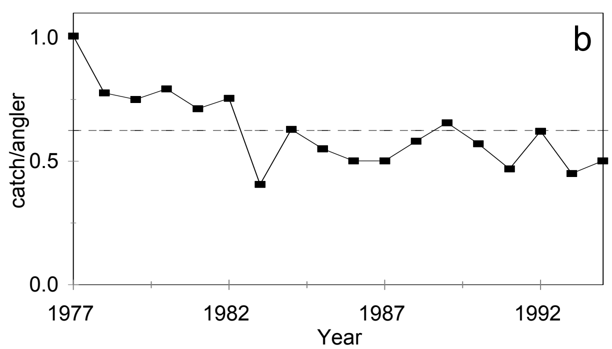
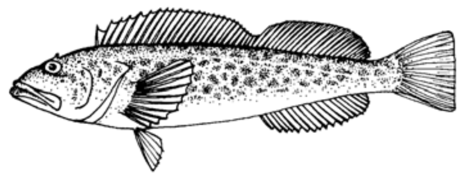


Figure 7a-b. Catch per unit effort of rockfish From the North Puget Sound (a) and South Puget Sound (b) recreational fisheries. Dashed lines represent long-term averages (from Palsson et al.1996)

Additional concern for these species is warranted because of possible history of recruitment overfishing and growth overfishing[1] in Puget Sound; rockfish surveyed in harvest refugia were larger, more abundant, and had a greater reproduction potential than those from nearby fished areas [Palsson and Pacunski 1995]. Further results from that study are presented in the Harvest Stressor section.

[1]See definitions in Harvest section.

Lingcod (*Ophiodon elongatus*)



RESOURCE

The lingcod (*Ophiodon elongatus*) is a large (up to 45 kg), predatory fish which is native to the west coast of North America. This species is found from Baja, California to the Shumagin Islands, Alaska, at depths from the intertidal to 2000 m. Lingcod are common in inland marine waters of Washington and British Columbia, where they have supported large, active fisheries for Native Americans as well as European immigrants from prehistoric times to the present. Cass et al. [1990] presented a thorough synopsis of the life history of, and fishery on, lingcod.

HABITAT REQUIREMENTS

Like other marine fishes, lingcod require several different habitats for the natural completion of their life cycle. Adult lingcod are typically found associated with rocky reefs or other complex substrata, with greatest densities found in depths from 10 to 100m. Adult lingcod typically exhibit a relatively small home range. They usually spawn sometime from December to March. This species is unusual among marine fishes in that it lays adhesive eggs in nests; females usually deposit eggs in rocky crevices in relatively shallow areas with strong water motion. Eggs are fertilized by males which vigorously defend nesting sites from potential egg-predators.

After hatching, lingcod disperse from their nests, and spend approximately two months in the pelagic (open water) habitat. During this period they are surface-oriented, and remain relatively close to shore [Phillips and Barraclough 1977]. Overall dispersal of lingcod larvae is apparently lower than broadcast spawners, and combined with the small home range of adults, these characteristics indicate that local stocks are mostly self-replenishing [Cass et al. 1990]. Pelagic lingcod larvae and juveniles are active swimmers, consuming a wide range of zooplankton. As pelagic lingcod juveniles grow, their diets shift to larger prey; large juvenile lingcod rely almost exclusively on juvenile herring [Cass et al. 1990].

In the late spring-early summer, juvenile lingcod move from the pelagic habitat to benthic (seafloor) habitats in a process known as settlement. Best information to date suggests that juvenile lingcod settle to shallow water habitats, in or near beds of vegetation such as kelp or eelgrass [Buckley et al. 1984; Cass et al. 1990]. They have also been observed near dense beds of tubeworms (*Eudistyla vancouveri*) [Daniel Doty, Washington Department of Fish and Wildlife, personal communication]. It is likely that juvenile lingcod use these habitats for shelter, as well as feeding grounds. In the fall of their first year, juvenile lingcod then move to flat, featureless bottoms, where they spend the next year or two. After they have reached a large enough size to avoid predation by large, reef-dwelling species (e.g., other lingcod, rockfish, and cabezon), lingcod then move to their adult habitat.

REASONS FOR CONCERN

Catch rates for lingcod have steadily and substantially declined in the North Puget Sound since 1983 (Figure 8), and lingcod populations in that area were considered "depressed" by Palsson et al. [1996]. Additional concern for these species is warranted because of a possible history of recruitment overfishing and growth overfishing[1] in Puget Sound; lingcod surveyed in harvest refugia were larger, more abundant, and had higher reproductive potential than those from nearby fished areas [Palsson and Pacunski 1995]. Further results from that study are presented in the Harvest Stressor section.

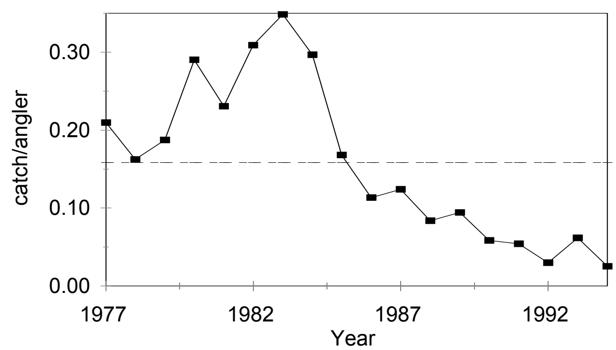
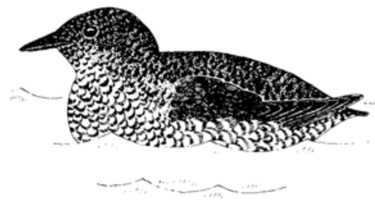


Figure 8. Catch per unit effort of lingcod from the North Puget Sound recreational fishery. The dashed line represents the long-term average. (from Palsson et al. 1996)

[1] See definitions in Harvest section

Marbled Murrelet (*Brachyramphus marmoratus*)



RESOURCE

The marbled murrelet is one of the smaller members of the family Alcidae, a group of diving seabirds. This species is indigenous to the west coast of North America, ranging as far south as central California. Marbled murrelets spend most of their lives on the ocean, and the species is distributed widely throughout Puget Sound. Their distribution in Washington's inland marine waters appears to be largely restricted to within about 1000 m of the shoreline. This species is well known because of its federal listing as a threatened species (see Washington Department of Wildlife [1993a]); its abundance in Washington is low. The Final Rule published by the US Fish and Wildlife Service [USFWS 1992] provides detailed reasons for concern and resulting protective actions.

HABITAT REQUIREMENTS

Terrestrial (nesting) habitat requirements for marbled murrelets are generally well known. The species nests inland in forests of old growth coniferous trees, selecting sites possibly based on characteristics of both the forest and trees. Recent reductions in this habitat as a result of logging typically has received the most attention in discussions of the decline in this species [Ralph et al. 1995]. Their use of marine habitats is less well known; however, marbled murrelets in inland waters generally forage for prey in nearshore areas.

REASONS FOR CONCERN

The primary reason for concern for marbled murrelets is loss of old-growth coniferous forests, required by the species as nesting habitat. This information is detailed in USFWS [1992] and Washington Department of Wildlife [1993a]. Concern over stressors encountered by marbled murrelets in marine environments was mentioned in these documents; however, lack of information precluded discussions of their potential effects on the species. The present report explores marine-related stressors a bit further, and in conjunction with similar species exposed to similar threats.

Common Murre (*Uria aalge*)

RESOURCE

The common murre is one of the largest members of the family Alcidae, commonly known as auks. This species occurs circum-globally along marine coastlines in the northern hemisphere, temperate to subarctic climates. Washington breeding colonies occur along the oceanic coastline; however, foraging individuals are commonly found in Washington's inland waters. The ecology, status, limiting factors of, and management recommendations for, this species have been discussed in detail by Warheit (*in review*). Many of his comments are summarized below.

HABITAT REQUIREMENTS

Common murres live most of their lives on open water, returning to land only to breed and raise their young. This species is highly colonial, nesting on wide, flat, cliff ledges or terraces, and on the tops of islands [Speich and Wahl 1989]. Ideal habitat is inaccessible to terrestrial predators such as coyote and racoons. Murres also require breeding habitat close to marine waters with adequate abundance of prey (primarily Pacific herring, Pacific sandlance, other fishes and euphausiids) for nesting success. Although Washington breeding populations of common murres nest only along the outer coast of the State, they (as well as common murres from northern California and British Columbia) use Puget Sound waters as foraging habitat during the winter months (Warheit, *in review*; Dave Nysewander and Chris Thompson, Washington Department of Fish and Wildlife, personal communications).

REASONS FOR CONCERN

Washington breeding populations declined from greater than 30,000 in the early 1980s to fewer than 300 in 1983 (Mahaffey et al. 1994; Warheit, *in review*). Although much of that decline was attributed to a particularly severe El Niño event (and a number of populations have since rebounded), “attendance[1]” of common murres at Washington breeding colonies has remained low. Warheit (*in review*) identified five factors limiting the recovery of common murres in Washington: (1) mortality from gillnets, (2) oil spills, (3) El Niño events, (4) eagle-induced reduction in breeding success, and (5) anthropogenic disturbance.

[1]The total number of birds (in any reproductive) condition counted at a breeding colony.

Tufted Puffin (*Fratercula cirrhata*)

RESOURCE

The tufted puffin (*Fratercula cirrhata*) is a medium size member of the family Alcidae, a relative of common murres and marbled murrelets. This species is easily identified and well known for its large, orange-red parrot-like bill, and tufts of yellow feathers hanging behind the eyes. Like other alcids, tufted puffins spend most of their lives on marine waters, returning to land only nest. This species is found along shorelines and on high seas from northern California to Siberia. In Washington's inland waters they nest mostly on Protection and Tatoosh Islands.

HABITAT REQUIREMENTS

Tufted Puffins nest in earth burrows on eroding cliff-edges, or on grassy slopes of islands. These habitats are limited in Washington, which has probably historically restricted their distribution in the State [Speich and Wahl 1989]. Young puffins leave the nesting area and move to the open ocean (with the adults -- sometimes hundreds of kilometers from shore) where they spend up to six years. After that time they return to coastal waters to breed. This species is carnivorous, consuming mostly small, schooling, surface-oriented fishes and squids.

REASONS FOR CONCERN

Breeding numbers have fallen from over 1100 birds to 13 pairs in the Strait of Juan de Fuca and their breeding colonies in Washington's inland waters are now restricted primarily to Protection Island [Ulrich Wilson, U.S. Fish and Wildlife Service, personal communication]. Mahaffy et al. [1994] reported numbers in the San Juan Islands and Strait of Juan de Fuca have been consistently low for the past 20 yrs. Large declines in nesting tufted puffins along the outer Washington coast have also been observed [Julia Parrish, University of Washington Department of Zoology, personal communication].

Harbor Porpoise (*Phocoena phocoena*)

RESOURCE

The harbor porpoise is a small cetacean, reaching 1.8m in length. This species occurs close to shorelines (shallower than 100m depth) the Gulf of Alaska to Southern California. Unlike other porpoise and dolphins, harbor porpoise are wary of humans and rarely approach boats. Harbor porpoise were once common in the inland marine waters of Puget Sound and Georgia Basin.

HABITAT REQUIREMENTS

Harbor porpoise are pelagic animals, consuming small, schooling fishes and squids. They seem to be especially sensitive to underwater noise, as created by boats, and are not commonly seen in areas with much human activity.

REASONS FOR CONCERN

Although once common in South Puget Sound, harbor porpoise are now rarely seen there, and a similar decline may have occurred in southern British Columbia [Calambokidis and Baird 1994].

Chapter III. Anthropogenic Stressors and Natural Limiting Factors

The following chapter presents an analysis of Stressors thought to contribute to declines in Resource populations in shared waters, including overharvest, loss or degradation of habitat, pollution, and disturbance. Natural variability in population abundance of Resources, resulting from the effects of Natural Limiting Factors (NLF), affects our ability to manage these species, and to recognize effects of Stressors. Variability in overall ecosystem productivity results from complex interactions of environment (e.g., climate and oceanography) and biota (e.g., patterns in life history, predation, and competition). Variability in climate may be defined and predicted, to a degree, at various scales to help scientists understand environmental effects on marine productivity. Many Stressor- or NLF-Resource effects are poorly understood and rarely discussed.

Several species considered in this document have complex life cycles, with eggs, larvae, juveniles, and adults all requiring different habitats. In many cases, progeny are dispersed over long distances, exposing them to a wide variety of environmental conditions. The successful completion of a life cycle requires adequate resources and suitable environmental conditions within each life-history stage; survival of individuals in each stage influences the success of subsequent stages. Therefore, the effects of each Stressor or NLF, when applicable, are evaluated for all life-history stages of each Resource. In some cases, little is known regarding Stressor- or NLF-Resource interactions even though the likelihood of such interactions is high (for example, contact of sea-surface pollution with eggs and larvae of some marine fish). In such cases, probable interactions are discussed using best available information, expert opinion, and common sense.

The status of each Stressor and for Natural Limiting Factors is first described, followed by management recommendations, with similarly affected groups of species combined. These recommendations are organized by the Stressor or NLF, and hence, species-specific recommendations are spread throughout the Chapter.

HARVEST

Of the thirteen species or groups in Table 1, nine are currently or have recently been harvested, including all the marine fishes and invertebrates. Catch rates of all harvested marine fishes in Table 1 (except Pacific herring) have declined substantially in recent years, with concomitant increases in fishing effort [Schmitt et al. 1994], and the population status of several of these species have been described as “critical”, or “depressed” [Palsson et al. 1996]. It is unknown specifically to what degree, and by what mechanisms, harvest has contributed to the decrease in abundance of these Resources in Puget Sound. For marine fish, a number of overfishing effects can contribute to reductions in abundance or to other indicators of population-level stress [Bohnsack 1992].

“Growth” overfishing causes a depression of the average size of fish in a given population, as a result of chronically harvesting the largest fish. This has profound effects on population-level fecundity[1], and on the quality of eggs and larvae produced. Smaller, younger individuals of marine fishes generally produce fewer larvae; fecundity increases exponentially with size in rockfish [DeLacey et al. 1964] and lingcod [Hart 1967]. The viability of eggs and larvae of many fishes is dependent on maternal condition, including size [Ellertsen and Solemdal 1990]). Recruitment overfishing occurs when adult populations are reduced to such levels that production of progeny is insufficient to maintain stocks at desirable levels.

Growth overfishing has been demonstrated, and recruitment overfishing is suspected, for demersal rockfishes and lingcod in Puget Sound. Palsson and Pacunski [1995] observed that lingcod, copper rockfish, and quillback rockfish in a marine protected area (where fishing had been prohibited for over 20 years) were not only more abundant, but were substantially larger than those from nearby fished areas. Based on both size and abundance differences, annual potential mean egg production of lingcod in the marine protected area (standardized by transect areas) was from ten times greater than for lingcod in fished areas, and that fished populations of copper rockfish in Central Puget Sound produced only 1% of the larvae per unit area as copper rockfish from the protected area.

Demographic overfishing refers to the reduction of age classes to the point where only a few year classes are left to maintain the fishery, thereby making the stock more susceptible to collapsing during years of naturally poor recruitment. Pacific cod, Pacific hake, and walleye pollock are all short lived species, with only a few year classes present at any time. Overfishing these species may have left them vulnerable to changes in environmental conditions (see section on Climate-Related Natural and Anthropogenic Variability).

[1]Fecundity is the number of eggs or larvae an individual or population produces.

Other problems associated with overfishing include potential changes in the genetic characteristics of a fished population. Fishing generally selects the largest fish in a population, and over time, this could cause selection for fish that mature at smaller sizes. This so-called genetic overfishing [Bergh and Getz 1989; RFPDT 1990; Bohnsack 1992] is a popular theory [Morgan 1992]; however, it has not been demonstrated in marine fish.

Indirect effects to the ecosystem from overharvest may also occur. Harvesting one species reduces the base of prey available to its predators, and reduces predation rates on species they consume. Such changes in the natural structure of food webs and related competitive interactions and displacements are often complex, and difficult to define. Suspected effects on Puget Sound biota from the harvest described in this Chapter are discussed in the separate Ecosystem Effects chapter.

The marine fishes and invertebrates discussed above are all targeted by fishers or harvesters. The three bird species and harbor porpoise are killed inadvertently during the normal operations of various fisheries, and comprise a portion of the non-targeted species known as “bycatch”. The following analysis of Harvest is presented in two sections, the first focusing on targeted harvest (fishes and invertebrates), and the second on bycatch mortality (fishes, birds, and porpoise). Each section is comprised of a Resource-by-Resource review of harvest effects, followed by recommendations grouped according to common Resource needs.

Targeted Harvest

Demersal Rockfish

Although demersal rockfish are common and can be locally abundant in Puget Sound, populations are prone to severe depletion from overfishing. Their site- and habitat-specificity see Matthews [1990] make these species susceptible to habitat degradation and an easy target for fishers. Adult populations of demersal rockfish can be overfished rapidly, and their long life-span and late maturation result in a long period of recovery when over-harvested.

Overfishing demersal rockfish in Puget Sound has been recognized by the Washington Department of Fish and Wildlife as a cause for serious concern [Schmitt et al. 1994]. Currently the WDFW manages the recreational rockfish fishery using bag limits[1] to allocate and restrict catch. The initial limit of fifteen rockfish per angler per day in Puget Sound has been reduced several times to its present limit; as of this writing, catches of rockfish in heavily fished areas (e.g., Central and South Puget Sound) are limited to 3 fish per angler per day, and five to 10 fish per day in other areas (e.g., the San Juan Islands)[Washington Department of Fish and Wildlife 1996].

In a study conducted in 1984 on the efficacy of bag limits on harvest rates of bottomfish, Bargmann [1985a] predicted that halving the (then) limit of ten rockfish to five would reduce rockfish harvest by only one to 16% (not including Admiralty Inlet or the Strait of Juan de Fuca), and that "severe" bag limit reductions would be required to substantially reduce the harvest of rockfish. In a review of management approaches to Puget Sound bottomfishes, WDFW fishery managers suggested that bag limits "have not maintained a stable catch per unit of effort", and that lack of abundance estimation for bottomfish (including rockfish) have hampered management and conservation efforts [Bargmann et al. 1991].

At present there is no targeted commercial fishery for demersal rockfish. Areas of high rockfish abundance have been closed to trawling, and gears designed specifically to harvest fish from rocky substrate (commercial bottomfish troll and jig gears) have been prohibited. Commercial landings of demersal rockfish are now limited to by-catch from trawling, and from setline and setnet fisheries targeting spiny dogfish (*Squalus acanthias*).

Lingcod

Declines in lingcod stocks in Puget Sound were noticed as early as the late 1940s [Palmen 1955], which were managed with wintertime fishing closures to protect spawning fish. Various area and season closures have been in effect for lingcod in Puget Sound since then, including a moratorium from 1978 to 1983 on all lingcod fishing south of Admiralty Inlet [Bargmann 1985b]. Currently, trawling for bottomfish in Washington State is allowed only in oceanic waters, Western

[1] Bag limits are used instead of size limits for Demersal rockfish because rockfish cannot compensate for the change in pressure when brought quickly to the surface by fishers. Hence, they typically die when caught.

Strait of Juan de Fuca, and North Puget Sound; commercial fishing using otter trawls has been banned in all other Washington marine waters.

Current regulations on the recreational fishery are designed to protect lingcod during their spawning season, protect juveniles and large, highly fecund females, minimize damage to caught-and-released individuals, limit the total number of lingcod taken, and distribute the Resource as equitably as possible to fishers. To that end, the season when lingcod may be fished in Puget Sound waters is short, from May 1 through June 15. For fish taken on hook-and-line, a 26 inch minimum size protects juvenile, pre-reproductive individuals, and a 40 inch maximum size protects large females (maximum size for male lingcod is approximately 35 inches). Gaffing fish is not allowed, which reduces injury to hooked lingcod if they are subsequently released. However, divers are allowed to take lingcod of any size. A daily bag limit of one applies to all fishing types in Puget Sound and the San Juan Islands.

Pacific cod

Commercial (trawl and setnet) and recreational (hook-and-line) fishery catches have declined steadily from the mid 1970s to recent times. Sport fishing for this species is strictly regulated by the WDFW with bag limits[1] ranging from two in Northern Puget Sound to zero in all areas of Puget Sound [Washington Department of Fish and Wildlife 1996]. Two Puget Sound fisheries have been closed because of low abundance of Pacific cod; the commercial set net, and the Agate Pass recreational fishery (during cod spawning season) [Schmitt et al. 1994]. A new fishery for Pacific cod in the western Strait of Juan de Fuca was severely limited in 1996 by WDFW because of uncertainty in the separateness of these populations from depleted stocks in the eastern Strait. New regulations have been adopted which will greatly restrict bottom trawling in northern Puget Sound to protect Pacific cod stocks [Greg Bargmann, Washington Department of Fish and Wildlife, personal communication].

[1] Bag limits are used instead of size limits for Pacific cod because cod cannot compensate for the change in pressure when brought quickly to the surface by fishers. Hence, they typically die when caught.

Pacific Hake (Whiting)

At one time, this species represented the largest fishery, by weight, in Puget Sound; however, hake abundance has been too low in recent years to allow a commercial fishery for the species. The WDFW conducts annual surveys of this species using hydro-acoustic methods; however, sampling is too infrequent to adequately monitor stock abundance.

Walleye Pollock

Bag limits of walleye pollock for the Puget Sound recreational fishery (not including San Juan Islands) have been reduced from 15 to 5 [Washington Department of Fish and Wildlife 1996] because of low abundance [Schmitt et al. 1994]. In 1997, the Fish and Wildlife Commission is considering lowering the bag limit to zero [Greg Bargmann, Washington Department of Fish and Wildlife, personal communication].

Pacific Herring

In Puget Sound, Pacific herring are harvested commercially and recreationally primarily for bait, and harvest has not historically been thought to play a major role in determining population abundance [Penttila *in press*]. The exploitation rate of this fishery has averaged approximately 7% in recent years, which is conservative relative to a generally accepted world-wide harvest-rate guideline of 20% [WDFW Forage Fish Unit *in press*]. The WDFW currently limits harvest of this species to 20 lbs. per person per day.

Pacific herring also support a “spawn-on-kelp” (SOK) fishery in the north Puget Sound, where spawning adults from the Cherry Point stock are captured, placed in net-enclosures, and allowed to spawn on kelp placed inside the enclosures. The eggs, attached to kelp, are then harvested and the adults released alive. This fishery handles approximately 6% of the Cherry Point herring stock.

Olympia Oyster

Harvest was identified as a threat to remaining populations of Olympia oysters [Dumbauld *in press*]. Discussions with Brett Dumbauld and Anita Cook, both biologists with the Washington Department of Fish and Wildlife, clarified a further issue with controlling harvest of this species. This species is currently not protected from harvest by WDFW regulation, because of the inability of most harvesters to distinguish the species from the introduced Pacific oyster (*Crassostrea gigas*). Reserves currently exist for Olympia oyster [Westley et al. 1985]; however, in most cases, harvest is allowed within the reserves, and since Pacific oyster are cultured in the reserves, species-specific harvest limits would not work there. A further complexity in the status of Olympia oyster is that many of the largest beds exist on private tidelands and are therefore privately owned. In such cases, state agencies would have no authority to protect the species; protection would have to be initiated by private citizens.

Pinto Abalone

Overharvest is thought by WDFW shellfish biologists to be a significant problem for this species, although population abundance of the species is not well known. Pinto abalone in Washington waters were harvested recreationally by divers until the fishery was closed by WDFW in 1994. Commercial harvest of the species has never been allowed by the State; however, substantial illegal commercial harvest of pinto abalone continues throughout their range, and is a cause for concern [Alex Bradbury, Washington Department of Fish and Wildlife, personal communication].

Unclassified Marine Invertebrates (UMI)

Harvest of the hundreds of species comprising this group is currently unregulated along most of Puget Sound's shoreline. The status and harvest of UMI have been recently investigated and discussed [Dethier et al. 1989; Kyte 1989; Carney and Kvitek 1991]; however, difficulties with simply noticing the problem, identifying the species involved, and establishing sensible means to quantify catch, have slowed movement towards protection of this group.

Targeted Harvest -- Summary and Recommendations

Management of harvests, including increasingly restrictive bag and size limits, season closures, and other regulations, appears to have been largely ineffective in reversing the trend of decreasing abundance of Resources in Puget Sound. Impediments to successfully protecting Resources include lack of reliable, regular estimation of population abundance, and incomplete knowledge of the degree to which harvest or other stressors have negatively affected Resources. These needs must be addressed; additionally, other means for restoring and maintaining Resources should be considered, including restoration of lost natural production, and enhancement and protection of existing natural production. The following recommendations address these issues, with the assumption that existing catch, season, and size restrictions remain in effect.

Unclassified Marine Invertebrates

UMI are the only targeted Resource whose harvest has been unmonitored or unregulated to date. Dethier et al. [1989], Kyte [1989], and Carney and Kvitek [1991] have proposed various management options to protect UMI. Four recommendations were consistent among these authors: (1) establishing harvest refugia where no collecting or harvesting is allowed. (2) Regulating harvest. Even though this is a costly and difficult activity, consensus among these authors was a need for regulation and enforcement of harvest limits in areas where harvest is allowed. (3) Education. Harvesters must be made aware of the potential damage caused by the cumulative impact of their activities on intertidal communities. This is an especially difficult problem because of the diversity of languages and cultures involved. However, public support for protecting this Resource is strong, as evidenced by letters received by the WDFW raising the issue [Mary Lou Mills, Washington Department of Fish and Wildlife, personal communication]. (4) Monitoring the Resource. Sufficient funding must be supplied to adequately inventory the Resource and monitor its health.

The WDFW has recognized a problem with potential overfishing of UMI in intertidal areas and is currently considering a variety of actions to protect UMI [Mary Lou Mills, Washington Department of Fish and Wildlife, personal communication]. The range of potential actions WDFW may propose includes: complete closure of harvest of all or most UMI; closure of some or all species at selected sites; and continuing *status quo* (ie. no protection). The continued lack of funding for management of these resources is an impediment to their protection while allowing some use of the resource. In addition, local, state or federal agencies, who may own some of the public beaches involved, potential stakeholders, and tribal comanagers need to be considered in the analysis.

Recommendations for Protecting UMI

The WDFW is studying a range of feasible alternatives to protecting UMI, using the full base of knowledge available (outlined above). It seems clear that **some regulation of harvest is warranted**, especially in the areas with most intense harvesting.

When regulations are enacted it is imperative that sufficient funding be made available to: **conduct outreach and provide education** for affected users; **include local stewards** (e.g., cities, counties, and private beach owners) in discussing protection options; **monitor the effects** of harvest and of harvest prohibitions on local UMI populations and communities.

Coordinate and consult with tribal comanagers in developing plans to protect UMI.

Abundance Estimation

One of the largest obstacles to effective management of Resources appears to be lack of reliable estimation of population abundance. Recommendations from an internal biometric review of WDFW management of bottomfish resources in Puget Sound concluded that "The basic elements for quantitative stock assessment and fishery management (reliable catch, effort, and biological data) are largely unavailable for Puget Sound groundfish[1]" [Tagart et al. 1996]. Populations of Olympia oyster, pinto abalone, and UMI are currently unmonitored in Puget Sound. The WDFW currently has an adequate program to monitor abundance of Pacific herring.

[1] this term is often used to describe the mix of species harvested with bottom- or midwater oriented gears, including lingcod, rockfish, Pacific cod, Pacific hake, and walleye pollock. Other major groups include "baitfish" or "forage fish", and anadromous species.

The WDFW currently conducts only limited, regular, fishery-independent stock assessment for Puget Sound bottomfish, and it does not routinely monitor key population parameters such as age- or size-structure, or maturity in most species. Evidence for declining stocks has come primarily from monitoring recreational and commercial fisheries, which provides, at best, an index of relative abundance (see Palsson et al. [1996]). However, Palsson et al. [1995] are currently developing a method to remotely assess population abundance of rockfish and lingcod non-destructively on rocky reefs using a video-acoustic technique (VAT). The VAT, although currently used only in depths less than 120 ft. and only on high-relief substrate, holds promise as a useful fishery-independent tool for monitoring rockfish and lingcod stocks in Puget Sound. New VAT technology may also allow estimation of fish size underwater, allowing non-destructive monitoring of size or age distribution.

The WDFW monitors catch of marine fishes from the recreational fishery to identify trends in catch and catch rates. However, the program is primarily designed to estimate catch of Pacific salmon, so if a salmon season or area is closed, the estimation of marine fish catch is lost. The WDFW has recently begun participating in a national fishery sampling plan called the Recreational Fishery Information Network (RECFIN). For Washington, RECFIN is designed to estimate catch of Puget Sound bottomfish from the recreational fishery. The program, however, does not collect all essential biological information such as age of fish, critical pieces of information required to manage individual species and to parameterize age- and size-based stock assessment models. In addition, the sampling scheme is designed to collect information for a nation-wide database -- at a scale too large to be useful for regional management.

Recommendations for Better Abundance Estimation

Continue evaluation of the **Video-Acoustic Technique** for estimating demersal rockfish and lingcod abundance, focusing on validation of the method, increasing capability to depths below 120 ft., and improving technology to estimate size of target species underwater.

Conduct periodic **surveys to estimate abundance and other population parameters of stressed Puget Sound fishes and invertebrates.** Wayne Palsson [Washington Department of Fish and Wildlife, personal communication] recommended increasing the frequency of existing hydroacoustic sampling of Pacific hake to at least three times per year. Species-specific, fishery-independent surveys would be necessary for demersal rockfish, lingcod, Pacific cod, walleye pollock, pinto abalone, Olympia oyster, and UMI.

Expand RECFIN program and implement collection of biological data for all fisheries for parameterization of stock-assessment models, and add sampling to provide more adequate regional coverage. Increase spatial and temporal coverage of species- and fishery-specific recreational fishing surveys, similar to the existing South Sound lingcod “Emphasis Survey”.

Harvest Refugia

In any analysis of overfishing as a stressor on marine species, a common denominator seems to be protection of adequate spawning potential of adults. The spawning stock size and age structure required to sustain or recover populations of stressed Resources in Puget Sound are currently unknown, so a conservative approach would provide significantly more protection than is currently afforded, and as much as is feasible. This could include protecting reproductive stocks, particularly large adults (whose fecundity is high) by (1) continuing existing, or imposing more restrictive harvest limits in the fisheries and (2) providing refuges where these species can successfully complete their life cycle.

A quickly growing body of evidence indicates that the use of marine reserves, or marine protected areas (MPAs), where harvest of any number of species is prohibited, could be a cost-effective, ecologically sound addition to management plans for protecting marine fishes and invertebrates. The British Columbia/Washington Marine Science Panel identified establishment of MPAs as the second highest priority (after minimizing loss of estuarine wetland habitat) for protecting the shared waters ecosystem [MSP 1994].

The preponderance of literature supporting the use of MPAs and consensus among Washington and British Columbia researchers and managers suggests that establishment of MPAs is clearly in the best interest of protecting marine life in shared waters, and should be supported at every level. A Transboundary British Columbia/Washington Marine Protected Areas Work Group has been convened to investigate the use of MPAs in the joint effort to protect living resources in shared marine waters.

Harvest Refugia Recommendations

Establish a program to create Marine Protected Areas or Harvest Refugia for harvested species, focusing on a community- or ecosystem-scale approach for design, placement, and evaluation of efficacy. Protection of the full range of habitats required to successfully complete life cycles of species or communities should be considered a high priority..

A harvest refugium for Olympia oysters has been proposed by the WDFW Shellfish division for 1997 regulations, wherein a diked **population of Olympia oysters in North Bay, Puget Sound, would be protected from harvest** [Anita Cook, Washington Department of Fish and Wildlife, personal communication]. If implemented, the effects of this effort on local or regional abundance of Olympia oyster should be evaluated.

Existing harvest bans on pinto abalone should be better enforced until adequate population abundance estimates are made for the species. This species occupies similar habitat to other Resources proposed for harvest protection, such as lingcod, rockfish, and UMI. Marine Protected Areas focusing on common habitat for a number of species like these would make enforcement easier if harvest of all species was prohibited in well defined areas.

Marine Fish Hatcheries

Marine fish hatcheries to enhance stocks have also been proposed in the Pacific Northwest as a tool to increase production of species important to commercial and recreational fisheries [Nosho and Freeman 1993]. Managers of Pacific salmon rely heavily on hatchery-reared salmon to augment depleted stocks. The use of hatcheries, however, continues to be hotly debated, resulting in a polarization of those involved [Daley 1993]. Long-term reliance on artificial propagation of fish has several drawbacks including (1) at best, drawing attention away from, and at worst, tacitly accepting, underlying causes of population declines, (2) perpetuating the notion that science and technology can always “fix” resource problems, which is especially problematic when technological advances cause the problems in the first place (termed “techno-arrogance” by Meffe [1992]), (3) reductions in genetic integrity and diversity of wild stocks, (4) other alteration of genotype, (5), alteration of behavior of reared species, (6) continued over-harvest of wild stocks, (7) difficulties in measuring effectiveness of programs, and (8) extremely high cost relative to other management tools.

Marine fish hatcheries have been used to enhance production of harvested species in the United States (e.g., red drum in Texas --[McEachron et al. 1995] and striped mullet in Hawaii -- [Leber et al. 1995]). A responsible approach to application of this technique to marine organisms has been proposed [Blankenship and Leber 1995]; however, lacking in the approach is a recommendation for analyzing the value of stock enhancement relative to, and within the context of, a wider range of resource management tools.

Marine Fish Hatchery Recommendation

If marine fish hatcheries were to be considered for enhancing depressed populations of marine fishes or invertebrates, **a conservative approach would address the above issues prior to accepting stock-enhancement as a management tool**. If implemented, stock enhancement programs should follow a conservative and responsible approach similar to that outlined by Blankenship and Leber [1995].

Harvest Bycatch

Unintentional capture of non-target species (bycatch) is a significant source of mortality for all of the fish listed in this report (except Pacific herring), as well as marbled murrelets, common murre, and harbor porpoise. The fish are taken in nets and on hooks by fishers targeting other species, and the birds and mammals are killed by drowning when they become entangled in drift gillnets used during normal operations of various salmon fisheries.

Fish Bycatch

Lingcod, rockfish, and codfishes are all taken by gears designed to harvest a number of other species including other bottomfish, salmon, and dogfish. Bycatch-mortality effects on stressed species are unknown in Puget Sound; however, bycatch contribute a substantial amount to overall mortality in these species [Wayne Palsson, Washington Department of Fish and Wildlife, personal communication].

Marbled Murrelets and Common Murre

Although these species are not harvested, bycatch continues to be a problem throughout the range of most alcids (see review in Mahaffy et al. [1994]). The principle cause of bycatch mortality is entanglement of birds in gillnets targeting Pacific salmon; however, some birds are probably killed when inadvertently hooked by recreational anglers [Washington Department of Wildlife 1993a]; mortality from purse seining operations is rare [Jeff June, Natural Resource Consultants, personal communication]. Species most likely killed in drift gillnets are common murres, western grebes, marbled murrelets, and rhinoceros auklets [Troutman et al. 1991]. Erstad et al. [1996] and Pierce et al. [1996] estimated mortality rates of seabirds resulting from entanglement in Puget Sound sockeye and chum salmon gillnets, respectively, in 1994. Extrapolating from those results, an estimated 14 marbled murrelets were taken in the 1994 Puget Sound sockeye fishery[1] in the San Juan Islands and northern Puget Sound, and 83 common murres were taken in the Puget Sound chum fishery from Central Puget Sound and Hood Canal. Research to estimate entanglement and mortality rates is fairly recent, and accuracy of estimates is probably compromised by the high level of variability in timing and distribution of seabirds in Puget Sound [Ed Melvin, Washington SeaGrant Program, personal communication].

Wilson [1991] and Warheit (*in review*) raised concern over the potential negative effects of gillnetting on Washington populations of common murres. However, because of uncertainty about the origin of killed in these fisheries, it is impossible to accurately estimate the effects such mortality has on Washington breeding populations of marbled murrelets and common murre. If, for instance, all of the common murres killed in Puget Sound gillnets were from Washington breeding populations, the total effect of bycatch mortality on that population would be substantial. More likely is that wintering Puget Sound populations of common murres are a mix of Washington breeders and birds from Oregon (and possibly from British Columbia, Alaska, and California).

[1] Marbled murrelets were the only seabirds discussed in this report, although other species were likely killed in the fishery.

Melvin and Conquest [1996] reviewed the current management of seabirds with respect to bycatch in the commercial drift gillnet fishery, and field-tested modifications to gillnet gear designed to reduce incidental catch of seabirds. The non-treaty commercial gillnet industry has responded to concerns by wildlife managers by preparing a five-year action plan to (1) assess the status of seabird populations and their interactions with fishing gears in Washington, (2) develop and use gears designed to reduce bycatch of birds and mammals, and (3) alter fishing practices to reduce interactions with seabirds. The WDFW has restricted gillnet openings to primarily daylight hours[1], and closed some areas frequented by marbled murrelets to all commercial fishing to protect that species. Melvin and Conquest [1996] had mixed success testing the efficacy of gillnets modified to reduce bycatch of seabirds; the birds avoided modified nets, but salmon catch was substantially reduced.

Net modifications involved replacing upper panels of gillnets with multifilament mesh. The multifilament is more visible to birds so they can more easily avoid entanglement. Melvin suggested implementing so-called “20 Mesh” treatments to gillnets, where the top one-eight of nets are modified; this treatment is relatively inexpensive (approximately $2000 per net), reduces seabird entanglements substantially (up to 43%), reduces fishing efficiency only slightly (by less than 8%), and is endorsed by non-treaty commercial fishers.

Harbor Porpoise

[1]In daylight hours, birds can presumably see, and avoid fishing boats and nets easier, and fishers can more easily avoid concentrations of birds.

Inadvertent mortality of harbor porpoise from entanglement in fishing nets has been implicated as one cause of their reduced abundance in Washington waters [Calambokidis and Baird 1994]. Erstad et al. [1996], and Pierce et al. [1996] estimated mortality rates of marine mammals resulting from interactions with Puget Sound sockeye and chum salmon gillnet fisheries, respectively, in 1994. Extrapolating from those results, an estimated 14 harbor porpoise were killed in the 1994 Puget Sound sockeye fishery in the San Juan Islands North Puget Sound, and none was killed in the Puget Sound chum fishery from Central Puget Sound and Hood Canal. Harbor porpoise in Washington inside waters numbered approximately 2000 in 1991 [Jeff Lake, National Marine Mammal Laboratory, personal communication]. Total annual mortality of harbor porpoise attributed to all fisheries in Washington's inland marine waters is estimated to be 16 porpoise. The "potential biological removal level"[1] for this species in inland Washington waters is 27 animals [Barlow et al. 1995]. Fishery mortality of harbor porpoise in Canadian waters is not included in these estimates; however, the combined fishery mortality in shared inland waters is thought to be just below the potential biological removal level [John Calambokidis, Cascadia Research, personal communication].

Research is being conducted to test the efficacy of underwater acoustic alarms ("pingers") attached to drift gillnets to prevent entanglements. Some success has been observed using these devices in oceanic waters, and they are currently being tested in inland waters [Gearin 1996].

[1]"...the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." (Barlow et al. 1995).

Harvest Bycatch Recommendations

Conduct basic research to estimate contribution of bycatch mortality to overall mortality of lingcod, demersal rockfishes, and codfishes

It appears that credible, effective measures are being pursued **to reduce bycatch of seabirds** in the Puget Sound commercial drift gillnet fishery. These should be continued

Encourage continued research to **design nets that reduce bycatch without severely reducing catch of salmon.** The "20 Mesh" modification (see above) appears to be a reasonable compromise between protection of birds and fishing efficiency.

In-season bird censuses and distribution surveys could help to direct sampling away from high concentration of seabirds, including continuation of the WDFW plan of time (daylight hours only) and location (avoiding concentrations of seabirds) restrictions.

Evaluate harbor porpoise-salmon fishery interactions better, focusing on timing and location of encounters. Further **evaluate the efficacy of gears fitted with underwater acoustic alarms for preventing entanglements**.

HABITAT LOSS AND DEGRADATION

Loss or degradation of habitat has probably been a major contributing factor to depressed populations of marine organisms in Puget Sound. Loss of intertidal and shallow subtidal habitat usually results from diking or filling, where the original marine habitat has been converted to terrestrial. Loss of habitat can also result when one habitat replaces another. For example, a mud flat may be lost to construction of a jetty; however, the jetty might then provide substrate for other productive habitats, such as forests of bull kelp. Changes in marine habitats have occurred from upland activities as well. Extensive commercial and residential developments, and agricultural and forest practices along the Puget Sound shoreline and watersheds have resulted in point- and non-point-source pollution, changes in drainage patterns, increased turbidity and siltation of marine waters, eutrophication, and changes in shoreline substrates, slopes, current patterns, wave energy, and temperature; all which have significantly altered intertidal and shallow subtidal habitats.

In this report relative value of natural habitats is not considered, nor are judgements about their relative ecological importance made. The intrinsic value of all natural habitats is assumed, and recognizing that many habitats change or are “lost” naturally, all anthropogenic changes to habitat are considered to be negative impacts to the historical structure of the Puget Sound ecosystem.

Habitats are critical components of all ecosystems, because they provide the space or substrate within, or upon, which organisms live. All of the species discussed in this report rely, either directly, or indirectly, on maintaining healthy habitats in Puget Sound. For instance, copper rockfish use pelagic habitats as larvae, submerged marine vegetation (SMV[1]) habitat as juveniles, and rocky-reef habitat as adults. Harbor porpoise and all the alcid birds rely indirectly on SMV because their primary prey (Pacific herring) use that habitat as a spawning substrate.

All marine habitats contribute intricately to the function of the Puget Sound ecosystem. It is probably impossible to model or describe their relative or absolute importance in the overall function of the ecosystem; however, SMV habitats are of particular interest

[1] Defined for this report as marine vegetation which is submerged during some part of the tidal cycle. Includes seagrasses, overstory and understory kelps, and turf algae.

to this report because a number of stressed Resources appear to rely directly on them for successful completion of their life cycle. In addition, SMV habitats support high diversity and abundance of organisms, and provide (1) a source of energy (through primary production), (2) refuge and foraging habitat for myriad organisms, (3) substrate for attachment of sessile organisms, (4) dissipation of wave and current energy, (5) stabilization of sediments and (6) transfer of energy to deep or other habitats.

Habitat-Resource Relationships

Specific habitat-Resource relationships which have likely been compromised by anthropogenic loss of habitat are described in this chapter. In most cases, this consists of reductions in habitats used by particularly sensitive life history stages of the species of concern from Table 1. At least four species or groups of marine fishes (lingcod, demersal rockfish, Pacific herring, and Pacific cod), one bivalve mollusc (Olympia oyster), and many UMI such as moon snails and other gastropods, shrimps, crabs, and worms are found in habitats which have experienced substantial losses or degradation over the past century, or are experiencing ongoing loss. SMV habitats such as eelgrass meadows, kelp forests, and other beds of vegetation are used as nursery or spawning habitats by the fish species [Miller et al. 1976; Haldorson and Richards 1987; Matthews 1988; Cass et al. 1990; Love et al. 1991; Norris 1991; West et al. 1994; Doty et al. 1995; West et al. 1995]. Olympia oysters require firm, clean, low intertidal substrate, with some hard surface for attachment (e.g., rock or shell), and clean, unpolluted water. [Dumbauld *in press*]. Loss or degradation of intertidal habitats may have affected a number of UMI species as well, especially if habitat is limiting to their survival or abundance.

For lingcod, demersal rockfish, and Pacific cod, nursery habitats provide refuge from predation and a productive source of food during a particularly vulnerable life stage, when these fish shift from pelagic to demersal habitats in their first year. For Pacific herring, SMV habitats provide a substrate upon which to deposit eggs. These habitats are, in most regions of Puget Sound, limited to a narrow band of shallow water along the shoreline suitable for growth of seagrasses and algae.

Spatial limitation of these habitats may limit survival of these species by creating a “bottleneck” in their life history. Such habitat-related demographic bottlenecks have been described or demonstrated for American lobster, stone crab, and spiny lobster [Wahle and Stenek 1991; Parrish and Polovina 1994; Beck 1995]. In such a situation, strongly substrate-associated species require specific habitats to provide specific resources, for example, refuge for juveniles from predation. As juvenile lingcod, demersal rockfish, and Pacific cod settle from pelagic to benthic habitats in their normal ontogeny, they also become strongly substrate-associated, orienting to marine vegetation. Those individuals encountering suitable nursery habitat would have a greater chance of survival than those that do not, and if the habitat is rare or spatially limited, presence of suitable habitat would be critical to the successful completion of their life cycle. Presence of suitable substrate for spawn-deposition is also thought to be of critical importance to the successful completion of the life cycle of Pacific herring [Penttila *in press*].

The geographic distribution of habitats may be an important component of their function. In many cases, stochastic processes probably play a strong role in the survival of larval marine fishes, and it may be important for habitat to be widely available to sustain widely distributed, if sporadic, supplies of juveniles. Doty et al. [1995] observed a strong spatial and temporal variability in the distribution of newly settled juvenile rockfish in Puget Sound nursery habitats. Such patterns indicate that any given nursery habitat may not be used every year by juvenile marine fish, with the distribution of juveniles in any year dictated by a combination of prevailing oceanographic conditions and the vagaries of larval supply. If the location of nursery habitats beds are changed through mitigation (e.g., transplanting eelgrass) or other human activities, existing patterns of supply of juveniles may not match the altered habitat distribution.

Olympia oysters require a firm substrate (such as a rock or shell) to which settling spat (larvae) attach, sufficient water flow to supply adequate food (phytoplankton), salinity greater than 20 parts per thousand, and temperature greater than 10°C [Dumbauld *in press*]. This species is especially susceptible to sedimentation, and this stressor is thought to be a substantial threat to the species, wherein spat are smothered after settling, or hard substrates are made unavailable by over covering with soft sediment. Anthropogenic increases in sediment loadings have been identified as a major stressor in Puget Sound [Newton et al. *in prep*], and macroalgae have been known to be smothered in areas of high deposition [Devinny and Volse 1978]. The extent of increases in sediment loads in Puget Sound is unknown; however, increased erosional sedimentation from upland activities such as development and logging have been implicated.

Habitat Assessment and Causes of Habitat Loss

Inventory, measurement, description, and monitoring of marine habitats in Puget Sound has proved difficult. Little baseline or historical data are available with which to compare recent changes in habitat type and quality. In addition, some anthropogenic environmental changes such as increased turbidity or altered substrate grain size may take decades to result in a measurable change in habitat. Levings and Thom [1994]

discussed the status of eight marine habitat types in Puget Sound (marsh/riparian, sandflats, mudflats, rock/gravel, unvegetated subtidal, kelp beds, intertidal algae, and eelgrass). They reported estimates of changes in areal extent on a Puget Sound-wide basis for only two types: a 75.9% loss in tidal marshes and riparian habitat, as a direct result of infilling, diking, and other shoreline development, and a 52.7% increase in area of bull kelp, perhaps as a result of shoreline armoring[1]. However, Mumford [1990] indicated that regional losses of bull kelp forests, in particular, South Puget Sound, have occurred as well.

Losses of other habitat types have proved difficult to measure, even though there is some consensus that seagrass habitats, in particular, have suffered major losses or degradation in recent years (see Wyllie-Echeverria and Phillips [1994]). Eelgrass and other seagrasses are sensitive to perturbations from many anthropogenic sources such as direct destruction resulting from various shoreline activities, including dredging, armoring, filling, construction, trampling, and boat grounding, and indirect effects such as shading by overwater structures, loss or alteration of substrate, reduction in light levels from anthropogenic turbidity, pollution, and eutrophication (which enhances growth of epiphytes and phytoplankton, both resulting in blockage of light) [Walker and McComb 1992; Bulthuis 1994; Bulthuis 1995; Fresh et al. 1995]. Fresh [1994] suggested that construction of marinas typically causes the greatest negative impacts on eelgrass meadows. Treatment of all these sources of habitat loss are beyond the scope of this report. Following is a brief discussion of selected issues that have not received much attention to date.

Ruckelshaus [1994] contended that fragmentation of large eelgrass beds in Puget Sound, has resulted in significant change in function of the habitat. Levings and Thom [1994] summarized undocumented losses of eelgrass habitat in Puget Sound based on the work of Thom and Hallum [1990] and Ronald Phillips. Bulthuis [1991] has documented the encroachment of substantial tracts of *Zostera marina* by the introduced *Z. japonica.* Pawlak and Olson [1995] suggested that *Z.marina* and *Z. japonica* will likely be shown to possess substantially different ecosystem function (also see Posey [1988]). Other introduced species such as *Sargassum muticum* and the cordgrasses *Spartina* spp are thought to have replaced eelgrass in some areas [Mumford 1990].

[1] Shoreline armoring consists of changing unconsolidated, soft substrate to consolidated, wave- and erosion-resistant substrate, including installation of bulkheads and jetties

Even though Thom and Hallum [1990] have estimated a substantial overall increase in shoreline length where bull kelp (*Nereocyctis luetkeana*) now grows in Puget Sound, this species, and other kelps, are experiencing anthropogenic stressors which affect distribution patterns, and may affect overall coverage in future years. Invading exotic species such as *Sargassum muticum* are thought to have outcompeted the native bull kelp for space in a number of areas in Puget Sound [Thom and Hallum 1990]. Bull kelp requires high levels of nutrients and light and its growth may be reduced or presence eliminated in areas where water quality has been degraded [Levings and Thom 1994]. In addition, Mumford [1990] has raised the issue of significant regional losses of these species.

Harvest of kelps and other nearshore macroalgae is a recent stressor impacting these habitats, especially on a small spatial (local) scale. Although small amounts of harvest of nearshore marine vegetation have occurred for centuries [Gunther 1945], recreational harvest of these species has risen greatly in the last few years [Mumford 1990]. The effects of such harvest are unknown at present; however, it is heavy enough to have warranted restrictions on recreational harvest of all seaweeds in State Park waters [Washington Department of Fish and Wildlife 1996]. Current harvest levels are thought to cause localized depletions, which may negatively affect already-stressed species that rely on the habitat. Current harvest levels of kelps, however, are unlikely to seriously impact kelp populations on a Puget Sound-wide scale [Tom Mumford, Washington Department of Natural Resources, personal communication].

The effects of aquaculture operations on nearshore vegetated habitats have been recently reviewed as a potential source of habitat loss or degradation in Puget Sound[1] [Simenstad and Fresh 1995]; however, a rigorous investigation is lacking. Simenstad and Fresh [1995] identified four major aquaculture operations that might negatively affect marine habitats: (1) enhancement of hardshell clam by beach graveling; (2) over covering hardshell clam beds with netting to exclude predators of clams; (3) spraying of pesticides in marine waters to kill burrowing shrimp (*Neotrypea* and *Upogebia*), naturally occurring species considered pests by oyster growers; and (4) removal of attached vegetation, such as eelgrass (also considered a nuisance), by oyster growers.

Pacific oysters are cultured extensively in Willapa Bay, and less so in Puget Sound. However, loss of nearshore vegetated habitat apparently routinely occurs in regions of

[1] See Hastings and Heinle [1995] for a national perspective.

Puget Sound where Pacific oysters are cultivated, such as Samish Bay. Substrate is routinely “harrowed”, or plowed, and eelgrass is sometimes mowed in these areas to facilitate culture operations. This practice is the only one allowed, on a regular basis in Puget Sound, to disrupt or kill large tracts of intertidal vegetated habitat with no mitigation or reparation. It appears that Pacific oyster culture operations are not subject to the normal permitting procedures where loss of marine habitat is an issue.

Culture of Pacific oysters in Puget Sound probably has had direct negative impacts (from displacement, or competition for space or food) on a number of nearshore species [Simenstad and Fresh 1995], including Olympia oysters and UMI. No research has been conducted locally to support this [Dumbauld *in press*]. However, intensive culture of bivalves in other ecosystems has been shown to deplete food resources for indigenous filter-feeders [Peterson and Black 1987].

Hueckel et al. [1989] described displacement of benthic organisms and impacts on nearby prey organisms resulting from construction of artificial reefs. Although the local effects are substantial, the overall scale of reef construction in the Puget Sound is small, and impacts to vegetated habitats negligible. Beach graveling also alters communities of benthic invertebrates and their predators [Newman and Cooke 1988; Simenstad and Fresh 1995]. However, beach graveling and netting of clam beds occurs infrequently, and enhancements are not allowed if they negatively impact seagrasses [Newman and Cooke 1988].

The effects of increased turbidity on vegetated habitats and on Olympia oyster habitats resulting from upland activities such as logging and land development are currently not being evaluated in Puget Sound, nor are negative effects from eutrophication of nearshore waters. These factors were identified by Mumford [1990] as important factors limiting distribution of seaweed in Puget Sound, and increased sedimentation was identified as a threat to Olympia oysters [Dumbauld *in press*]. One study documented negative changes in a nearshore kelp forest in Puget Sound resulting from a nearby landslide [Shaffer and Parks 1994]. Bulthuis [1994] and Thom [1995] have discussed the limiting effects of light, and the negative impacts of increased turbidity and nutrients (eutrophication) on depth distribution of eelgrass.

Habitat Management

Management of nearshore marine habitats is a complex, multi-agency effort; those involved vary, depending on which owns the land, or where a development project is located. The Washington Departments of Fish and Wildlife (WDFW) and Natural Resources (WDNR) currently operate under a policy of "no net loss",wherein vegetated habitat damaged or lost through human activities must be replaced through mitigation

(WDFW Policy # 410, 10 September, 1990; WDNR Policy # POL-0300, 9 January, 1991). A Transboundary Habitat Loss Work Group has been assembled to evaluate the efficacy of these and other efforts in minimizing loss of habitat in shared waters. Hence, the remainder of this section will focus on a summary and collation of recommendations already made, but not yet implemented, to better protect and enhance marine habitats in Washington's waters. It is important to reiterate here that the habitat discussion in this document has been focused on those habitats important to the stressed Resources described herein. All marine habitats contribute directly or indirectly to natural function of the marine ecosystem, and for that reason alone, function of all habitats should be preserved. However, recommendations specific to stressed Resources have been developed as follows from the discussions above.

In order to maintain natural production of the stressed Resources discussed in this document, all habitats used by these species should be protected, preserved, and, where possible, restored. The Transboundary Marine Science Panel recommended minimizing estuarine habitat losses as the highest priority for the Environmental Cooperation Council [MSP 1994]. The primary direct impacts of habitat loss on the species of interest in this document are (1) loss or alteration of nearshore vegetated nursery habitats for demersal rockfish, lingcod and Pacific cod, (2) loss or degradation of spawning habitats used by Pacific herring, and (3) loss or alteration of habitat used by Olympia oyster. Recommendations to preserve these habitat functions are outlined below.

Fresh [1994] reviewed management of seagrasses in Washington State, and provided recommendations for better management of these habitats including (1) increasing communication between agencies and user groups, to avoid the appearance of inconsistency in the project approval process[1], (2) development of policies specific to the protection of eelgrass, including a formal mitigation policy, and (3) computerized tracking system with area maps to evaluate success of the no-net-loss policy. In addition, the WDFW no-net-loss policy and mitigation requirements are applied unequally and inconsistently regionally, resulting in a fragmented approach to habitat protection and management.

Pawlak and Olson [1995] agreed, with additional recommendations: (1) a clearly documented and formalized seagrass policy, uniformly accepted by all natural resource

[1] This appearance of inconsistency results from a lack of understanding by the public as to how decisions are made by regulatory agencies. For example, some permits may be approved with mitigation, and others denied because mitigation was determined to not be an effective alternative. If the rationale for decisions concerning the applicability of mitigation are not clearly explained, then the process may appear inconsistent.

agencies, is needed; (2) a watershed approach (linking management of upland activities with marine habitat management) would allow the inclusion of indirect effects; and (3) we should anticipate the likelihood that *Zostera japonica* and *Z. marina* will be shown to possess substantially different ecosystem function[1].

Although Agency policies exist to protect nearshore vegetated habitats, many Puget Sound researchers and managers think that significant anthropogenic loss of eelgrass continues, whether from shoreline substrate changes resulting from legal and illegal structures[2], changes in water quality, or impact of exotic species. The Washington Department of Natural Resources (WDNR) currently monitors intertidal and shallow subtidal habitat as part of the Puget Sound Ambient Monitoring Program. Eelgrass habitat is a focus for that group; however, the WDNR program lacks capability to distinguish *Zostera marina* from the congeneric exotic *Z. japonica*, and it is restricted to the intertidal and very shallow subtidal zones. This precludes accurate monitoring of more than half of the State's overall *Zostera marina* habitat [Tom Mumford, Washington Department of Natural Resources, personal communication].

In addition, the existing "no net loss" policy for vegetated shoreline habitat should be revisited to address several issues raised above, including the functional differences occurring in the ecosystem when habitats are displaced, as occurs when vegetated habitat is allowed to be destroyed as long as it has been "mitigated", or replaced elsewhere. Current WDFW and WDNR policies recognize the importance of preserving the productivity of these habitats; however, specific functions are often not addressed.

Likewise, they do not address differences in function of eelgrass habitat that may be the result of geographic placement or other factors. In addition, existing policies do not ensure equal application across all regions, resulting in a fragmented approach. Much of the decision-making concerning the effects of proposed development projects on marine habitats, as well as the extent and types of mitigation required, are made by regional habitat managers without ecosystem-wide coordination, tracking or inventory. This has resulted in a fragmented approach to protecting sensitive habitats. Many habitat managers and scientists are concerned by the cumulative effects of losing what are usually considered insignificant increments of shoreline habitat. There is currently

[1] In fact, *Z. Japonica* does not function adequately as spawning habitat for Pacific herring (Dan Penttila, Washington Department of Fish and Wildlife, personal communication).

[2] Effects from structures installed before prohibitions were established may not be apparent until decades later. These losses have not been evaluated or monitored. Also, currently legal structures such as bulkheads installed above the high tide line may interrupt the natural flow of material from so-called "feeder bluffs", resulting in changes in substrate grain size in adjacent nearshore habitats.

no system to track the cumulative ecosystem-level effects of the normal application of Agency policies on marine habitats. Finally, the introduced eelgrass species *Zostera japonica* is afforded the same protection as the endemic *Z. marina*, and is accepted as a substitute in mitigation efforts. This acceptance does not replace the function of eelgrass beds as spawning habitat for Pacific herring; *Z. japonica* re-seeds annually *(Z. marina* is a perennial), and beds are not established until after the February-through-March spawning season (Dan Penttila, Washington Department of Fish and Wildlife, personal communication).

Mumford [1988, 1990] reviewed the status and management of harvested macroalgae, including kelps, and also provided management recommendations for these species. Recommendations included conducting research to gather data to answer three major questions: (1) what are the effects of harvest and anthropogenic environmental change on the long-term viability of seaweeds, (2) what is the habitat value of these seaweeds, or the function of these habitats within the ecosystem, and (3) what are the trends in distribution and population abundance of these species. Mumford [1990] also discussed the need to incorporate marine ecosystem issues such as these in the Timber, Fish and Wildlife process negotiations, in order to better protect marine habitats from upland activities. Education and outreach concerning existing regulations, the value of marine vegetation as habitat for other organisms, and ways to harvest portions of seaweed without killing the plant were also named as important issues.

Dumbauld [*in press*] reviewed the status of the native Olympia oyster and outlined recommendations to protect this species, with overall management objectives of retaining healthy populations and avoiding “threatened” or “endangered” listings. Most of the recommendations regarding Olympia oyster pertain to maintaining healthy habitat. Dumbauld [*in press*] posed five major recommendations including (1) mapping the current distribution, abundance, and habitat of the species in all Washington waters, (2) prohibiting harvest on the species until proper evaluation of population parameters can be conducted, and estimates of allowable harvest made, (3) controlling loss of and monitoring habitat changes in Olympia oyster habitat, with special emphasis on degradation of water quality (this includes the effects of pollution, eutrophication, and increased erosional siltation from upland development activities), (4) developing a base of information to help efforts in habitat restoration and restocking, and (5) continuing controls on the introduced “pest” Japanese oyster drill, with additional focus on Olympia oyster. Dumbauld [*in press*] also considered competition with the introduced Pacific oyster as warranting further investigation.

The recommendations discussed above are all consistent with protecting the natural function of vegetated habitats and of habitats for Olympia oyster in Puget Sound. Some of the plant species involved in these discussions may be considered stressed themselves, and worthy of consideration separately; however, it appears that this is unnecessary since their needs are dealt with in protecting their habitat function. Most recommendations have an underlying basis whereby understanding and dealing with human-ecosystem interactions on a watershed or ecosystem scale is important; a difficult task for any agency charged with managing natural resources. Where extraction or consumption of Resources is an issue, sustainability of the ecosystem as a producer of the Resources we use must be brought closer to the fore in making management decisions. Management of habitats on a regional scale is effective in maintaining overall ecosystem health only if regional efforts works towards that common goal.

Habitat Loss Recommendations

Establish a **clearly documented and formalized seagrass and seaweed policy**, uniformly applied and accepted by all natural resource agencies. Such a policy could use the existing no-net-loss approach; however, mitigation procedures should be formalized, especially addressing replacement of the function of displaced habitats. The policy would need to **distinguish between *Zostera marina* and *Z. japonica.*** The policy should have a **centralized tracking system** to evaluate habitat changes on a Sound-wide basis. The Timber Fish and Wildlife (TFW) process could be included in developing the policy; this would **link upland and marine habitat management** to account for the effects of upland activities on marine habitats, as well as the value of marine habitats on species managed in the TFW.

Expand the PSAMP Habitat Component to include **monitoring the areal coverage and function of subtidal habitats**. Possibly coordinate with WDFW Shellfish Program to **map and monitor Olympia oyster habitat**. Expand the PSAMP Habitat Component program to include **monitoring of turbidity and eutrophication**, and assessing their effects on the distribution of intertidal and shallow subtidal plant species (especially depth range) and of Olympia oyster. **Monitor encroachment of exotic species** such as *Spartina* spp, *Sargassum muticum*, and *Zostera japonica* on native species.

Provide Agency funds for, or encourage Universities to **support applied**

research addressing specific needs for better managing and protecting the habitats that support species in this report. These include: the effects of increased sedimentation and nutrients on nearshore vegetated habitats and Olympia oyster habitat; the function of nearshore vegetated habitats, especially with respect to their value as nurseries for lingcod, demersal rockfish, and Pacific cod; and population parameters of Olympia oysters needed to evaluate allowable harvest of the species.

Support and enhance existing **education and outreach programs**, especially those designed to enhance conservation and wise use of Resources.

Evaluate the potential of **Marine Protected Areas** specifically designed to protect existing populations of stressed species by **providing functional habitat required for the natural completion of their life cycle**. A focus on providing suitable habitat for all life stages of the organism should be maintained.

Continue and enhance **controls on the introduction of exotic species**, and continue monitoring effects of the Japanese oyster drill on Olympia oyster.

Investigate the degree to which aquaculture of Pacific oysters impacts endemic habitat in Puget Sound, especially relative to the scale at which other stressors affect these habitats. If found significant, pursue mitigation or reparation from these activities.

POLLUTION

Overview of Puget Sound Contaminant Research

A variety of contaminants have been identified in organisms from Puget Sound and the Georgia Basin. Contaminants include metals such as lead and mercury, pesticides, aromatic hydrocarbons (AHs), and other chlorinated organics such as polychlorinated biphenyls (PCBs). Chemical contaminants have been detected in a wide taxonomic range of Puget Sound organisms [Landolt et al. 1987, Malins et al. 1980, 1982, 1984] including harbor seals (*Phoca vitulina*) [Calambokidis et al. 1988], glaucous-winged gulls (*Larus glaucescens*) [Speich et al. 1988; Mahaffy et al. 1994], Pacific salmon (*Oncorhynchus* spp), rockfish (*Sebastes* spp), and English sole (*Pleuronectes vetulus*) [O'Neill et al. 1995], Pacific herring *(Clupea harengus pallasi*) native littleneck clams (*Protothaca staminea*) [Woolrich and Patrick 1995] blue mussels [Kagley et al. 1995], and planktonic copepods *Eurytemora americana* and *Pseudocalanus newmani* [Jones 1996].

Fish sampled from contaminated areas of Puget Sound are known to bioaccumulate persistent pollutants [O'Neill et al. 1996; West and O'Neill 1995; O'Neill et al. *in prep*], some to levels of concern for human consumption [West 1996, O'Neill *in prep*]. The potential effects of these contaminant levels on the health of marine organisms is not well known. However, negative effects from exposure have been demonstrated in one Puget Sound fish species, English sole. Although there has been little or no fishing pressure on English sole from contaminated urban sites for several years, mortality rates of English sole from these areas were comparable to those from uncontaminated areas, where fishing pressure has historically been high [Johnson et al. 1995]. These researchers also estimated a substantial reduction of overall reproductive output of English sole from contaminated sites (Eagle Harbor, Sinclair Inlet, and the Duwamish Estuary) in comparison to an uncontaminated reference site (Port Susan), based on differences in ovarian recrudescence, spawning, fertilization, and larval development. Projected population trajectories using these results suggest the potential for a depression in reproductive potential from contaminated sites (also see Johnson et al. [1988]; Johnson et al. [1991]; Johnson et al. [1993]; Johnson and Landahl [1994]).

Other species may be negatively affected by accumulating contaminants; however, research is lacking to document this. Five major factors play a role in the accumulation of persistent pollutants in marine organisms, and these may be used to help identify the species experiencing the greatest exposure.

(1) Proximity to source. Organisms living in direct contact with contaminants or feeding on contaminated food experience greater exposure.

(2) Duration of exposure, a combination of the lifespan of a species, and its movement patterns. Long-lived species with small home ranges are at greatest risk if their habitat or food supply is contaminated

(3) Trophic level. Organisms higher on the food chain tend to accumulate greater contaminant concentrations through biomagnification.

(4) Fat content. Organisms with higher fat content tend to retain more lipophilic[1] compounds, such as polychlorinated biphenyls (PCBs).

(5) Ability to metabolize or excrete contaminants.

Of the species listed in Table 1, Olympia oysters, UMI, lingcod, demersal rockfish, Pacific herring, marbled murrelet, common murre, tufted puffin, and harbor porpoise possess one or more of these traits which may predispose them to accumulation of contamination. Olympia oysters and UMI live in direct contact with sediments; lingcod are long-lived, highly piscivorous[2], non-migratory, and live in direct contact with sediments; demersal rockfish are carnivorous, extremely long-lived, non-migratory, and live close to sediments; Pacific herring contain high levels of fat; the alcid birds are piscivorous, and marbled murrelets feed almost exclusively close to shore, nearer to contaminated sediments; harbor porpoise are piscivorous and are long-lived.

Contaminants in a few of any of these species have been investigated. Some of the highest levels of contaminants such as mercury and PCBs found in Puget Sound fishes have been measured in quillback rockfish [O'Neill et al. 1995; West 1996; West and O'Neill *in prep*]. Because this species is long-lived, relatively high in the food chain, and non-migratory, it tends to accumulate persistent pollutants when present in their environment. The effects of these contaminants on rockfish are unknown; however, reproductive impairment documented in English sole (described above) occurred at lower contaminant concentrations, so it is likely that impairment exists in demersal rockfish. Relatively high levels of PCBs have been recently observed in Pacific herring

[1]Chemically attracted to lipids, or fats.

[2]Consumer of fish.

as well [Washington Department of Fish and Wildlife PSAMP, unpublished data]. Although this species is short-lived, its tissues contain naturally high levels of lipids, so lipophilic compounds like PCBs are more likely to be retained after ingestion.

In order to better understand the effects of contaminants on these Resources, specific research must be conducted targeting the health effects of contaminants. Areas of specific concern are being identified by a number of working groups including the Puget Sound Ambient Monitoring Program (PSAMP) Fish Component [O'Neill et al. 1995] and Sediment Component [Llansó 1995], and the Environmental Conservation Division (ECD) of the National Marine Fisheries Service. The PSAMP Fish Component, with ECD input, plans to begin monitoring additional indicators of fish health beginning in 1997. An evaluation of contaminant-effects on quillback rockfish by the Puget Sound Ambient Monitoring Program Fish Component is in progress, but results to date have been limited to measuring contaminant levels in fish tissue [O'Neill et al. 1995; West and O'Neill 1995]. The PSAMP Fish Component also conducted a pilot study of contaminants in Pacific herring in 1995, and is planning pilot studies of lingcod for 1998. The PSAMP Marine Birds and Mammals Component has begun sampling surf scoters [Mary Mahaffy, U.S. Fish and Wildlife Service, personal communication] and harbor seals [Nysewander 1995] for contaminants (harbor seal results may be useful as a proxy for harbor porpoise). Contaminants in Olympia oysters have not been assessed in recent years; however, Puget Sound bivalve molluscs (primarily native littleneck clams, *Protothaca staminea*) were monitored for several years by the PSAMP Shellfish Component [Prescott 1992], and then discontinued in 1994 (because of low contaminant levels and budget cutbacks).

Recommendations from Pollution Overview

Evaluate the effects of contaminants on reproductive success in marine organisms from Puget Sound, and **continue present PSAMP work with English sole as a model** for and indicator of fishes.

Reintroduce monitoring of contaminants in at least one species of invertebrate (possibly a longer-lived species such as the geoduck, *Panope generosa*), as a model for and indicator of contaminants in sessile marine invertebrates.

Sea-Surface Pollution

The pollution-organism interactions described above presume that sediments are the primary source, or sink, of contaminants. Pollution of the sea-surface may also present a significant source of contamination to a number of marine organisms. The sea-surface is of great importance to the many seabirds relying on that habitat for food, refuge, and resting, and the neustonic[1] zone is a highly productive habitat for myriad organisms, including fishes and invertebrates, their planktonic eggs and larvae, and phytoplankton. Contamination of the sea-surface occurs episodically, with disasters like oil spills, or chronically, with pollutants from a number of sources including terrestrial runoff and atmospheric deposition (hereafter referred to chronic sea-surface pollution, or CSSP).

Oil Spills

The direct, short-term effects of oil spills and other episodic disasters on seabirds is usually visible, and obvious to even a casual observer. Alcids were identified by Mahaffy et al. [1994] as among those likely to suffer greatest losses resulting form an oil spill in shared waters[2]. Common murres were heavily impacted in California from an oil spill near San Francisco [Speich and Wahl 1989]. Effects of the relatively large *Exxon Valdez* oil spill were substantial on marbled murrelets [Kuletz 1996], common murres [Piatt and Anderson 1996], and other seabirds [Ford et al. 1996; Piatt and Ford 1996].

[1]The neustonic zone occurs from the sea surface to a depth of approximately 10 cm.

[2]This type of disaster is also especially worrisome for harlequin ducks (*Histrionicus histrionicus*). Although not considered a stressed species in Washington in this report, they are especially vulnerable to oil spills because their winter-time aggregations occur in areas where spills might occur (Mahaffy et al. 1994).

Oil Spill Recommendations

Recommendations for preventing, controlling, and mitigating the effects of oil spill in Washington waters are beyond the scope of this report. The WDFW is currently preparing Agency policies on spill response and damage assessments, as well as a plan for spill-response procedures [Thom Hooper, Washington Department of Fish and Wildlife, personal communication]. However, the threat of a major oil spill in Washington looms as a potential cause for mortality of common murres, marbled murrelets, and tufted puffins, as well as other pelagic, surface oriented species (e.g., harbor porpoise) or pelagic life-stages (e.g., eggs and larvae of marine fishes and invertebrates), and shoreline species such as Olympia oyster and UMI. **A rational, protective policy would focus on ways to prevent disasters**.

Chronic Sea-Surface Pollution (CSSP)

The sea-surface is a concentration point for many CSSP contaminants including pesticides, metals, PCBs, and polycyclic aromatic hydrocarbons (PAHs) [Cross et al. 1987; Hardy et al. 1987a; Word et al. 1987; Hardy and Antrim 1988; McFadzen and Cleary 1994; Chernyak et al. 1996]. Concentrations of PCBs, PAHs, and metals exceeding US Environmental Protection Agency water quality standards by orders of magnitude have been measured in Puget Sound at the sea-surface [Hardy et al. 1987a; Hardy and Antrim 1988].

The pelagic larval phase is thought to be of critical importance in the life history of many marine fishes, wherein predation, availability of food, and effects of maternal condition on egg and larval competence contribute to survival (see reviews in Thorisson [1994] and Browman [1995]). The sea surface, or neustonic zone (from 0 to 10 cm in depth), provides a productive nursery habitat for eggs, larvae, or juveniles of a number of important marine fishes, including hexagrammids (greenlings and lingcod), rockfish, sandlance *(Ammodytes hexapterus*), Pacific herring (*Clupea harengus pallasi*) and many flatfishes [Hardy et al. 1987b; Doyle 1992; Doyle et al. 1994]. Larvae of these species appear to rely on food resources produced at, or near, the sea-surface.

Eggs of sand sole (*Psettichthys melanostictus*) incubated *in situ* at the sea-surface of three urban areas in Puget Sound exhibited poorer survival, and a lowered rate of hatching of normal larvae, than those from rural controls [Hardy et al. 1987b]. Other studies have demonstrated sea-surface contaminant-related effects in larvae of herring, cod, turbot, kelp bass, oyster, and clam [Cross et al. 1987; Kocan et al. 1987; vonWesternhagen et al. 1987; Doyle et al. 1994; McFadzen and Cleary 1994]. The population-level effects of such toxicity are unknown.

Juveniles or larvae of some marine species such as lingcod [Phillips and Barraclough 1977], rockfish [Doyle 1992], walleye pollock and hake [Morgan Busby, National Marine Fisheries Service, personal communication] aggregate in surface waters, and may be exposed to contaminated water or feed on potentially contaminated prey there. Planktonic organisms accumulate at the sea surface as a result of meso-scale oceanographic phenomena such as convergence zones, fronts, and surface slicks[1] [Kingsford and Choat 1986]. These forces also aggregate debris and surface contaminants, often visible at the sea surface. Many organisms also migrate vertically in the water column diurnally, occupying surface waters during some part of the 24 hour cycle. These and other species that aggregate with drift habitat or feed at the surface in oceanographic frontal or convergence zones may be exposed to higher levels of contamination.

Pollution of the sea-surface may present a source of stress to larvae and juveniles of demersal rockfish. The ecology of rockfish larvae and juveniles in pelagic habitats of Puget Sound is not well known; however, copper and quillback rockfish are known to associate with drift habitat[2] prior to settling to the seafloor [Lamb and Edgell 1986; Larsen 1993], as are two congeners [Buckley et al. 1995; Shaffer et al. 1995]. This habitat is considered an intermediate habitat as these fish develop from pelagic to demersal stages [Buckley et al. 1995]. The importance of this intermediate habitat in the successful completion of the life cycle of these species is unknown. However, juvenile rockfishes feed on organisms found in the drift habitat [Shaffer et al. 1995], and if these prey organisms are contaminated by CSSP, such an interaction may result in negative effects.

[1] a natural phenomenon, not to be confused with oil slicks

[2] comprised mostly of detached, floating vegetation and debris

Pacific herring may also be exposed to CSSP. Eggs of this species are deposited on the blades of intertidal eelgrass and algae, often very near the sea-surface. After hatching, larval and juvenile Pacific herring are planktonic, commonly aggregating along shorelines and in shallow, protected embayments. Water quality in spawning and nursery habitats has been suggested as an important factor in the survival of these sensitive life-stages [Penttila *in press*]. If oil spills or CSSP occur in these areas, negative effects on herring larvae may result. Smith [1985] suggested that survival of pre-adult stages in these nursery areas may be an important determiner of long-term survival and maintenance of adult populations.

Evidence for CSSP effects on living marine resources in shared waters is compelling, and should be more seriously and closely assessed. Prudent management of marine resources requires adequate knowledge of the effects of such stressors, especially in terms of how they affect sensitive life history stages (e.g., reproductive, or larval phases).

CSSP also possibly presents a threat to seabirds in Puget Sound. Seabirds that rest or feed at the sea surface are in constant contact with CSSP. These surface-water contaminants may adhere strongly to bird feathers, and seabirds may ingest substantial quantities of contaminants during their normal preening behavior [Chris Thompson, Washington Department of Fish and Wildlife, personal communication]. Additionally, birds such as the three alcids species discussed in this report, are moderate to high-level carnivores, consuming primarily surface-dwelling planktivorous fishes and invertebrates. This presents a high probability for bioconcentration of CSSP contaminants via the food chain.

CSSP Recommendations

Investigate CSSP effects on **neustonic (surface-dwelling) organisms**, especially the eggs and larvae of stressed species.

Investigate CSSP effects on **health and reproduction of seabirds**, beginning with one or a few indicator species (e.g., pigeon guillemots or double-crested cormorants) .

Investigate CSSP effects on communities associated with **surface vegetation (e.g., intertidal eelgrass) and drift habitat**

Finally, we currently lack baseline information required to assess damage to the ecosystem and its components caused by both episodic and chronic pollution of the sea-surface.

Index or reference sites should be established throughout shared waters to monitor CSSP and its effects on neustonic (surface-dwelling) and intertidal communities, and to **establish baseline data** to better prepare for assessing damage caused by sea-surface pollution.

Such efforts would need to be coordinated with existing monitoring efforts (e.g., the Puget Sound Ambient Monitoring Program), and proposed efforts to monitor baseline mortality of seabirds (ie. beached-bird surveys -- Chris Thompson, Washington Department of Fish and Wildlife, personal communication) and to estimate baseline contaminant conditions in shallow-water habitats and organisms (Dan Doty, Washington Department of Fish and Wildlife, personal communication).

DISTURBANCE

It appears that for some species, the very presence of humans or anthropogenic noise such as boat motors can cause enough distress that the individuals alter their normal distribution patterns. Harbor porpoise, in particular, seem to be particularly sensitive to underwater noise, so much so that researchers have begun testing underwater noise makers attached to salmon gillnets to help this species avoid the nets. Increased boat traffic in inland marine water is thought to be a major contributor to the decline in harbor porpoise abundance in Puget Sound since the 1950s [Calambokidis and Baird 1994], and [Steve Jeffries, Washington Department of Fish and Wildlife, personal communication]. Presence of humans on some of the San Juan Islands is also thought to be a factor in abandonment of those areas by nesting seabirds such as tufted puffins [Ulrich Wilson, U.S. Fish and Wildlife Service, personal communication].

Disturbance Recommendations

Some well-known nesting habitats for the bird species are already protected from most anthropogenic disturbances. **Other habitats should be identified and protected** as well, especially those in previously used (but now thought to be abandoned) areas in the San Juan Islands.

Consider establishing areas with reduced noise and vessel activity to protect surface-dwelling, noise-sensitive species like harbor porpoise and seabirds.

Consider **limiting surface noise-output** from vessels.

Encourage development of technology to **reduce underwater noise from vessels**.

Enhance education and outreach programs to help people realize the potential effects of their actions in the ecosystem.

CLIMATE-RELATED NATURAL AND ANTHROPOGENIC VARIABILITY

Historical shifts in decadal-scale climate conditions have been described for the Northeast Pacific Ocean and Puget Sound [Ebbesmeyer et al. 1989; Ebbesmeyer et al. 1991]. These long-term, unpredictable climate fluctuations, as well as other climatic trends, such as those related to El Niño Southern Oscillation (ENSO -- see Newton [1995]) may have profound effects on fish abundance or size [Sissenwine 1984; Koslow 1989; Hollowed and Wooster 1992; Beamish and Bouillon 1993; Francis and Hare 1994; Beamish 1995; Zorpe 1995] and in forage resources for fishery-exploited species [Brodeur 1992; Roemmich and McGowan 1995]. Shorter-term variability in environmental conditions (e.g., temperature, freshwater input, salinity, upwelling, and distribution and timing of oceanographic fronts) have also had significant effects on the abundance of marine organisms, from plankton to higher vertebrates [Bertram et al. 1991; McFarlane and Beamish 1992; Beamish and Bouillon 1993; Bertram and Kaiser 1993; Beamish et al. 1994; Leaman 1996].

Natural Variability

Shifts in climate can occur as a result of natural environmental processes, or from anthropogenic effects, such as global warming. Both present challenges to resource managers, in terms of incorporating short- and long-term climate-related variability in productivity into management plans, as well as formulating strategies to reduce or halt global warming. Fishery scientists and common sense dictate that an understanding of the natural variability in populations of exploited species is important for effective resource management, and is a prerequisite for estimating additional variability imposed by anthropogenic stressors. Whether resource managers adjust quotas based on interpretation of long-term environmental indicators, or they establish fixed exploitation rates that can cope with climate change (see Walters and Parma [1996], better understanding of natural forcing functions is needed. Such an understanding is also needed to accurately evaluate the effects of all the anthropogenic stressors discussed above.

Natural Variability Recommendation

To achieve an understanding of natural variability, it seems clear that harvest-independent **monitoring of exploited species, their food resources, and non-harvested indicator species is required**.

Seabirds

Natural, climate-related variability may contribute to some of the decline in marbled murrelet or tufted puffin populations, although there is no clear evidence of this. The sharp decline in Washington breeding populations of common murre in the early 1980s was attributed to effects from a particularly severe El Niño event (Warheit *in review*), which apparently limited the supply of prey organisms to required for successful reproduction in this species.

Trends in abundance or availability of Pacific sandlance in Washington and British Columbia are thought to be a major factor controlling growth rate and success of nestling rhinoceros auklet (*Cerorhinca monocerata*), a confamilial of the three alcids discussed in this report [Wilson and Manuwal 1986; Bertram et al. 1991]. Abundance of Pacific sandlance exploited by these birds also appeared to be positively correlated with ocean productivity, which was, in turn, correlated with temperature, salinity, and upwelling regimes in the North Pacific Ocean during the years of these studies [Bertram et al. 1991; Ware and Thomson 1991; McFarlane and Beamish 1992; Bertram and Kaiser 1993]. In fact, Bertram and Kaiser [1993] recommended monitoring seabird nestling diets to provide a relatively inexpensive index of natural variability in populations of major prey.

Codfishes

Sea temperature may play an important role in the distribution of the three species of gadid cods considered in this report (Pacific cod, Pacific hake, and walleye pollock). Puget Sound is considered the southern limit of Pacific cod, which is a primarily subarctic species. Pacific cod prefer cold (<7°c.) water [Ketchen 1961; Westrheim and Tagart 1984], a condition not always occurring in Puget Sound waters. Palsson [1990] reviewed the biology of this species, comparing its temperature requirements with a Puget Sound climate index based on snowfall and sea temperature. He observed a negative relationship of El Niño events and catches of Pacific cod, and concluded that sea temperature likely contributed to the recent decline in Pacific cod abundance in

Puget Sound (an hypothesis corroborated by Strickland [1984]). Palsson [1990] further suggested that future monitoring of this species' abundance and the climate index would help to resolve the strength of this association.

Walleye pollock and Pacific hake are also considered to be at the southern and northern, respectively, limits of their range in inland Washington waters; however, the effects of water temperature on their latitudinal distribution are less clear. Inada [1986] suggested that sea temperature requirements of Pacific hake eggs and larvae combined with competition with Pacific cod and walleye pollock limit its northern distribution. In the absence of anthropogenic stressors, sea temperature or other oceanic conditions may be primary factors determining the distribution of these species in Pacific waters (Thomson 1996)

Pacific Herring

Little is known about the effects of environmental or climate variation and production of Pacific herring in Puget Sound. However, Canadian researchers have observed a strong link between climate and Pacific herring abundance along the west coast of Vancouver Island. In years with relatively high sea temperature, survival of Pacific herring is poor because of a direct, negative effect on survival and growth, and because of increased predation by an extension of the northern range of southern, warmer-water predators such as Pacific hake and Pacific mackerel [Pacific Biological Station 1996]. These factors (especially migration of Pacific mackerel into Washington's inland marine waters) are thought to have contributed to recent increases in natural mortality of Pacific herring observed in Puget Sound [Norm Lemberg, Washington Department of Fish and Wildlife, personal communication].

Recommendation for Seabirds and Fishes

Coordinate annual codfish surveys (recommended in the Harvest section) and Pacific herring surveys with existing PSAMP water-column monitoring, and search for correlations between cod and herring abundance with water temperature. Measuring sea temperature may provide fishery scientists with an inexpensive tool to help predict the likelihood of the production of successful year classes in these species.

Investigate the effects of sea temperature on the abundance of transient (southerly) predators such as Pacific mackerel and estimate the consumption of Pacific herring by these species. This would contribute to better prediction of herring production using an inexpensively sampled environmental indicator.

Investigate the effects of prey abundance in shared waters on survival and growth of nestling common murre, tufted puffin, and marbled murrelet. Methodology for estimating prey abundance could include monitoring diets of seabird nestlings.

Anthropogenic Climate Changes

Documentation of stress on marine organisms attributable to anthropogenic effects on climate are rare. Two major anthropogenic effects on climate commonly discussed are increases in ultraviolet radiation at the earth's surface (resulting from atmospheric ozone depletion) and global warming, or the global temperature increase associated with the greenhouse effect. The eggs of Pacific herring have been shown to be sensitive to high levels of ultraviolet (UV) radiation [Brian Bingham, Western Washington University, personal communication]. The potential effects of the recent increase in UV radiation at the earth's surface (presumably resulting from loss of atmospheric ozone) on the reproductive cycle of Pacific herring should be studied to determine whether this is a source of stress for the species.

Of concern on a longer time scale is the loss of habitat predicted to occur when sea levels rise as a result of global warming. Addressing this issue was one of the main recommendations put forth by the Georgia Basin counterpart to the present report

[Ramsay and Beamish *in prep*]. The Puget Sound shoreline has many shoreline structures which, in 100 years or so, may become submerged. These structures would present a drastic change to the character of intertidal habitats. The changes in depth regimes will be particularly problematic for shallow-water species with inflexible habitat or substrate requirements.

In addition, climate change at this scale would have profound effects on many basic environmental parameters such as sea temperature, timing and amount of fresh water input (from changes in precipitation patterns), storm events, and wind. These would, in turn, likely alter the distribution and abundance of many marine organisms. Beamish et al. [*in prep*] speculate on the potential effects of global warming on fishes in the Georgia Basin.

Anthropogenic Climate Change Recommendations

Ecosystem, wildlife, and fishery managers should **begin discussing and planning for the potential effects of global warming and the rise in sea-level on the Puget Sound ecosystem.** A starting point for the discussion is available from Beamish et al. [*in prep*].

Evaluate the effects of increased ultraviolet radiation at the sea-surface on reproductive success of Pacific herring.

Chapter IV. Ecosystem Effects

Loss or reduction of a single species or group has effects, not just on the abundance or demographic characteristics of that species, but on the species they consume, are consumed by, or compete with for various resources. Predator-prey interactions among marine organisms, their predators, and their prey, form a complex food web, with many potential direct or indirect effects resulting from anthropogenic changes in the abundance of any species. Such ecosystem-level effects are difficult to define and quantify, and little information is available to quantitatively assess such effects in Puget Sound. However, a simple analysis of a subset of the trophic (food web) interactions in this ecosystem may help to understand some of the possible impacts.

Of the stressed Resources in Table 1, five species or groups of fish (lingcod, Pacific cod, Pacific hake, walleye pollock, and demersal rockfish), three birds, and harbor porpoise are considered significant predators of fishes (piscivores). Major piscivores in the Puget Sound ecosystem not considered stressed or in decline include harbor seals, killer whales, California sea lions, spiny dogfish, bald eagles, and several diving birds. Coho and chinook are also considered piscivores in this syste; however, it is unknown whether total numbers of Pacific salmon in Puget Sound are increasing or decreasing.

The trophic interactions of these species, which represents virtually all of the major piscivores in the Puget Sound ecosystem, are summarized in a simple food web (Figure 9). Each species shown here consumes a wide variety of fish and invertebrate prey; however, for simplicity, only the major fish prey for each species are shown. Hence, although euphausiid shrimp and a myriad other species are important prey for these predators, they have been omitted from this analysis. Within this simplistic food web, the six fish species currently considered to have depressed population abundance, are identified with a (-). Species with average or above average population abundance are denoted with a (+). Coho and chinook salmon populations in Puget Sound are unknown (denoted with a "?"); however, population abundance of resident coho and chinook salmon should be increasing if current salmon management is working (see below).

The base of fish prey supporting the community of piscivores in Puget Sound consists primarily of Pacific herring, Pacific sandlance, smelts, juvenile Pacific hake, and juvenile walleye pollock (all except smelts and Pacific sandlance[1] are considered stressed and

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[1]The status of smelts and sandlance is unknown, at present.

Chapter IV. Ecosystem Effects

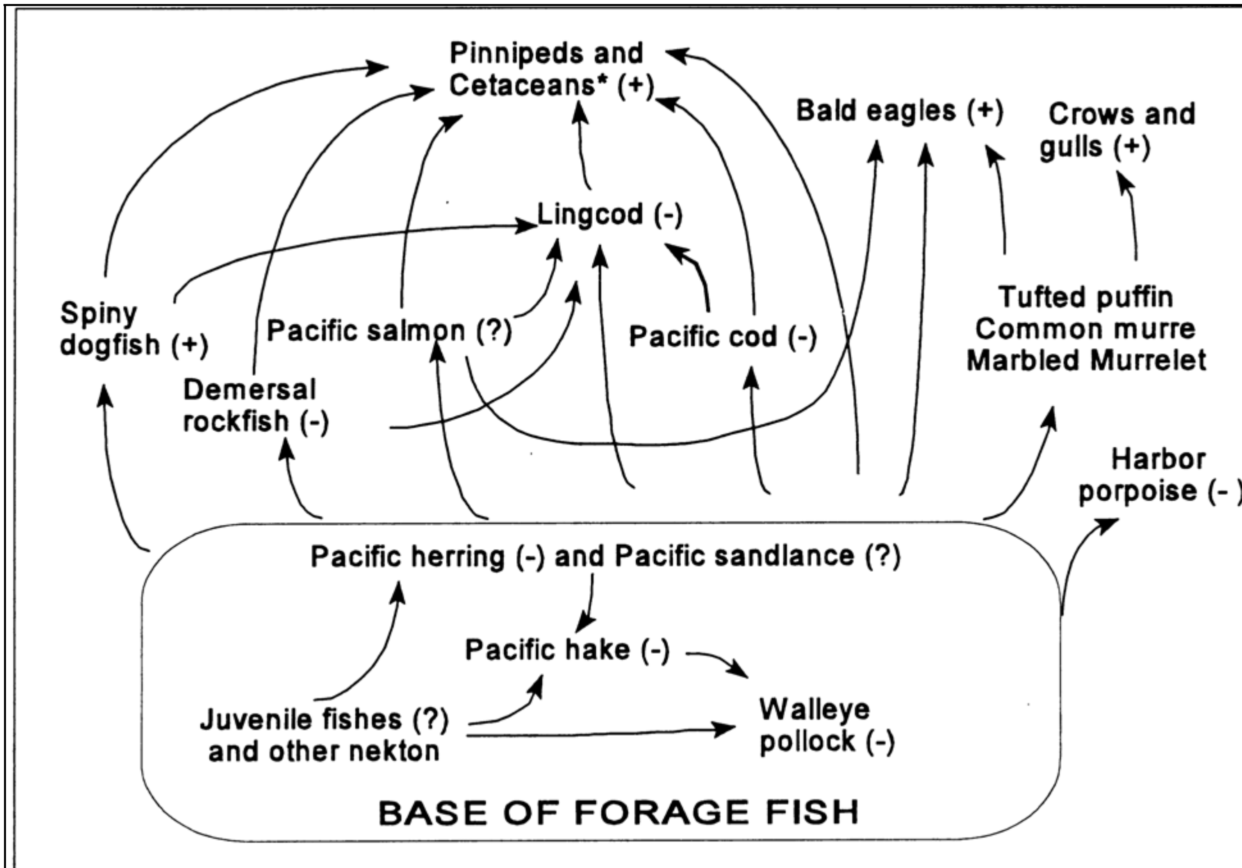

Figure 9. Simplified food web of piscivorous species in Puget Sound . (-) indicates species abundance in decline, (+) indicates average or increasing abundance.
* except harbor porpoise, shown separately

are found in Table 1). In addition, Pacific hake prey on Pacific herring, but are, in turn, preyed upon by walleye pollock. All three are consumed by most piscivores. Pelagic larvae and juveniles of all fish species are likely consumed by these piscivores, as well as by many other planktivores (not shown).

In the prey base, several Pacific herring stocks in Puget Sound are considered depressed, and all Pacific hake and walleye pollock populations in Puget Sound are below their long-term average in abundance (see Resource Descriptions). Abundance of smelts and Pacific sandlance is unknown [Washington Department of Fish and Wildlife and Tribes 1995]. It is impossible to estimate the actual impact loss of any species in this web may have on its predators or prey; however, qualitatively, it is clear that a few fish species support most of the piscivores in Puget Sound, and that many of these species are considered stressed, depressed, or their status is unknown.

In addition to the potential effects from reducing species abundance, artificially increasing species abundance may create unintended ecosystem effects. Fishery-enhancement or aquaculture efforts may inadvertently affect non-target species, and may disturb marine or estuarine ecosystems. For examples, creation of artificial reefs or artificial hardshell clam habitat covers over or replaces existing organisms and habitat [Newman and Cooke 1988; Hueckel et al. 1989]. Hatchery- or other stock enhancements may result in undesirable predator-prey or competitive interactions with non-target species. Aquaculture operations may physically disturb and alter existing communities or habitats, cause chemical disturbances or contamination, or inadvertently introduce exotic pest species [Simenstad and Fresh 1995]. In the Pacific Northwest, aquaculture and other fishery-enhancements have been historically regarded as a right of humans to fully exploit natural resources, with little attention paid to the potential negative effects of these activities at a community or ecosystem scale. As a result, focus has been shifted towards more obvious stressors such as harvest, pollution, and habitat loss [Simenstad and Fresh 1995].

Following are examples of how artificially increasing and decreasing species abundance may affect the ecosystem. Similar analyses could possibly be made for a number of management practices, including existing programs where salmon are released with "normal" timing, or for proposed marine fish hatcheries. However, for simplicity and brevity, the following examples are presented. Habitat changes from aquaculture operations (e.g., culture of Pacific oysters) are discussed in the section on Habitat Loss and Degradation.

Extended Rearing of Pacific Salmon

> Delaying the release of hatchery-reared Pacific salmon (*Oncorhynchus* spp) to increase the number of resident salmon in Puget Sound may be a contributing factor in the decline in abundance of some marine species. Evidence for this is circumstantial and the following discussion is speculative; however, competitive and predator-prey interactions are based on known trophic (food web) connections among Pacific salmon, their competitors, and prey (Figure 9). A number of these competitors and prey are stressed Resources from Table 1. These interactions are described below, beginning with a bit of background[1] summarizing the development of delayed-release management practices.

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[1] I thank Ray Buckley of the Washington Department of Fish and Wildlife for providing valuable background information.

Normally, coho and chinook salmon spend a portion of their early lives in their natal fresh waters and in the estuarine and marine waters of Puget Sound before migrating to the open ocean. Puget Sound historically had populations of coho and chinook salmon which remained in Puget Sound their entire lives (termed "resident" salmon; see Pressey [1953], Allen [1956], and Buckley [1969]). These resident salmon supported a popular, year-round fishery. Naturally occurring resident chinook salmon are thought to be those that had spawned high in the watershed, resulting in different timing of their migration out of fresh waters as juveniles. Naturally occurring resident coho salmon were thought to be those that had delayed their out-migration in lakes and slow moving streams, taking advantage of food resources there. Such natural delays in timing of out-migration of juvenile coho and chinook salmon resulted in those fish entering Puget Sound after the bulk of the "normal" salmon had left the Sound for the ocean. The carrying capacity of Puget Sound was apparently sufficient to sustain these small populations, resulting in them remaining in Puget Sound for their entire lives, until their return to natal watersheds for spawning.

This pattern of naturally occurring resident salmon was interrupted by development impacts (e.g., construction of dams, and urbanization of lowland lakes and streams) to the watersheds that produced the specific conditions resulting in naturally delayed out-migration. The decline of resident salmon populations also apparently coincided with the practice of screening inlets and outlets of lowland lakes (interrupting migrations of anadromous fish), poisoning endemic populations of lake fishes, and releasing hatchery-reared rainbow trout to enhance fishing opportunities.

In the late 1960s and early 1970s, biologists working for the (then) Washington Department of Fisheries attempted to reestablish resident Pacific salmon in Puget Sound by delaying the release of a small number (50,000 to 70,000) of hatchery-reared coho and chinook salmon. This was designed to mimic the delay in naturally occurring outmigrants which were lost to the activities described above. These efforts were highly successful, resulting in a contribution of resident salmon to the fishery of greater than 10% in 1971 and 1973 [Buckley and Haw 1978].

Marine organisms have presumably evolved reproductive and other strategies to cope with relatively predictable seasonal influxes of salmon predation on their pelagic eggs, larvae, and juveniles, as well as competition for food as these predators move through the Puget Sound ecosystem on their way to and from oceanic waters. In addition, they have presumably evolved to cope with the more permanent presence of relatively small populations of resident Pacific salmon as predators and competitors in the Puget Sound ecosystem.

The WDFW and northwest native American tribal hatcheries have continued the practice of delaying the release of portions of their hatchery-reared Pacific salmon to create resident populations; however, the number of fish released has increased by at least ten times in recent years. One to six million delayed-release coho, and up to three million extended-reared chinook salmon have been released, per year, into the Puget Sound from State, tribal, and cooperative hatcheries since 1972 [Appleby and Doty 1995]. Availability of adequate prey has been suggested as a determinant of survival or retention of resident Pacific salmon produced by the extended rearing program [Appleby and Doty 1995] and in outmigrating juvenile salmon [Healey 1980; Simenstad et al. 1980]. Doty [1994] reported an inverse relationship between release numbers of extended-reared coho and chinook salmon and their saltwater survival. These observations support the notion that carrying capacity of Puget Sound for coho and chinook salmon may be based on the availability of food, and that current release numbers exceed carrying capacity of the ecosystem.

Salmon Prey

Diets of chinook and coho salmon in Puget Sound and the Strait of Juan de Fuca have been described by Fresh et al. [1981] and Beacham [1986], respectively. Chinook salmon prey in both areas were diverse, depending on size of salmon, and the habitat and season in which they were sampled. In Puget Sound, chinook salmon diets switched from primarily crustacean (dominated by brachyuran crabs) to primarily fish (dominated by Pacific herring and Pacific sandlance) as the salmon grew in size. In British Columbia, Pacific herring, Pacific sandlance, and euphausiids dominated the diets of all sizes of chinook salmon (although juveniles were not examined). Coho salmon in both areas consumed primarily crustacean prey; however Pacific herring were important in their diets as well. Both species are also known to consume pelagic larvae and juveniles of a number of marine fishes, including rockfish (*Sebastes* spp), gadids[1], and lingcod [Merkel 1957; Prakash 1962; Peterson et al. 1982; Beacham 1986].

[1]the family of codfishes which includes Pacific cod, walleye pollock, and Pacific hake

Predation and Competition

The predation and competitive effects of the recent order-of-magnitude increases in production of delayed-release Pacific salmon on resident prey and competitors are unknown. Population abundance of forage fish in Puget Sound is variable [Washington Department of Fish and Wildlife and Tribes 1995] and in years of low, or limiting abundance, it is likely that resident salmon would either migrate from the Puget Sound, consume other prey, or die. It is in such years that secondary prey species, such as marine fish juveniles and larvae (other than Pacific herring and Pacific sandlance) would likely experience increased predation-mortality.

Most marine fish species, including all those listed in Table1 produce pelagic larvae which remain in pelagic waters for a few to many months. During this phase they are susceptible to pelagic predators, such as Pacific salmon. If extended rearing of Pacific salmon is successful, predation potential on these species is probably increased.

Pacific salmon, especially coho and chinook salmon, are also suspected of competing with walleye pollock and Pacific hake for available food resources [Fresh et al. 1981]. Increasing the population of resident Pacific salmon with extended rearing programs may increase such competition, which may be a factor in the recent depression in population abundance of Pacific hake and walleye pollock in Puget Sound.

Salmon Extended-Rearing Summary

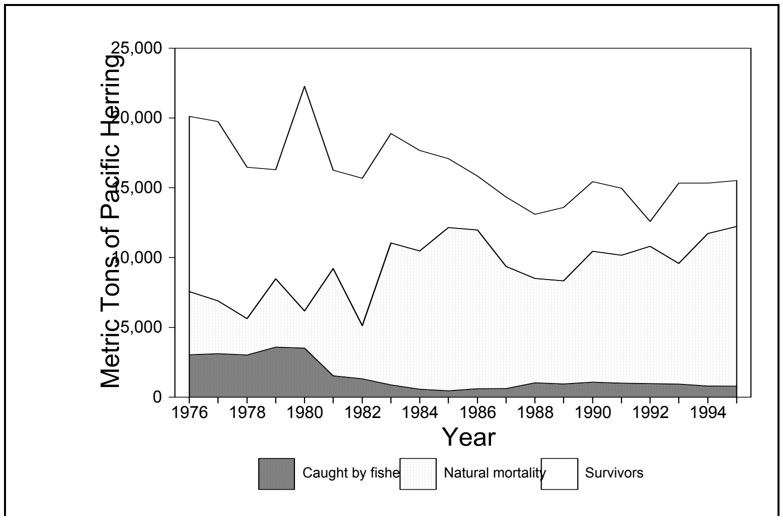
Ecosystem-level effects of fishery enhancement practices are currently not considered by fishery managers for practical reasons, not the least of which is, lack of reliable information needed to predict interactions. However, most Pacific salmon produced in the extended rearing program are determined by legislative mandate (ESHSB 2055 calls for production of 3 million delayed-release chinook salmon in Puget Sound by the year 2000), rather than on any estimate of the ability of the ecosystem to support the numbers produced without compounding stress to marine species of concern. To avoid exceeding carrying capacity, and overtaxing prey resources (e.g., herring, sandlance, and other resident marine species) in years of low prey availability, release numbers of salmon could better be tailored to expected carrying capacity, as measured by abundance of forage fish, based on in-season estimates of herring supply by the WDFW Forage Fish Division. In years when future prey abundance is predicted to be low, more

Pacific salmon could be released with “normal” timing, and in years when future prey abundance is predicted to be high, releases of greater numbers could be delayed.

Predation and Pacific Herring

An analysis of predators that consume Pacific herring may provide another illustration of potential unintended ecosystem effects as a result of managing or manipulating the abundance of their predators. Abundance or predation potential of three managed species that are also major predators of Pacific herring (harbor seals, spiny dogfish, Pacific salmon) have likely increased in Puget Sound since 1980, as a direct result of resource management actions or changes in fisheries. Abundance of a fourth predator (Pacific mackerel - *Scomber japonicus*) appears to have increased as well, probably as a result of sea-temperature variability. These four predators are opportunistic carnivores, consuming a wide variety of fish and invertebrate prey; Pacific herring is considered a primary prey for all. Food habits of Pacific salmon and harbor seals are discussed elsewhere in this report. For food habits of spiny dogfish see Jones and Geen [1977], McFarlane et al. [1984], and Tanasichuk et al. [1991]. Food habits of Pacific mackerel in Washington are unknown; however, because of their generally carnivorous habits and spatial overlap with Pacific herring, they are presumed to consume herring.

Following is a somewhat speculative interpretation of data, presented to compare trends in abundance of herring predators from 1975 to the present, with a decrease in survival of Pacific herring observed during the same period.
The overall population size of Pacific herring has declined in the past 20 years in Puget Sound (Figure 10), and several individual stocks have declined precipitously in recent years (see Resource Descriptions). Natural (non-fishery) mortality has increased since 1980; the loss of primarily older ages classes has been attributed to increases in predation-mortality [WDFW Forage Fish Unit *in press*]. The increase in natural mortality has been offset somewhat by a concomitant reduction in fishery harvest (Figure 10). Annual survival of Pacific herring (the inverse of natural mortality) has declined steadily from 1980 to the present Figure 11a.



Current herring populations are supported by recent large recruitment of two- and three-year old herring, and WDFW forage fish biologists have attributed this loss of older age classes to increases in predation. Indeed, other Stressors like pollution and habitat loss would likely affect younger life-stages (e.g., egg and larval phases -- see Pollution Section). Harvest has not been implicated as a major Stressor on Pacific herring; fishery-mortality on Pacific herring has declined by roughly half from 1980 to the present, and accounts for only about 7%of total mortality for the species [WDFW Forage Fish Unit *in press*].

The harbor seal population in Washington's inland marine waters[1] has increased from an estimated 7,380 in 1983 to 15,634 in 1993 [WDFW and National Marine Mammal Laboratory] (Figure 11b [2]), probably a direct result of prohibiting harvest of this species through the Marine Mammal Protection Act (MMPA --[Barlow et al. 1995])[3].

Populations of resident chinook salmon in Puget Sound are unknown as well; however, hatchery releases designed to increase populations of resident chinook

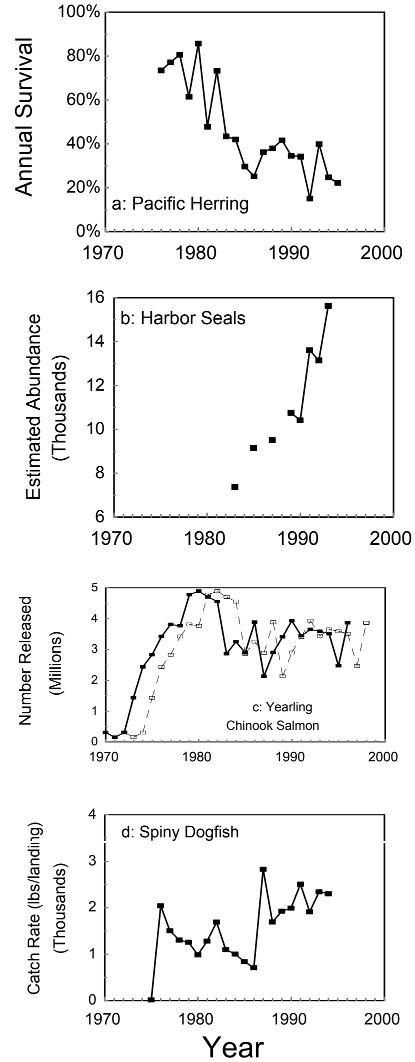
salmon[1] have increased by about 50% from 1980 to 1990 (Figure 11c). Complexities

[1]Eastward of the Dungeness spit.

[2]Figure created from estimates provided by the NMML. Any errors in this process are this author's.

[3]Populations of California sea lions have increased as well. For simplicity, however, I have focused on harbor seals as a major pinniped predator of Pacific herring.

such as their unknown residence time in Puget Sound, and the lag-time that occurs between hatchery-release and consumption of herring, make interpretation of this potential interaction difficult. Incorporating this lag into Figure 11c (as a dotted line) shows that the presumed concurrent increase in predation potential from releases of yearling chinook salmon in the 1980s overlaps with the observed increase in natural mortality of Pacific herring (Figure 11a).



Population abundance estimates for a third herring predator, spiny dogfish, are not available; however the generally increasing trend of catch per unit effort (Figure 11d) may be indicative of population increases. A commercial fishery for this species began in 1975, with increasing effort for about ten years, after which fishing effort dropped off. With low fishing effort from 1986 to the present, populations are thought to have increased, as reflected in increased catch per effort (little change in fishing methods occurred during this period). The status of spiny dogfish populations in Puget Sound was reported as "above average" by Palsson et al. [1996].

Abundance of a fourth predator, Pacific mackerel, is thought to have recently increased in Washington's inland marine waters, as evidenced by increased catches of this species. However, this increase is considered a result of sea-temperature increases (related to El Niño events) extending the northern range of this primarily

[1]Numbers of extended-reared coho salmon have increased as well. For simplicity, however, I have focused on chinook salmon as a major predator of Pacific herring

warmer-water species. Increased abundance of Pacific mackerel has been mentioned as a potential cause of increased natural mortality of Pacific herring [WDFW Forage Fish Unit *in press*].

The relative contribution of harbor seals, Pacific salmon, spiny dogfish, and Pacific mackerel to natural mortality of Pacific herring is unknown. The trends presented above indicate areas where additional information might allow better management of this Stressed Resource. Implementation of the MMPA has resulted in substantial increases in the potential for predation on their primary prey species in Puget Sound. Consumption by harbor seals of Pacific herring is thought to be a major contributor to mortality in this species [Cyreis Schmitt Washington Department of Fish and Wildlife, personal communication]; however, funds are lacking to complete an investigation already in progress, of this potential interaction. Accurate estimation of the consumption of Pacific herring by harbor seals and other predators would allow more realistic estimation of acceptable harvest yields. In addition, a thorough analysis of the relationship of Pacific herring (and other prey) abundance and survival of Pacific salmon may allow more efficient hatchery-production scenarios, as well as avoidance of exceeding the carrying capacity of the ecosystem.

Pinnipeds and Pacific Hake

The recent increase in populations of harbor seals (Figure 11b) and California sea lions[1] in shared waters is thought to be a substantial limiting factor in the recovery of Pacific hake [Schmitt et al. 1995]. These predators are also thought to play a role in the increase in natural mortality observed in Pacific herring in Puget Sound since the early 1980s (see above). Predation on lingcod by these predators may be substantial as well [Smith et al. 1990], with increased impacts on nesting males likely [Wayne Palsson, Washington Department of Fish and Wildlife, personal communication].

Harbor seals and California sea lions are opportunistic carnivores; the diet of

[1] California sea lion populations have been increasing about 5% annually in Puget Sound (Calambokidis et al, 1994). California sea lions were uncommon in Puget Sound prior to the mid 1970s; in recent times they have exceeded 1,000 in number in Puget Sound (Schmitt et al. 1995).

these species the Georgia Basin and Puget Sound have been described as dominated by Pacific hake, Pacific herring, Pacific salmon (harbor seals only), spiny dogfish (California sea lions only), Pacific cod, other codfishes, plainfin midshipman, lingcod, cephalopods, surfperches, flatfishes, sculpins, and rockfishes [Olesiuk et al. 1990; Olesiuk 1993; Schmitt et al. 1995]. Olesiuk et al. [1990] estimated that harbor seals in the Strait of Georgia consumed 3.5% of the estimated total Pacific hake biomass, 3.2% of the estimated total Pacific herring biomass, and that consumption by harbor seals was roughly equivalent to fishery harvests of lingcod.

Harbor seals and California sea lions have been estimated to consume two to three times the weight of marine fishes taken in recreational and commercial fisheries in Puget Sound [Schmitt et al. 1995]. This high percentage results from the combination of recent increases in population abundance of pinnipeds and the reduction of fishery harvests in Puget Sound. Total marine fish landings from the mid 1980s would have been more than double the amount consumed by pinnipeds estimated for 1993. In any case, it appears that pinniped predation on many of the Resources discussed in this report is substantial -- comparable to fishery landings -- and should be considered when predicting allowable catch for fisheries. Other studies have quantified and compared fishery landings with consumption rates of predators, and have recommended accounting for such competition in fishery catch models [Ajiad et al. 1991; Dolgaya and Tretyak 1991; Tretyak et al. 1991]

Species Replacements

In an ecosystem where the populations of a number of species have been substantially altered (reduced with harvest or increased through enhancements), it is important to understand how such changes affect non-targeted species and the rest of the ecosystem. Significant changes in community composition have occurred in ecosystems which have experienced heavy losses in an important species [Somerton *in prep*]. A phenomenon similar to this occurred in the northwest Atlantic cod fishery, where overfishing one group of predators (codfishes) resulted in population increases in their competitors (small sharks, skates, and rays).

> The stock status[1] of spiny dogfish was "above average" in Puget Sound [Palsson et al. 1996], while the status of most of its potential competitors and prey were declining. The status of two stocks of skates was also considered "above average" or "unknown" in Puget Sound [Palsson et al. 1996]. The decline in abundance of major piscivores in Puget Sound (codfishes, lingcod) may release spiny dogfish from some competition for food resources, possibly resulting in an increase in their population. However, population abundance of California sea lions, a significant predator of spiny dogfish, continues to increase, possibly damping such effects. Better understanding of trophic interactions such as these may help fishery managers predict, and prevent, undesirable species replacements, as have occurred in the Northwest Atlantic groundfish fishery.

There is no ongoing comprehensive monitoring of the population abundance of marine fishes in Puget Sound. The WDFW conducts trawl surveys to estimate abundance of bottom-dwelling fishes and some benthic macroinvertebrates; however, the surveys have been conducted sporadically, and with inconsistent equipment. The WDFW currently conducts annual surveys of the abundance of Pacific herring, which is the most abundant species in the base of forage fish supporting most marine piscivores (Figure 9). Periodic surveys of exploited invertebrates (e.g., bivalve shellfish, crustaceans, and urchins) are conducted by the WDFW to estimate harvest levels (see Tagart et al. 1996), and populations of several marine birds and mammals are conducted regularly by the WDFW, and the U.S. Fish and Wildlife Service.

Reiterating a recommendation made in the chapter on Natural Variability, Schmitt et al. [1994] recommended that a "Comprehensive and standardized monitoring system to census a representative sampling of the 200 species in the (Puget Sound and) Georgia Basin annually or biannually, rather than focusing only on the commercially important stocks, should be instituted." Such studies could be coordinated and integrated with shellfish, forage fish, bird, and mammal censuses, to describe a more accurate and complete picture of the overall condition of the Puget Sound ecosystem. Ecosystem managers could use such information to better judge how species-specific management might affect other ecosystem components.

A coordinated census effort such as this would augment existing efforts to monitor the health of Puget Sound's living resources, organized by the Puget Sound Water Quality

[1] See Palsson et al. 1996 for definition of "status" terminology.

Action Team, and implemented by the Puget Sound Ambient Monitoring Program. The PSAMP is designed to coordinate such activities to help monitor the health of the Puget Sound ecosystem.

Bald Eagles and Seabirds

Predation by bald eagles, gulls, and crows (see Figure 9) has been implicated as a factor in the recent declines in abundance of common murres, tufted puffins. These predators take eggs of common murres[1] and fledglings of both species when parents have been frightened from their nests either by the presence of eagles, or by human activities [Julia Parrish, University of Washington Department of Zoology, personal communication; Speich and Wahl [1989]. This predator-prey interaction is a normal occurrence; however, some biologists think that recent increases in populations of bald eagles, gulls, and crows have overwhelmed the coping mechanisms of common murres and tufted puffins, whose populations have already been reduced by other factors [Julia Parrish, University of Washington Department of Zoology; Chris Thompson, Washington Department of Fish and Wildlife, personal communication]. Populations of bald eagles, crows and gulls have increased in recent years, possibly from increases in food made available from road kills, garbage dumps, and fish carcasses from recreational and commercial fisheries. Protection of bald eagles from hunting has also probably allowed their numbers to increase.

In any case, the role humans play in this trend is unclear. Certainly predation on eggs of common murres and nestlings of common murres and tufted puffins occurs when nesting parents are disturbed by humans (disturbances such as low flying aircraft, boats, and foot traffic). Less apparent is the role humans have played in the abundance of the bald eagles, gulls, and crows relative to seabirds. It is possible that normal, unstressed populations of seabirds can cope with such predation by “swamping” predators (in this case, young seabirds all hatch around the same time, overwhelming the ability of predators to consume them in large numbers, thereby reducing the relative impact of predation). However, if humans have contributed to the decline of alcid populations by gillnet mortality, pollution, and disturbance of their normal distribution patterns, normal predation pressure from increasing abundances of predators may inhibit the recovery of

[1]Particularly severe with common murres nesting on Tatoosh Island.

alcids even if anthropogenic stressors are relaxed. An analogous mechanism has been proposed to explain the continued depression in Pacific hake abundance in Puget Sound after harvest pressure was relaxed [Schmitt et al. 1995].

Ecosystem Effects Recommendations

Evaluate the **effects of Pacific salmon extended rearing practices on resident marine organisms** in Puget Sound, and investigate ways to better **tailor releases (in terms of timing, locations, and size of releases) of Pacific salmon to the carrying capacity of the ecosystem**.

Establish a standardized, fishery-independent, annual survey of marine fishes and invertebrates, focusing on strategies to identify temporal and spatial trends in abundance, distribution, and other population- and community-level parameters. The WDFW has conducted trawl-surveys for this purpose; however, the effort has been sporadic and inconsistent, and only censuses species susceptible to that gear. Formalizing a more comprehensive census-monitoring effort, and **coordinating with census efforts of other major marine species groups (such as seabirds and marine mammals)** would provide the information to better understand and predict the ecosystem effects of our management activities.

Conduct basic research on the trophic and competitive interactions among stressed Resources and other ecosystem components.

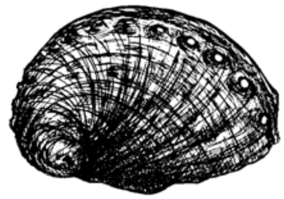
Continue basic research on the **predator-prey interactions of bald eagles, gulls, and crows on nesting seabirds** in Washington, with a focus on possible anthropogenic contributions to recent increases in the interactions.

Coordinate these studies with environmental monitoring efforts described in previous chapters

Chapter V. Resource-Specific Management Recommendations

Resource-specific management recommendations are presented as follows in one- or two-page summaries. Recommendations were extracted and derived from discussions presented in previous chapters.

Pinto Abalone (*Haliotis kamtschatkana*)



SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

The primary anthropogenic Stressor on Pinto abalone in Washington's waters is thought to be overharvest.

SUMMARY OF RECOMMENDATIONS

- continue harvest bans (or establish harvest refugia) until routine monitoring of population abundance is established, and estimates of acceptable harvest made
- consider harvest bans of pinto abalone within the context of protecting a community of species or habitats, using Marine Protected Areas as harvest refugia
- provide outreach and education to make the public aware of the reasons for prohibiting harvest of pinto abalone

Olympia Oyster (*Ostrea lurida*[1])

SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major factors contributing to declines in abundance of Olympia oyster in Puget Sound probably include:

- loss or degradation of habitat, primarily a result of increased sediment loading from erosional runoff

[1]Also known as the Native Pacific Oyster.

- overharvest
- historical pollution events
- effects of introduced pest species such as the oyster drill

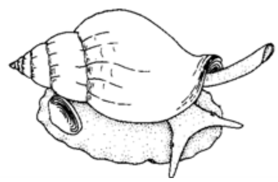
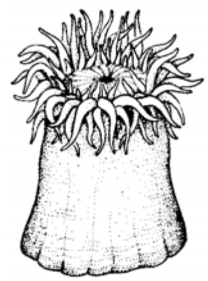
Other factors possibly contributing to stress in this species include:

- ongoing chemical contamination

SUMMARY OF RECOMMENDATIONS

- establish harvest refugia for populations of Olympia oyster on public lands to protect natural reproduction of the species
- monitor and evaluate the effects of changes in habitat and water quality on survival and fitness of Olympia oyster
- continue to enhance protection of marine habitats per recommendations in the section on Habitat Loss and Degradation
- investigate ways to mitigate the negative effects of introduced pest species
- reintroduce to the PSAMP Shellfish Component monitoring of contaminants in at least one species of bivalve mollusc as a model for contamination in other species like Olympia oyster
- encourage conservation of the species and its habitats on private lands using outreach and education

Unclassified Marine Invertebrates[1]


SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major factors contributing to declines in abundance of unclassified marine invertebrates in Puget Sound probably include:

- harvest
- loss or degradation of habitat (including pollution)

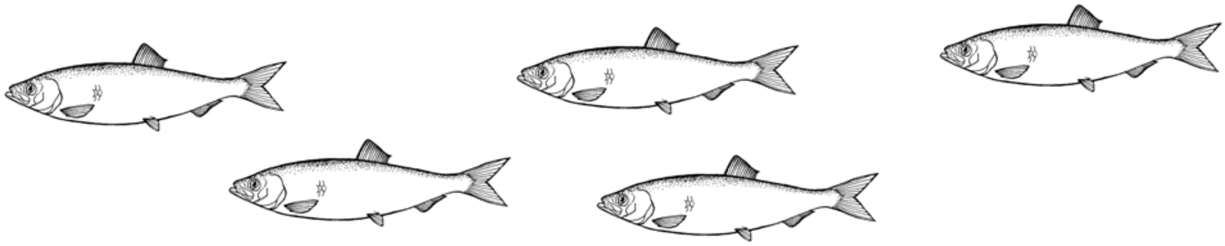
SUMMARY OF RECOMMENDATIONS

- increase WDFW efforts to develop and implement a management plan for these species
- a conservative approach would include restricting harvest along stretches of shoreline (perhaps as Marine Protected Areas in conjunction with other species
- discussed in this document) to protect abundance and diversity of UMI, and hence, their function in the ecosystem
- recommendations in the separate section on Habitat Loss and Degradation
- encourage basic research on the ecology of this group, including life-history
- studies, to identify their susceptibility to Stressors.
- Enhance education and outreach efforts to promote protection and sustainable
- use of UMI

[1]Unclassified means that the species has not been designated by the WDFW as a foodfish or shellfish. Most, if not all, are currently unmanaged by the WDFW

Chapter V. Resource-Specific Management Recommendations

Pacific Herring (*Clupea harengus pallasi*)



SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major Stressors affecting Pacific herring populations in Puget Sound probably include:

- climatic trends creating environmental conditions (high temperature) unfavorable to propagation of Pacific herring and favorable to their predators
- increased predation by pinnipeds, spiny dogfish, and Pacific salmon

Other factors possibly contributing to stress in this species include:

- loss of nearshore, vegetated spawning habitat
- contamination of nearshore nursery areas
- contaminant accumulation affecting reproduction and development

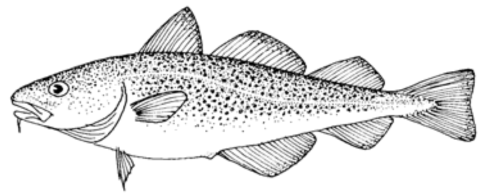
SUMMARY OF RECOMMENDATIONS

- continue monitoring abundance and mortality of Pacific herring
- coordinate with PSAMP to correlate climatic and environmental variables with Pacific herring abundance
- continue and expand research on accumulation, effects, and sources of contamination in Pacific herring
- continue and enhance protection of vegetated habitats per recommendations in the separate section on Habitat Loss and Degradation
- investigate relative contribution of predators to natural mortality of Pacific herring, focusing on predator species whose populations have changed

- substantially in recent years (e.g., harbor seals, California sea lions, Pacific salmon, spiny dogfish, codfishes, and lingcod). Such estimates could be used to help predict abundance trends in Pacific herring.

Chapter V. Resource-Specific Management Recommendations

Pacific Cod (*Gadus macrocephalus*)



SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major factors contributing to declines in Pacific cod abundance in Puget Sound probably include:

- commercial and recreational harvest
- a change in oceanographic conditions to warmer sea temperatures which has reduced the range of this primarily subarctic species,

Other factors possibly contributing to stress in this species include:

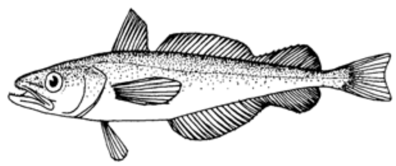
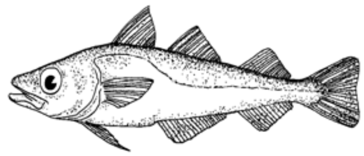
- an increase in the abundance of California sea lions (*Zalophus californianus*), harbor seals (*Phoca vitulina*), and spiny dogfish has probably increased predation on Pacific cod, possibly impeding its recovery.
- reduction in the abundance of two species of its primary prey, Pacific herring (*Clupea harengus pallasi*), and walleye pollock (*Theragra chalcogramma*)
- loss or degradation of nearshore nursery habitats, possibly decreasing survival of juveniles
- increased predation on larval and juvenile Pacific cod by delayed-release Pacific salmon
- increased competition for prey with delayed-release Pacific salmon

SUMMARY OF RECOMMENDATIONS

- continue harvest restrictions on Pacific cod in all of Washington's inland waters to protect remaining populations of Pacific cod

- monitor abundance of Pacific cod using a fishery-independent survey, coordinating sampling with PSAMP monitoring of environmental parameters such as temperature and salinity, and with British Columbian researchers conducting similar research in Canadian waters
- encourage research to investigate natural (predation) mortality of Pacific cod, as well as its trophic (food web) and competitive interactions with other species such as delayed-release pacific salmon
- continue and enhance protection of nursery (marine vegetated) habitats per recommendations in the separate section on Habitat Loss and Degradation

Pacific Hake (*Merluccius productus*) and
Walleye Pollock (*Theragra chalcogramma*)

SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major factors contributing to declines in Pacific hake and walleye pollock abundance in Puget Sound probably include:

- overharvest
- natural variability associated with environmental factors such as temperature and productivity
- an increase in the abundance of California sea lions (*Zalophus californianus*), harbor seals (*Phoca vitulina*), and spiny dogfish has probably increased predation on Pacific hake and walleye pollock, impeding their recovery

Other factors possibly contributing to stress in this species include:

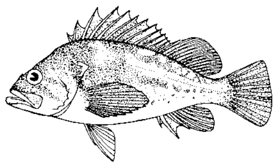
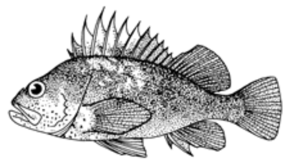
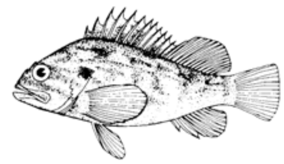
- competition with delayed-release resident Pacific salmon for food resources
- loss or degradation of nearshore nursery habitats, possibly decreasing survival of juveniles

SUMMARY OF RECOMMENDATIONS

- continue harvest bans on Pacific hake and walleye pollock
- continue hydroacoustic monitoring of Pacific hake populations, increasing sample periodicity to at least three times yearly
- monitor abundance of walleye pollock in Puget Sound using fishery census studies such as RECFIN and fishery-independent surveys
- coordinate abundance surveys with PSAMP monitoring of environmental parameters such as temperature and salinity to better understand the effects of environmental conditions on the abundance of these species
- coordinate abundance surveys and environmental studies with British Columbian researchers

- continue and enhance protection of nursery (marine vegetated) habitats per recommendations in the separate section on Habitat Loss and Degradation

Demersal Rockfish (*Sebastes caurinus, S. maliger*, and *S. auriculatus*)

SUMMARY OF ANTHROPOGENIC STRESSORS AND NATURAL LIMITING FACTORS

The major factor contributing to declines in the abundance of demersal rockfish in Puget Sound is probably:

- overharvest

Other factors possibly contributing to stress in this species include:

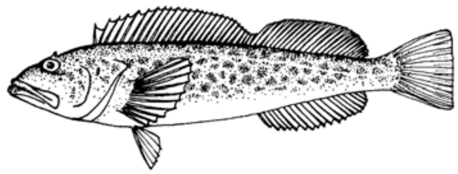
- loss or degradation of nearshore nursery habitats, possibly decreasing survival of juveniles
- the increase in abundance of California sea lions (*Zalophus californianus*) and harbor seals (*Phoca vitulina*) in Puget Sound may have caused increased predation on demersal rockfish, impeding their recovery.
- increased predation on larval and juvenile demersal rockfish by delayed-release Pacific salmon
- disease related to accumulation of contaminants in adult rockfish
- exposure of larvae and juveniles to sea-surface contaminants

SUMMARY OF RECOMMENDATIONS

- continue and possibly increase catch restrictions on these species until adequate routine estimation of their abundance identifies populations large enough to support fisheries
- establish Marine Protected Areas targeting protection of habitats used by adult and juvenile demersal rockfish
- continue assessing accumulation, source, and effects of contaminants in demersal rockfish

- encourage research to investigate the effects of marine mammal predation on demersal rockfish, as well as their trophic (food web) and competitive interactions with other species
- continue the development of fishery-independent monitoring of demersal rockfish using video-acoustic technique, with emphasis on extending the depth range of the technique, and estimating size of fish underwater
- expand RECFIN program or initiate fishery-surveys to collect age and location-specific information from demersal rockfish taken in the recreational fishery
- continue and enhance protection of nursery (marine vegetated) habitats per recommendations in the separate section on Habitat Loss and Degradation

Lingcod (*Ophiodon elongatus*)



SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

The major factor contributing to declines in lingcod abundance in Puget Sound is probably:

- overharvest

Other factors possibly contributing to stress in this species include:

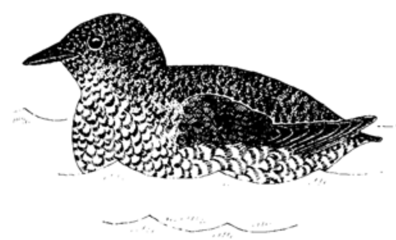
- loss or degradation of nearshore nursery habitats, possibly decreasing survival of juveniles
- an increase in the abundance of California sea lions (*Zalophus californianus*) and harbor seals (*Phoca vitulina*) has probably increased predation on lingcod, impeding its recovery.
- increased predation on larval and juvenile lingcod by resident delayed-release Pacific salmon
- disease related to accumulation of contaminants in adults
- exposure to contaminants as larvae

SUMMARY OF RECOMMENDATIONS

- continue and possibly increase catch restrictions of lingcod until adequate routine estimation of their abundance demonstrates populations large enough to support fisheries
- establish Marine Protected Areas targeting protection of habitats used by lingcod adults and juveniles
- assess accumulation, source, and effects of contaminants in lingcod
-
-

- encourage research to investigate the effects of marine mammal predation on lingcod, as well as its trophic (food web) and competitive interactions with other species
- continue the development of fishery-independent monitoring of lingcod using video-acoustic technique, with emphasis on extending the depth range of the technique, and estimating size of fish underwater
- continue and enhance protection of marine habitats per recommendations in the separate section on Habitat Loss and Degradation

Marbled Murrelet (*Brachyramphus marmoratus*)



SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

In addition to the major terrestrial factors contributing to declines in the abundance of marbled murrelet in Washington's waters, factors in the marine environment probably include:

- mortality from entanglement in salmon drift gillnets
- negative effects from exposure to contamination, either from the food chain or directly from contaminated surface water
- natural and anthropogenic variability in availability of prey

SUMMARY OF RECOMMENDATIONS

- continue monitoring mortality of seabirds in net-fisheries, and continue supporting research to modify gear and fishing practices to reduce bycatch of seabirds
- integrate research on marine and terrestrial stressors, especially concerning the effects of prey availability on nestling success
- continue monitoring abundance of marbled murrelets, including nesting colony and at-sea surveys
- assess the degree to which natural productivity and availability of prey determine populations abundance of marbled murrelets
- continue PSAMP pilot studies addressing contaminants in an alcid species that could be used as an indicator for other alcids like tufted puffins, marbled murrelets, and common murres.
- enhance education and outreach programs to help reduce disturbance of sensitive species

Common Murre (*Uria aalge*)

SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Factors contributing to declines in abundance of common murre in Puget Sound probably include:

- mortality from entanglement in salmon drift gillnets
- pollution from their prey base or from direct contact with contaminated waters
- increased predation from bald eagles, crows, and gulls
- disturbance by humans
- natural variability in population abundance

SUMMARY OF RECOMMENDATIONS[1]

- continue monitoring mortality of seabirds to net-fisheries, and continue supporting research to modify gear and fishing practices to reduce bycatch of seabirds
- continue monitoring abundance of common murres, including nesting colony and at-sea surveys
- assess the degree to which natural productivity and availability of prey determine populations abundance of common murres

(cont'd)

[1] These recommendations are presented in greater detail in Mahaffy et al. [1994].

- continue PSAMP pilot studies addressing contaminants in an alcid species that could be used as an indicator for other alcids like tufted puffins, marbled murrelets, and common murres. If present, determine source of contamination (e.g., direct exposure from contaminated waters or indirect exposure via the food web)
- determine whether there are anthropogenic components to increases in populations of bald eagles, crows, and gulls, which have reduced reproductive success of common murres nesting on Tatoosh Island
- enhance education and outreach programs to help reduce disturbance of sensitive species

Tufted Puffin (*Fratercula cirrhata*)

SUMMARY OF ANTHROPOGENIC STRESSORS
AND NATURAL LIMITING FACTORS

Major factors contributing to declines in abundance of tufted puffins in Washington waters are unclear, but probably include:

- increased predation from bald eagles, crows, and gulls
- oil spills
- disturbance by humans
- pollution from their prey base or from direct contact with contaminated waters
- natural population trends

SUMMARY OF RECOMMENDATIONS[1]

- continue monitoring mortality of seabirds to net-fisheries, and continue supporting research to modify gear and fishing practices to reduce bycatch of seabirds
- continue monitoring seabird abundance, including nesting colony and at-sea surveys
- assess the degree to which natural productivity and availability of prey determine populations abundance of tufted puffins
- continue protection of nesting tufted puffins from human disturbance
- continue PSAMP pilot studies addressing contaminants in an alcid species that could be used as an indicator for other alcids like tufted puffins, marbled murrelets, and common murres.
- determine whether there is an anthropogenic component to the recent increase in predation by bald eagles and gulls on nesting puffins
- enhance education and outreach programs to help reduce disturbance of sensitive species

[1]Most of these recommendations are presented in greater detail in Mahaffy et al. 1994]

Harbor Porpoise (*Phocoena phocoena*)

SUMMARY OF ANTHROPOGENIC STRESSORS AND NATURAL LIMITING FACTORS

Major factors contributing to declines in harbor porpoise abundance in Puget Sound probably include:

- avoidance of humans and anthropogenic noise
- mortality from entanglement in salmon drift gillnets
- pollution effects

SUMMARY OF RECOMMENDATIONS

- continue research on the efficacy of underwater acoustic alarms designed to warn harbor porpoise of the presence of gillnets
- continue monitoring population abundance of harbor porpoise
- conduct quantitative, statistically rigorous evaluation of the effects of gillnet mortality on harbor porpoise populations
- continue monitoring contamination and its effects on harbor porpoise
- consider establishing areas with reduced noise and vessel activity to protect surface-dwelling, noise-sensitive species like harbor porpoise
- consider limiting surface noise-output from vessels
- encourage development of technology to reduce underwater noise from vessels
- enhance education and outreach programs to help reduce disturbance of sensitive species

Chapter VI. Summary and Conclusions

This report reviews the status of thirteen species or species groups considered "stressed" in Washington's inland marine waters. The stressed designation mostly means "in decline"; however, other measures of stress (e.g., decreased average size of a species, or truncation of age class distributions) are used when appropriate. Several stressed species are not considered in the report, most notably, Pacific salmon (*Oncorhynchus* spp), Steller sea lion (*Eumetopias jubatus*), harlequin ducks (*Histrionicus histrionicus*), and scoters (*Melanitta* spp)

The life cycle, habitat use, and reasons for concern are first discussed for each species. Reasons for concern include: declines in catch per unit effort of harvested species; declines in estimated abundance; increases in natural mortality rates; decline in average size of harvested species; bycatch rates of non-targeted species in fishery harvests; drastic increases in unregulated harvest; reductions in breeding populations (birds); significant alteration in geographic distribution; and concern by experts that a species was declining in numbers even though evidence was lacking to document the decline. Marine fishes and invertebrates have complex life cycles, of which each phase is evaluated individually for all identified stressors. In most cases, the species addressed in this report are not considered stressed throughout their range, but their populations in Washington's inland marine waters are stressed.

The potential and realized impacts of four major anthropogenic stressors -- harvest, habitat loss, pollution, and disturbance -- as well as the effects of climate and other natural limiting factors, are evaluated for all species throughout their life history phases. A summary of recommendations organized by Stressor is presented in Table 2.

Table 2. Synopsis of recommendations for all species, summarized from Chapters III and IV. Supporting rationale for these recommendations are taken from those chapters. Individual Resource recommendations are found in Resource-Specific Management Recommendations.

RESOURCE	RECOMMENDATIONS: HARVEST
All harvested species (demersal rockfish, lingcod, Pacific hake, walleye pollock, Pacific cod, Pacific herring, pinto abalone, and UMI)	Continue existing catch, season, and size restrictions Conduct fishery independent and other surveys to regularly estimate abundance of Resources Establish harvest refugia (Marine Protected Areas) Enforce existing prohibitions on commercial harvest of pinto abalone Enhance education and outreach efforts to promote protection and sustainable use of UMI
Lingcod, demersal rockfish, and codfishes	Conduct basic research to understand pertinent UMI life history characteristics before allowing harvest Conduct basic research to estimate the effects of mortality on populations of lingcod, demersal rockfishes, and codfishes
Birds and mammals killed as bycatch	Continue research to design gillnets to reduce bycatch without reducing catch of salmon Conduct in-season bird censuses to direct fishers away from high concentrations of seabirds Evaluate harbor porpoise-salmon fishery interactions better Continue to test the efficacy of gillnets fitted with underwater acoustic alarms to prevent porpoise entanglements

(cont'd).

Table 2 (cont'd)

RESOURCE	RECOMMENDATIONS: HABITAT LOSS AND DEGRADATION
Lingcod, Pacific cod, walleye pollock, demersal rockfish, UMI	Establish a clearly documented and formalized seagrass and seaweed protection and mitigation policy, uniformly applied and accepted by all natural resource agencies, with a centralized tracking system to evaluate habitat changes on a Sound-wide basis.
All stressed species	Expand PSAMP Habitat Component program to include monitoring and inventory of subtidal habitats. Possibly coordinate with WDFW Shellfish Program to map and monitor Olympia oyster habitat.
	Provide Agency funds for, or encourage Universities to support applied research addressing specific needs for better managing and protecting the habitats that support species in this report.
	Support and enhance existing education and outreach programs, especially those designed to enhance conservation and wise use of Resources.
	Evaluate the potential of Marine Protected Areas specifically designed to protect existing populations of stressed species by providing functional habitat required for the natural completion of their life cycle.
Olympia oyster	Continue and enhance controls on the introduction of exotic species, and continue monitoring effects of the Japanese oyster drill on Olympia oyster.
All stressed species	Investigate the degree to which aquaculture of Pacific oysters impacts endemic habitat in Puget Sound.

(cont'd.)

Table 2 (cont'd)

RESOURCE	**RECOMMENDATIONS: POLLUTION**
All stressed species	Evaluate the effects of contaminants on reproductive success in marine organisms from Puget Sound, and continue work with English sole as a model for, and indicator of, fishes.
Olympia Oyster, UMI	Reintroduce monitoring of contaminants in at least one invertebrate (possibly a longer-lived species such as the geoduck, *Panope generosa*), as a model for and indicator of contaminants in marine invertebrates.
Seabirds	Investigate CSSP[1] effects on health and reproduction of seabirds, beginning with one or a few indicator species.
Pacific herring, rockfish, possibly some UMI	Investigate CSSP effects on neustonic organisms, especially the eggs and larvae of stressed species.
Rockfish, Pacific herring, some UMI	Investigate CSSP effects on communities associated with surface vegetation (e.g., intertidal eelgrass) and drift habitat
All stressed species	Establish index or reference sites throughout shared waters to monitor CSSP and its effects on organisms, and to establish a baseline of contaminant conditions.

[1] Chronic sea-surface pollution

(cont'd.)

Table 2 (cont'd)

RESOURCE	**RECOMMENDATIONS: CLIMATE-RELATED NATURAL AND ANTHROPOGENIC VARIABILITY**
All stressed species	Develop a comprehensive, standardized, and consistent monitoring effort to monitor abundance of organisms in shared waters.
Codfishes and Pacific herring	Coordinate annual codfish surveys (recommended in the Harvest section) and Pacific herring surveys with existing PSAMP water-column monitoring
Codfishes and Pacific herring	Investigate the effects of sea temperature on the abundance of transient (southerly) predators such as Pacific mackerel.
All species	Ecosystem, wildlife, and fishery managers should begin discussing and planning for the potential effects of global warming and the rise in sea-level on Washington's intertidal organisms.
Pacific herring	Evaluate the effects of increased ultraviolet radiation at the sea-surface on reproductive success of Pacific herring.

RESOURCE	**RECOMMENDATIONS: DISTURBANCE**
Seabirds	More nesting habitats for the seabirds should be identified and protected.
Seabirds and harbor porpoise	Consider establishing areas with reduced noise and vessel activity to protect surface-dwelling, noise-sensitive species like harbor porpoise and seabirds.

	Consider limiting surface noise output from vessels.
Harbor porpoise	Encourage development of technology to reduce underwater noise from vessels.
Seabirds and harbor porpoise	Enhance education and outreach programs to help people realize the potential effects of their actions in the ecosystem.
(cont'd.)	

Table 2 (cont'd)

RESOURCE	RECOMMENDATIONS: ECOSYSTEM EFFECTS
Marine fishes and invertebrates	Evaluate the effects of Pacific salmon extended rearing practices on resident marine organisms in Puget Sound, and investigate ways to better tailor releases of Pacific salmon to the carrying capacity of the ecosystem.
All stressed species	Establish a standardized, fishery-independent, annual survey of marine fishes and invertebrates, and coordinate such an effort with census efforts of other major marine species groups (e.g., birds and mammals).
	Conduct basic research on the trophic and competitive interactions among stressed Resources and other ecosystem components.
Seabirds	Continue basic research on the predator-prey interactions of bald eagles, gulls, and crows on nesting seabirds in Washington, with a focus on possible anthropogenic contributions to recent increases in the interactions.
All stressed species	Coordinate these studies with environmental monitoring studies described in previous chapters

All harvested species require continued and, perhaps, more stringent, harvest limits; however, the status of some species such as Pacific cod and Pacific hake was thought to be equally or more affected by natural limiting factors, including temperature and natural predation from rebounding harbor seal and sea lion populations. Unclassified Marine Invertebrates (UMI) present a special challenge because of the diversity of species involved and paucity of information concerning their ecology and the stressors affecting them. Harvest is thought to be the stressor of most immediate concern for this group; however, because of their distribution in intertidal and shallow subtidal habitats, pollution and habitat loss may contribute to stress in UMI. WDFW plans being developed to protect this group may be adequate, if the Agency adopts and fully implements the plans.

Establishing a well designed and extensive system of harvest refugia or Marine Protected Areas may protect reproductive potential of some species, especially those with well defined habitats and small home ranges such as pinto abalone, Olympia oyster, demersal rockfish, and lingcod. Other MPA options (e.g., large geographic - scale harvest restrictions) may be used for wider ranging species. Current Transboundary Work Group efforts to pursue this management tool should continue.

Bycatch of seabirds and harbor porpoise continues to be a source of stress for these species. Some attention is being paid to the problem already, including development of nets that reduce entanglement of birds and marine mammals. These efforts, as well as developing ways to avoid encounters (e.g., only daylight fishing) should continue. The extent of bycatch on non-targeted fishes and invertebrates should be investigated to evaluate the effects of this stressor on populations of species killed as bycatch.

Habitat loss and pollution are commonly thought to cause stress in many marine species; however, causes and effects for these Stressors have not been demonstrated for the Resources discussed in this report. More basic research is needed to identify health effects of pollution on marine organisms. Ongoing PSAMP and other investigations on contaminant-related health impact on marine organisms should be encouraged.

The link between habitat and productivity is better established, yet efforts to protect habitats in shared waters have not always been successful. This paper outlines some specific examples where habitat-related bottlenecks were thought to exist in the life cycle of Stressed Resources. Submerged marine vegetation serves as nursery habitat for many marine species, and its protection requires better coordination among natural resource agencies, along with a more clearly defined and universally accepted policy for protection. Other habitats may be equally, or more important to Stressed Resources; basic research is lacking to demonstrate these linkages and their importance. Protecting all habitats is important for maintaining healthy function of the shared-waters ecosystem.

Disturbance by anthropogenic noise or presence of humans is thought to affect primarily seabirds and harbor porpoise. Several recommendations are made to help minimize these impacts. Strong outreach and education programs may help to reduce disturbance from people unaware of the effects of their activities.

Unintended ecosystem effects from harvesting or enhancing marine species are discussed at some length. Because of the complexity of predator-prey, competitive, and displacement interactions among species in the ecosystem, it is difficult for natural resource agencies to predict effects of such interactions. However, examples are presented, outlining the potential negative ecosystem effects from harvest and enhancement activities. A better understanding of basic trophic (food web) interactions and well-designed, consistent monitoring of organism abundance and distribution would help resource scientists better predict negative effects from anthropogenic activities such as harvest and resource enhancement.

It is clear that much basic scientific information is lacking to adequately protect Stressed Resources, while allowing some reasonable harvest. Because money to manage resources is severely limited, prioritization of our management activities is required. Recent highly publicized comments made by respected scientists indicate that protecting somewhere between 20 to 50% of marine habitat area is required to preserve ecosystem function. Although not a sure fix, establishing protected areas is a conservative tool that can preserve the natural productivity of large tracts. Creating a well designed system of Marine Protected Areas should be considered a high priority in Washington’s inland marine waters.

Of high priority as well, is gathering the information needed to predict, or at least document, significant anthropogenic problems in the ecosystem such as those outlined in this report. Basic monitoring of population and community parameters such as species abundance and diversity, tightly coordinated among researches and managers, is essential to protecting marine life.

Populations of all species vary substantially as a normal manifestation of the cyclic nature of ecosystem productivity. The species in this report were included in a large part because they are valuable to humans in some way. However, it is clear that all species contribute to the normal function of an ecosystem, regardless of their value to humans. Maintaining ecosystem health relies on our ability to protect the viability of all species to some degree, as well as their habitats. Successful protection and restoration of a healthy ecosystem that can provide sustainable harvests has two important prerequisites: (1) a clear mandate to managers that the ecological connectedness of all species be considered in management schemes, and (2) provision of the resources with which to accomplish this.

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