Final Programmatic Environmental Impact Statement

Fish Culture in Floating Net-Pens

Washington Department of Fisheries

January 1990

FINAL PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT
FISH CULTURE IN FLOATING NET PENS

Prepared for:

WASHINGTON STATE DEPARTMENT OF FISHERIES
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January 1990

JOSEPH R. BLUM
Director

STATE OF WASHINGTON
DEPARTMENT OF FISHERIES
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January 31, 1990

Dear Reader:

The attached document, together with the separately bound "Response to Comment," and "Technical Appendices," comprise the Final Programmatic Environmental Impact Statement (FEIS) for "Fish Culture in Floating Net Pens in Puget Sound." This FEIS was prepared at the direction of the Washington State Legislature by the Department of Fisheries (WDF). Throughout preparation, WDF consulted extensively with the Departments of Agriculture, Ecology, and Natural Resources, and with numerous county officials, scientific researchers, and private individuals.

The FEIS was prepared to assist state, county, and local decisionmakers in evaluating proposals for fish farm sites by compiling existing knowledge regarding potential significant environmental impacts of siting fish farms in Puget Sound, and also by identifying areas where information may be lacking.

An array of issues concerning the natural and built environments has been considered, with the principal ones being impacts on sedimentation, water quality, and aesthetics. The FEIS is constructed on two identified alternatives: the "no-action" alternative which evaluates siting of fish farms based on existing regulations and guidelines; and the "preferred" alternative which evaluates siting of fish farms based on expanded regulations, guidelines, and recommended WAC adoptions.

WDF wishes to thank those to took the time to review the draft EIS and to provide the comments incorporated into the final document.

Sincerely,

Joseph R. Blum
Director

FACT SHEET

A. Nature and Location of Proposal: This non-project, or programmatic Final EIS (FEIS) evaluates the environmental impacts of the commercial culture of fish in floating fish farms under two regulatory alternatives. The objective of this FEIS is to provide information to regulators, the public, and the Legislature for assessing the adequacy of existing regulations that affect the fish farming industry in Washington, as well as presenting a Preferred Alternative that identifies actions that State and local governments can undertake to avoid significant adverse environmental impacts.

The location of the proposal encompasses all Washington State marine waters from the west end of the Strait of Juan de Fuca, north to the Canadian border and south to Olympia. This area includes Hood Canal and all marine bays, harbors, inlets, and passages in Puget Sound.

B. Proponent and Date of Implementation: At the direction of the Washington State Legislature, the Department of Fisheries is preparing this EIS in consultation with the Departments of Ecology, Natural Resources, and Agriculture. The nominal lead agency is the Washington Department of Fisheries.

C. Lead Agency, Responsible Official, and Contact Person:

Responsible Official:

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D. Licenses Required: No licenses are required for this proposal. Numerous permits and approvals are required for specific fish farm projects (see Appendix F).

E. Authors and Principal Contributors:

Name	Areas of Contribution
Parametrix, Inc.	Principal author Bottom sediments and benthos Fish farm modeling Water quality Fish and shellfish Importation of new fish species

	Genetic issues Marine mammals and birds Odors Noise Upland and shoreline use Visual quality Navigation Commercial fishing Recreation Local services
Battelle Pacific NW Labs	Disease Human health Chemicals
Rensel Associates	Phytoplankton

F. Date of Issue of Final EIS: January 31, 1990.

G. Nature and Date of Final Action: No specific action is proposed by the Department of Fisheries at this time.

H. Type and Timing of Subsequent Environmental Review: Individual fish farm projects will be reviewed case-by-case under the State Environmental Policy Act (SEPA) as they are proposed. Any subsequent regulations or policies developed by State or local officials pursuant to this FEIS will be subject to review under SEPA.

I. Location of Background Data: Copies of the background data used in the preparation of this EIS are available for review at the Department of Fisheries (see location in Item C above).

J. Cost to the Public for Copy of Final EIS: Copies will be provided at no cost to libraries, State and local agencies, legislators and associations with a known interest, and persons/entities providing comments on the Draft EIS. Copies will be available to all others at a cost based on the actual cost of reproduction and mailing.

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C Phytoplankton and Nutrient Studies Near Salmon Fish Farms at Squaxin Island, Washington

D Infectious Diseases of Salmon in the Pacific Northwest

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SUMMARY

OBJECTIVE OF PROPOSAL:

The objective of this Final EIS (FEIS) is to evaluate the environmental impacts of the commercial culture of fish in floating fish farms under two alternatives:

- **No-Action - Existing Regulations and Guidelines.** This alternative evaluates the impacts of floating fish farms under the regulations and guidelines that presently affect the fish farming industry. Included in this alternative are relevant State and federal regulations, local shoreline master programs, and guidelines such as the *Recommended Interim Guidelines for the Management of Salmon Net-Pen Culture in Puget Sound*, and the *Aquaculture Siting Study*.

- **Preferred Alternative.** This alternative evaluates the impacts of floating fish farms under existing regulations with recommendations for expanded regulations, additional guidelines, and additional scientific research. This alternative recommends measures that State and local governments can take to avoid significant adverse impacts.

  The recommendations in the Preferred Alternative comprise two different approaches. Some of the recommendations include establishing regulations as a minimum standard. For example, the recommendation to adopt into the WACs the annual monitoring discussed in the *Interim Guidelines* creates a standard that will be applied in each fish farm proposal. If site specific conditions warrant additional monitoring, then additional monitoring would be used as a mitigation measure for an individual farm.

  The other approach used in the recommendations is to establish a performance standard. For example, the Preferred Alternative recommends guidelines such as siting a farm near the shoreline to reduce the impact on navigation. However, if the objective of reducing the impact on navigation can be accomplished without employing this guideline, then it need not be used.

  If the recommendations for expanded regulations included in this FEIS are not adopted into WACs, they would still function as existing guidelines for State and local governments. State and local governments can use all of the recommendations in this FEIS as mitigation measures through the SEPA process for individual farms.

PURPOSE OF THIS EIS:

Recent commercial fish farming has been marked by controversy and concern that the fish farming may harm the marine environment, conflict with existing uses of the water, and be incompatible with shoreline residential use. This controversy has resulted in litigation, legislative action, anger, and frustration by all parties.

To assist in the resolution of this conflict, the Washington State Legislature directed the Department of Fisheries to evaluate the environmental impacts of fish farms on the biological and built (human) environments. This FEIS was prepared by the Department of

Fisheries in consultation with the Departments of Ecology, Natural Resources, and Agriculture. This information is intended to assist State, county, and local decisionmakers in evaluating fish farm proposals.

To assist the reader in reviewing this document, the following three tables are included at the end of the Summary: (1) Table 1 briefly summarizes the alternatives presented in this FEIS, (2) Table 2 identifies State, local, and federal agencies with authority and/or expertise in relation to the issues discussed in this document, and (3) Table 3 provides a list of abbreviations and acronyms used throughout the FEIS.

The following section summarizes the findings of the FEIS for each issue that was discussed in the FEIS.

SUMMARY BY ELEMENT OF THE ENVIRONMENT:

Bottom Sediments and Benthos

The settling of organic matter, mostly from excess food and feces from the fish farm, is the source of impacts to bottom-dwelling plants and animals (benthos) from fish farms. The severity of the impacts depends on several factors including loading (poundage of fish raised in the farm), pen size, water depth and current velocity, pen configuration, bottom current velocity, feed type, feeding method, and the existing bottom sediments and benthic community.

Sedimentation from fish farms decreases benthic sediment oxygen levels by increasing the demand for oxygen, and by decreasing both diffusion and water flow into the interstitial spaces of the sediment. As increasing amounts of fine sediment accumulate, the depth to which oxygen penetrates is reduced, and the underlying sediment layers become devoid of oxygen and unable to support animal life.

Organic enrichment from fish food and feces which are high in organic carbon and nitrogen. At low levels of nutrient enrichment, these particles may enhance the abundance of the established benthic community by providing an additional food or energy source for deposit- and filter-feeding organisms and for scavengers.

WDF has the authority to preserve, protect, perpetuate, and manage food fish and shellfish resources in Washington. The HPA permit and SEPA review processes provide WDF with the opportunity to evaluate specific conditions, and approve or deny individual fish farm proposals on a case-by-case basis using the most current information available for a specific site. Ecology is developing sediment quality standards that will specify the degree of effects allowed in sediments throughout Puget Sound.

The site surveys and monitoring requirements in the *Interim Guidelines* were found to provide an adequate framework for determining potential impacts to the benthos. The *Guidelines* took a conservative approach to preventing benthic impacts, and the depth and current guidelines should continue to be used.

It is recommended that the site surveys and monitoring requirements identified in the *Interim Guidelines* be adopted into WACs. It is also recommended that DNR, Ecology, and WDF annually review monitoring reports from farms to determine if depth and current guidelines should be revised.

Significant adverse impacts to the benthic community can be avoided by conducting site surveys prior to construction of fish farms and by monitoring the area annually after a farm is installed. NPDES permit requirements and the State sediment quality standards will provide adequate regulatory control to avoid significant impacts to the benthos.

Water Quality

Several water quality variables including turbidity, pH, temperature, fecal coliforms, nutrients, toxicity, and dissolved oxygen were researched to determine if fish farms would have potential significant adverse impacts. It was found that for the variables of pH and temperature, the impacts from fish farms would be negligible. Turbidity would increase, primarily during net cleaning. Higher turbidity levels during net cleaning activities would not adversely affect aquatic organisms, but would reduce the clarity of the water. The potential for toxicity would be greatest from the increased production of dissolved nitrogen (including ammonia) that is typically associated with fish farms. However, even within fish farms, un-ionized ammonia levels are well below the maximum four-day, chronic exposure level recommended by EPA.

The variables of nutrients and dissolved oxygen have the largest potential to be affected by fish farms. The effects of nutrients are analyzed in the discussion on phytoplankton.

Dissolved oxygen consumption by fish, and by microbial decomposition of fish wastes and excess food, could reduce dissolved oxygen concentrations near a fish farm. In general, however, the dissolved oxygen requirements of salmon raised in farms limit the impact fish farms can have on the environment. Salmon are sensitive to the level of dissolved oxygen, and the water quality criteria for oxygen are based in large part on the requirements of rearing salmon. The impact of low dissolved oxygen is likely to affect the farm before having an effect on the surrounding environment. Most studies have shown that fish farms do not have a significant adverse impact on dissolved oxygen. Exceptions to this have occurred during summer or autumn at sites that had low background dissolved oxygen levels and did not have adequate current flow through the nets. One of the beneficial impacts of fish farm development is that fish farms monitor water quality parameters at their sites and can provide an early indication of water quality problems in an area.

Commercial fish farms producing more than 20,000 lbs per year are required to obtain a NPDES permit to ensure that the farm will not exceed State and federal water quality standards. The *Interim Guidelines* recommend that a hydrographic survey of the fish farm site be completed before starting the permitting process, and that annual monitoring of water quality parameters be completed for each site.

Significant adverse impacts to water quality can be avoided by adopting provisions of the *Interim Guidelines* into WACs and by monitoring turbidity during net cleaning operations during periods of high natural turbidity. These measures, along with implementation of the NPDES permit requirements, will ensure that no significant adverse impacts will occur as the result of fish farm development.

Phytoplankton

Salmon farms may cause or increase blooms of phytoplankton by localized nutrient enrichment. This enrichment could occur when excessive dissolved nutrients are discharged into semi-enclosed waters with limited tidal mixing and strong vertical stratification. However, in all but a few localized areas of Puget Sound, limited increases in phytoplankton production would have no adverse effect and would merely contribute more food to the food chain.

The *Interim Guidelines* provide an adequate framework for establishing which embayments are nutrient sensitive. The *Guidelines* used a reasonable approach to ensure that fish farms would not create significant impacts on potentially nutrient sensitive areas.

It is recommended that the areas defined as sensitive in the *Guidelines* (Holmes Harbor, Budd Inlet, and Hood Canal south of Hazel Point) be identified as such in WACs. For these areas, it is also recommended that fish production be limited to that which will not adversely affect existing biota. Use of predictive models is recommended to estimate allowable production levels in sensitive areas.

It is also recommended that the maximum production levels for fish farms in the 19 embayments identified in the *Guidelines* be adopted into WACs. Any subsequent fish farm proposals must demonstrate to State resource agencies by field and modeling studies that additional proposed development will not adversely affect existing biota.

The adoption of provisions in the *Guidelines* into WACs and the case-by-case SEPA process will ensure that no significant adverse impacts occur to biota in nutrient sensitive embayments as a result of fish farm development.

Chemicals

Fish farming involves the use of antibiotics and antifoulants. Studies indicate that the concentrations of antibiotics reaching the environment from fish farms are very small. Also, there seems to be little potential for shellfish near fish farms to bioaccumulate antibiotics used at the farm. Shellfish held within a fish farm did not accumulate detectable levels of the antibiotic OTC. This observation, and the calculated dilution of any quantities of antibiotics away from fish farms, suggest that any quantities of antibiotics accumulated in shellfish, or other benthic or planktonic marine invertebrates, if any, would be below levels of concern.

The transfer of drug resistance from fish to human pathogenic bacteria seems unlikely. It appears such transfer is a laboratory phenomenon that requires highly controlled conditions and is not representative of phenomena that occur in the natural environment.

Other than requiring the use of FDA-approved antibiotics, there are currently no State standards for the use of antibiotics at fish farms and some risk of adverse impacts could exist if farms are inappropriately sited, or mismanaged. It is recommended that any potential risk could be minimized by: (1) using vaccination to reduce the need for antibiotics, (2) requiring farms to report antibiotic use to the State, (3) developing programs to educate farmers on the use of antibiotics and vaccination, (4) undertaking additional research to verify that shellfish held near fish farms in various environments do not accumulate significant amounts of antibiotics, and (5) undertaking further research to establish any potential amounts of antibiotics in sediments near fish farms, if sediments occur.

Use of existing regulations with the adoption of these recommendations would be adequate to avoid significant adverse impacts.

Food Fish and Shellfish

The primary impacts floating fish farms are likely to have on food fish and shellfish populations are from sedimentation that may occur under the farm and the farm structure itself.

At low rates of sediment deposition, filter feeders such as clams may be enhanced. Previous studies have found that mobile predators/scavengers, for example crabs, are attracted to the area around aquaculture facilities to feed on excess food and on the small organisms which are enhanced around the farm.

At high levels, immobile organisms will be displaced from the area below the farm. Fish and shellfish could also be adversely affected by the deposition of organic sediments upon important habitats. For example, a farm directly above a clam or geoduck bed could create an azoic zone immediately below the farm, killing all the shellfish within the zone. Sedimentation over spawning areas could smother eggs and eliminate the area for further spawning use.

The farm structures provide a habitat in the open-water environment to attract fish, such as surfperch and rockfish, in larger numbers than would normally be found. Fish farms and their floats also provide a substrate on which algae and invertebrates grow, providing a food source that attracts various fishes. Fish associated with farms in Puget Sound include shiner perch and other surfperch, true cod, lingcod, dogfish, sculpins, and flatfish.

There are several permitting procedures and regulations which will ensure that fish farms do not have a significant adverse impact on food fish and shellfish resources. These include: the HPA and NPDES permits, SEPA review, DNR's

Aquatic Land Lease program, and the habitat management policy of WDF. These mechanisms also provide protection for habitats such as herring spawning areas.

The *Interim Guidelines* recommend that fish farms not be sited where they are likely to adversely affect habitats important to commercial or sport food fish or shellfish fisheries, that are of critical ecological importance, or that are especially sensitive to degradation by cultural activities. The *Guidelines* also establish buffer zones around habitats of special significance.

It is recommended that the habitats identified in the *Guidelines* should be adopted into WACs as habitats of special significance. It is also recommended that a case-by-case evaluation of potential additional habitats of special significance and the need for buffer zones around habitats of special significance be incorporated into WACs using the distances discussed in the *Guidelines* as a reference.

Importation of New Fish Species

The introduction of a new species into an area always poses some level of risk. While this risk can be minimized, it cannot be entirely eliminated. In order for Atlantic salmon to affect existing fish populations, significant numbers would have to escape from a fish farm and then be able to outcompete resident stocks of salmon and steelhead.

Intentional and accidental releases of Atlantic salmon into Puget Sound and other northeastern Pacific waters have all been unsuccessful in establishing self-sustaining runs. Based on this persistent lack of success in establishing Atlantic salmon where other salmonid populations exist, it is unlikely that they could establish self-sustaining runs in Washington rivers.

There are several federal and State regulations that have been designed to ensure that importation of new species does not adversely affect existing species. In addition, the HPA and SEPA review processes allow a case-by-case evaluation of proposals using the most current information. The existing regulations are adequate to avoid significant adverse impacts to indigenous species of food fish and shellfish.

Genetic Issues

Farm-reared fish can only have a genetic impact on wild fish populations if the following three conditions are met: (1) significant numbers must escape from fish farms, (2) the escapees must survive and return to mix with a wild population on the spawning grounds in numbers large enough to affect the wild population, and (3) if the other two conditions have been met, the escapees must have the genetic capacity to either breed with or outcompete the wild population.

As stated above, past experience indicates that Atlantic salmon are not capable of effectively competing with Pacific salmon and trout. Furthermore, Atlantic salmon are genetically incapable of breeding with Pacific salmon and trout and producing viable offspring.

If the escapees were farmed Pacific salmon, interbreeding with wild populations would be genetically possible. The impacts to the wild population, if any, may be a genetic alteration of the population. Without constant infusion of genes from escaped fish, any maladaptive genes would disappear rapidly due to selective pressure. Therefore, any genetic impacts would be temporary.

WDF has the responsibility to preserve, protect, perpetuate, and manage fisheries resources. This responsibility provides WDF with the authority to ensure that fish farm proposals would not have an adverse impact on indigenous fish. In addition, the SEPA review and HPA permitting processes provide an opportunity to evaluate fish farm proposals on a case-by-case basis at specific sites using the most current scientific information.

It is recommended that the following three guidelines be used by WDF when reviewing fish farm proposals: (1) when Pacific salmon stocks are proposed in areas where WDF determines there is a risk to indigenous species, WDF should only approve those stocks with the greatest similarity to local stocks near the farm site, (2) in areas where WDF determines there is a risk of significant interbreeding or establishment of harmful self-sustaining populations, WDF should only approve the farming of sterile or monosexual individuals or genetically incompatible species, and (3) in areas where WDF determines that wild populations could be vulnerable to genetic degradation, WDF should establish a minimum distance of separation between farms and river mouths.

The potential for significant genetic impacts resulting from farm escapees interbreeding with wild stocks is low. Use of existing regulations with the guidelines identified above are adequate to avoid significant adverse impacts.

Disease

The primary concern with the growth of the fish farming industry in Washington has been the possibility of increased risk of introduction of exotic diseases. However, this increased risk is minimal because regulations currently in place restrict the importation of serious exotic pathogens of salmon.

The risk of transmission of disease from farms to wild fish is not likely a significant problem. Diseases observed in fish farm culture of salmonids in Washington result from the holding of the fish in captivity. Such diseases are non-exotic; infectious agents that cause such diseases originate from environmental sources or wild fish.

There is no impact related to infectious diseases on invertebrate populations that can be reasonably predicted as a result of salmon farming practices. This is because fish pathogens are largely distinct from invertebrate pathogens.

Existing regulations allow a small, but manageable potential for adverse impacts. It is recommended that enough regional brood stock to support the salmon farming industry be developed to eliminate the risk of importing exotic salmon diseases with infected eggs. While the current regulatory policies allow some controlled risk, the development of a local brood stock would further reduce the risk. Implementing the recommendation in conjunction with the use of existing regulations would avoid any significant adverse impacts.

Marine Mammals and Birds

Construction and operation of a fish farm would alter habitats for birds and mammals. Some species can tolerate or benefit from the presence of a fish farm facility, while species sensitive to human activity are forced to seek habitat elsewhere. The significance of potential impacts will depend on site specific considerations such as types and numbers of species in the area and proximity to sensitive habitat areas. Disturbances would probably be greatest during construction of the facility.

The use of lethal methods to control predators, if widespread, could have an adverse impact on marine mammal and bird populations. However, because non-lethal methods provide effective control, significant impacts on populations are not expected.

The existing State and federal review processes allow site specific factors and the most current data to be considered in the process of siting fish farms. In areas where WDW, NMFS, or USFWS indicate that predators may be present, it is recommended that fish farmers be required to use anti-predator nets. This requirement should be adopted into the appropriate WACs. The use of the current regulations along with the suggested anti-predator net requirement would avoid significant adverse impacts to marine mammals and birds.

Visual Quality

The visual impact of fish farms on observers varies considerably with the distance between the observer and the farm, the altitude of the observer, and the surrounding views. While location and observer position are very important, the attitude of the observer is also critical. Some would consider a farm to be a visual intrusion, while others would consider the same facility to be a neutral or interesting part of the visual environment.

Visual quality impacts from fish farms are site specific. The various factors influencing the potential for impacts (topography, number, location, attitudes of observers, and existing visual and development character) vary within Puget Sound and adjacent waters. Given this variability, specific visual quality guidelines that would apply throughout the region are not appropriate. Specific guidelines are best determined by local jurisdictions, and expressed as policies and regulations in individual shoreline master programs. It is recommended that local governments adopt measures that modify either the design or location of farm facilities to minimize visual impacts.

Navigation

Fish farms can affect navigation if sited in established navigation lanes, narrow channels, or where boats would be unable to navigate safely around them. In addition, if fish farms break loose from their anchors during severe weather conditions they could become a hazard to vessel traffic. If fish farms are inadequately lighted or made visually unobtrusive, they pose a greater risk to navigating vessels and may be a significant safety hazard, especially at night or during inclement weather. The further offshore a farm is located, the greater the navigational risk because structures are not expected, reference points are not nearby, traffic is more intense, and vessels are usually travelling faster.

Fish farms may also have a beneficial impact on navigation by providing a point of assistance or refuge to boaters.

The USCG has the responsibility for reviewing all proposed structures in Puget Sound for potential navigation hazards through the ACOE Section 10 permitting process. Local governments also consider navigation issues during the SEPA review and shoreline permitting processes. These reviews ensure that fish farm proposals are considered on a case-by-case basis using the most current information about navigation patterns, and that they will not be sited in established navigation areas. DNR requires a bond from fish farmers to ensure cleanup of any debris caused by any accidental destruction of the farm.

It is recommended that local governments provide major recreational and commercial boating organizations with SEPA and shoreline permit notices to help identify areas of special importance to boaters. In addition, it is recommended that local governments notify recreational and commercial boating organizations and all marinas and ports near the farm of their precise location and their aids to navigation.

The SEPA and Section 10 permitting processes allow fish farm proposals to be evaluated on a case-by-case basis in consideration of local navigational use. The use of existing regulations and the implementation of the two notification recommendations are adequate to avoid significant adverse navigation impacts.

Commercial Fishing

The direct impact of floating fish farms on commercial fishing is the potential for collision or entanglement of the fishing nets with the farms, resulting in damaged gear and a loss of available fishing time and area. Results of this impact can be displacement of fishers from a productive and accustomed fishing area, lost harvest potential, and reduced opportunity of the fishers to catch their allotment of salmon. The significance of the potential impact depends on site-specific conditions. If non-tribal fishers have the opportunity to catch the same fish in another area, the displacement of the fishers from a particular site may not be a significant adverse impact. The potential displacement of tribal fishers could also occur. If a farm prevents a particular tribe from fishing in their "usual and accustomed" fishing areas, the tribe would have nowhere else to fish and a significant impact could result.

WDF is required to promote orderly fisheries, and enhance and improve recreational and commercial fishing in Washington. WDF has the authority to ensure that a fish farm would not interfere with an orderly fishery. The SEPA review process, and the HPA and Section 10 permitting programs allow a case-by-case evaluation of fish farm proposals using the most current information about a specific site.

It is recommended that local governments implement the following two measures through their SEPA and shoreline permitting processes: (1) provide commercial fishing organizations and tribes with SEPA notices related to fish farm proposals to help identify areas of special importance, and (2) provide commercial fishing organizations and tribes with the precise location of farms and the layout of their anchor lines.

The SEPA review, and HPA and Section 10 permitting processes also allow a case-by-case assessment of fish farm proposals using the most current information regarding commercial and tribal fishing activities. The use of existing regulations and the implementation of the recommendations described above are adequate to avoid significant adverse impacts.

Human Health

Fish farming activities will not contribute bacterial human pathogens to the environment because the bacteria associated with salmonid and other cold water fish farming activities are distinct from human pathogens. In addition, the occurrence of *Vibrio parahaemolyticus* gastroenteritis is relatively rare and is most commonly associated with poor food handling processes. Fish farming appears unlikely to have an effect on cases of parahaemolytic gastroenteritis associated with eating contaminated raw shellfish.

Preliminary research indicates that salmon raised in fish farms have an absence of parasitic worms that sometimes afflict humans eating raw salmon in products such as sushi or sashimi. Fish farms may have a slight beneficial impact because of this, but further research is necessary to determine whether these findings have any general applicability.

The FDA, DOH, and WSDA are responsible for regulating the safety of food fish. DOH regulates food protection and storage. They are also charged with approving shellfish growing areas and assuring that these areas, and the commercially harvested shellfish from these areas, are not contaminated. WSDA prohibits the sale of fish which are decomposed or contain antibiotic residues.

While human health risks appear to be minimal, it is recommended that the following four measures be implemented to further reduce any potential impacts on human health: (1) site fish farms in areas providing water quality compatible with good husbandry practices to ensure that farms are not sited in warm, rich embayments of Puget Sound susceptible to seasonal increase levels of *V. parahaemolyticus*, (2) conduct further research to determine bacteriological characteristics of fish food, (3) conduct further research to validate the geographic distribution of lowered parasite loads in farmed fish, and (4) provide advisory notices to fish farmers about the proper storage of fish food.

Implementing the measures recommended above in conjunction with existing federal health regulations would avoid significant adverse impacts.

Recreation

Fish farms have the potential to affect recreational activities by obstructing access to shore or water areas traditionally used for recreation, or disrupting the intrinsic and visual quality of the area. Floating fish farms can also have positive impacts on recreational activities, because personnel from farms could provide assistance during boating emergencies. In addition, the farm structure itself could be used for temporary moorage during an emergency.

WDF is required to promote orderly fisheries, and enhance and improve recreational and commercial fishing in Washington. WDF has the authority to ensure that a fish farm proposal does not interfere with an orderly recreational fishery. The SEPA review process, and the HPA and Section 10 permitting programs also provide an opportunity to assess the potential impacts of a fish farm proposal on a case-by-case basis. These review and permitting processes allow the most current information on recreational activities at a specific site to be incorporated into the decisionmaking process. These review and permitting processes and the use of existing regulations are adequate to avoid significant adverse impacts to recreation.

Noise

Potential noise impacts would primarily occur during daytime hours when farm operations take place. Sources of noise from fish farms would include boats servicing the farms, motors, compressors for aeration, and incidental noise from personnel working on the facility. Because of the usual absence of obstructions above the water surface, any noise produced by farm operations will tend to carry farther than would be expected for a similar noise source located on land.

There are a number of State, federal, and local regulations and guidelines that address the impacts from noise. It is recommended that local governments implement the following three measures through their shoreline permitting process to further reduce potential noise impacts related to fish farms: (1) require installation and regular maintenance of mufflers on all motorized equipment, (2) require enclosures on all motorized equipment, and (3) require farms to use electric motors to operate pumps and compressors when the farms have access to shoreline electrical power (for example, adjacent to a dock). Use of existing State noise standards and the implementation of the three measures identified above would avoid significant noise impacts from fish farms.

Odors

Fish farms have the potential to be a concentrated source of odors because of the large amount of organic matter associated with marine facilities. All odor impacts would be occasional and intermittent. The major potential sources of odors are spilled or improperly stored fish food, air drying of nets fouled with attached marine life, and dead fish. In addition, decaying organic matter from all of these sources can accumulate on the farm walkways. Boats servicing the facility and internal-combustion motors used to power pumps and aeration equipment would contribute minor amounts of exhaust fumes to the immediate area of the facility.

Most local shoreline master programs discuss odor in relationship to aquaculture facilities, and some shoreline programs require the proper disposal of wastes. It is recommended that best management practices be developed for the fish farming industry to include measures such as: (1) daily removal and disposal of dead fish and cleanup of spilled food, (2) regular cleaning of nets, (3) storage of food in closed containers, and (4) use of walkways that are designed to allow spilled food to readily fall into the water. In addition, local governments may want to encourage sites downwind of residences, and sites that increase the distance between the farm and residences in areas where this would not increase potential navigation conflicts.

Use of existing regulations and the development of best management practices for the fish farming industry would avoid significant adverse odor impacts.

Upland and Shoreline Use

Fish farms have the potential to influence future development patterns in an area. Fish held in pens are particularly sensitive to degradation of water quality. Once a fish farm is installed it will highlight water quality concerns in the area. Therefore, greater attention may be brought to bear on activities that are not presently meeting water quality standards, or proposed activities which could adversely affect water quality. This increased concern may result in local and State agencies placing additional restrictions on upland projects to prevent water quality degradation. Upland users may also be subject to liability if their action, in violation of pollution laws, were to damage the fish in the pens.

Highlighting activities that may degrade water quality and subjecting them to greater regulatory control would not be an adverse impact. All activities along the shoreline should minimize or prevent water quality degradation. If a fish farm serves to increase awareness of water quality needs, or results in changes to upland activities that are degrading water quality, it would be a beneficial impact.

Some local shoreline master programs include provisions for protecting aquaculture activities from incompatible upland uses. In addition, some local shoreline programs include provisions that require farms to properly dispose of waste to prevent the degradation of associated upland area.

Existing regulations are adequate to avoid significant adverse impacts to upland and shoreline uses.

Local Services

The operation of fish farms does not require large amounts of fresh water or electricity. Fish farms must dispose of solid waste generated at the farm site. The major component of this waste is fish that die and are not harvestable for commercial sale. There are three ways that fish farms presently dispose of their dead fish: (1) dispose of the fish at landfill sites, (2) reprocess the fish into fish food, and (3) incorporate the fish into local agricultural activities. Fish farms would not have an impact on other local services.

Increasing the number of farms in a localized area would probably result in a cumulative impact on local services, because any particular service would likely be provided by a single purveyor. Because any one farm results in an insignificant impact on local services, the size of the cumulative impact of several farms would be minor.

There are numerous State regulations that address local services such as fire and police services, sewage and water services, and landfills. It is recommended that local governments require fish farm applicants to provide the following information as part of their shoreline permit application: (1) a high and low estimation of the volume of waste that may be produced by the proposal, including potential catastrophic losses, and (2) the process by which the farm will dispose of its waste.

Use of existing regulations with implementation of the recommendations above would avoid significant adverse impacts to local services.

Cumulative Impacts

The potential cumulative impacts from fish farm development in Puget Sound would be minimized by the evaluation process resulting in the proper siting of individual farms. Siting five farms in an embayment, or a number of farms throughout Puget Sound, would not have a cumulative impact on the elements of the environment discussed in this FEIS if the locations of other nearby farms were considered in the permitting process.

The process of analyzing cumulative impacts of fish farms must be sequential. Individual farms would receive their own site specific SEPA review and undergo scrutiny for compliance with the regulations discussed throughout this FEIS, including consideration of nearby fish farm development.

PHASED REVIEW:

This is a programmatic EIS that assesses the environmental impacts of floating fish farms. It does not assess the impacts of any individual proposal. Public officials and agencies may elect to utilize the information presented in this FEIS to develop policies and rules for floating fish farms in Puget Sound. These actions would then be subject to SEPA.

Fish farms that are proposed subsequent to this FEIS must comply with the provisions of SEPA on their own, individual merits. State agencies and local governments can use the information provided in this FEIS to assist them in making SEPA threshold determinations and shoreline permitting decisions, help them define specific additional information that may be necessary from fish farm proponents, and help them properly site floating fish farm proposals in Puget Sound.

Table 1. Summary of alternatives.

No-Action Alternative	Preferred Alternative
BOTTOM SEDIMENTS AND BENTHOS	
Interim Guidelines include minimum depth and current guidelines, and bathymetric, diver, and baseline surveys. Annual monitoring of sediment impacts under fish farms. Ecology sediment quality standards. SEPA and HPA case-by-case review.	Continue to use depth and current guidelines. Adopt surveys and annual monitoring identified in the *Guidelines* into WACs. Annual review of monitoring reports by Ecology, WDF, DNR to determine if depth and current guidelines should be revised.
WATER QUALITY	
Ecology will receive NPDES permits for commercial farms producing over 20,000 lbs of fish per year. Compliance with State water quality regulations. Hydrographic survey of site before permitting. Annual water quality monitoring. SEPA review.	Adopt surveys and annual monitoring identified in the *Guidelines* into WACs. During periods of naturally high turbidity, require farmers to monitor turbidity net cleaning activities, and increase the frequency of net cleaning to ensure compliance with State water quality standards.
PHYTOPLANKTON	
Guidelines define geographical areas in Puget Sound that are nutrient sensitive, and maximum production limits in embayments.	Identify Holmes Harbor, Budd Inlet, and Hood Canal south of Hazel Point as nutrient sensitive in WACs. Limit total fish production within these sensitive areas to that which will not adversely affect existing biotas. Adopt maximum production levels for the 19 embayments identified in the *Guidelines* into WACs and require any subsequent fish farm development to demonstrate with field and modeling studies that further development will not adversely affect existing biota.
CHEMICALS	
Use of FDA-approved chemicals. SEPA review.	Recommend using vaccination to reduce use of antibiotics, requiring farms to report antibiotic use to the State, developing educational programs to educate farmers on use of antibiotics and vaccination, undertaking research to verify shellfish near fish farms do not accumulate significant amounts of antibiotics, and undertaking additional research to establish any potential amounts of antibiotics in sediments near fish farms, if sediments occur.
FOOD FISH AND SHELLFISH	
HPA, Section 10, and NPDES permits required for fish farms. WDF authority to "preserve, protect, perpetuate, and manage. . ." food fish and shellfish resources. DNR Aquatic land Lease program. *Guidelines* include siting criteria for fish farms and buffer zones around significant habitats. Diver survey to aid in identifying habitats. SEPA review.	Adopt habitats of special significance identified in the *Guidelines* into WACs. Adopt a requirement for a case-by-case evaluation of both the need for additional habitats of special significance, and the need for buffer zones around habitats of special significance into WACs.

Table 1. Summary of alternatives (continued).

No-Action Alternative	Preferred Alternative
IMPORTATION OF NEW FISH SPECIES	
Several State and federal regulations designed to ensure importation of new species does not adversely affect existing species. HPA and Section 10 permitting processes. SEPA review.	Existing regulations are adequate to avoid significant adverse impacts. No additional recommendations.
GENETIC ISSUES	
WDF has responsibility to preserve, protect, perpetuate, and manage fishery resources. Authority to ensure fish farms would not have an adverse impact on indigenous species. Hydraulic Code and HPA permit review. SEPA review.	Recommend WDF use of following guidelines when reviewing fish farm proposals. When indigenous stocks are proposed for farms, WDF should only approve those with the greatest similarity to local stocks. In areas with risk of significant interbreeding or establishment of deleterious self-sustaining populations, WDF should only approve the farming of sterile or mono-sexual individuals. Establish minimum distance between farms and river mouths in areas where wild populations could be vulnerable to genetic degradation.
DISEASE	
Washington State and federal laws require certification that all salmon eggs not contain any virus or other significant fish pathogens before fish can be placed in State waters. Finfish Transfer/Import permit.	Require development of enough regional broodstock to support the Washington fish farming industry.
MARINE MAMMALS AND BIRDS	
Various local, State, and federal laws and programs include language protecting marine mammals and birds. These include local shoreline master programs, the Marine Mammal Protection Act, the Migratory Bird Treaty Act, the Endangered Species Act, and the Bald Eagle Protection rules. The *Guidelines* recommend separating fish farms 1,500 ft from habitats of special significance depending on the site characteristics and nature of the farm. Non-lethal techniques (following federal and state rules) should be used to discourage predators. SEPA review and the Section 10 permitting processes allow evaluation of proposals using the most current information for a specific site.	Adopt requirement into WACs for the use of anti-predator nets in areas identified by WDW, USFWS, or NMFS as areas where predators may be present.

Table 1. Summary of alternatives (continued).

No-Action Alternative	Preferred Alternative
VISUAL QUALITY	
The Shoreline Management Act and local shoreline programs include broad guidelines for addressing visual impacts. The *Aquaculture Siting Study* includes general design and location guidelines and recommends siting fish farms 1,500 to 2,000 ft offshore to minimize visual impacts. SEPA review. Ecology review of shoreline permits.	Local governments should adopt measures to modify either the design or location of farm facilities to minimize visual impacts.
NAVIGATION	
Section 10 permit. USCG review for potential navigation hazards. USCG may require fish farms to install private aids to navigation. DNR requires a bond from the fish farm to ensure cleanup in case of accidental destruction of the farm. SEPA review.	Recommended that local governments: (1) provide major recreational and commercial boating organizations with SEPA and Shoreline permit notices, and (2) notify recreational and commercial boating organizations and marinas and ports near the farm with its precise location and aids to navigation. In suitable areas, place farms close to shoreline or near existing impediments to navigation such as marinas and docks.
COMMERCIAL FISHING	
WDF required to promote orderly fisheries, and enhance and improve commercial fishing. HPA and Section 10 permits, and SEPA review, allow case-by-case review of individual proposals using current information on fishing activities. The U.S. v. Washington (Boldt decision states that treaty tribes in Puget Sound shall be allowed to fish in their "usual and accustomed" fishing areas.	Recommend that local government: provide commercial fishing organizations and tribes with SEPA notices, and notify commercial fishing organizations and tribes of the precise location of farms and anchor lines. In suitable areas, place farms close to shoreline or near existing impediments to navigation such as marinas and docks.
HUMAN HEALTH	
FDA, DOH, and WSDA have the responsibility for regulating the safety and food fish. DOH regulations food protection and storage. WSDA prohibits sale of adulterated fish, which includes decomposed fish and fish containing antibiotic residues.	Recommend four measures: (1) site fish farms in areas that provide water quality compatible with good husbandry practices, (2) conduct further research to determine the bacteriological characteristics of fish food, (3) advise fish farmers on proper storage for fish food, and (4) conduct additional research to validate the geographic distribution of a lower number of parasites in farm fish.
RECREATION	
WDF has responsibility to promote orderly fisheries, and enhance recreational fishing in Washington. Local shoreline, SEPA, HPA, and Section 10 permitting processes allow case-by-case analysis to incorporate the most current information on recreational activities for a particular site. WSPRC review near State marine parks.	Site specific review and permitting processes are adequate to avoid significant adverse impacts to recreation.

Table 1. Summary of alternatives (continued).

No-Action Alternative	Preferred Alternative
NOISE	
Noise sources other than recreational watercraft are subject to the State Maximum Environmental Noise Levels. EPA noise guidelines. SEPA review.	Recommend that local governments require mufflers and enclosures on all motorized fish farm equipment, and require farms to use electric motors in areas with access to electricity such as adjacent to docks.
ODORS	
State laws prevent nuisances to individuals. Language in local shoreline master programs concerning odor and proper disposal of wastes. SEPA review.	Develop best management practices to reduce odor including: (1) daily removal and disposal of dead fish, (2) regular cleaning of nets, (3) storage of food in closed containers, and (4) use of walkways that readily allow spilled food to fall into the water. Local governments may also want to encourage sites that increase the distance between farms and residences and encourage farms to be placed downwind of residences.
UPLAND AND SHORELINE USE	
Some local shoreline programs provide regulations that protect fish farms from incompatible upland uses. Some local programs include provisions that require farms to properly dispose of wastes to prevent degrading upland areas. SEPA review.	Use of existing regulations are adequate to avoid significant adverse impact to upland and shoreline uses.
LOCAL SERVICES	
Numerous State regulations that address local services such as police and fire, landfills, and water and sewer service. SEPA review.	Recommend that local government require a high and low estimation of the volume of waste to be produced by the farm, including catastrophic losses. Also recommend that local government require information on the process by which the farm will dispose of its waste.

Table 2. Agencies with specific authority and/or expertise.

	STATE AGENCIES							LOCAL	FEDERAL AGENCIES				
ISSUES	WDF	WDOE	WDW	WSDA	DNR	WSPRC	WDOH	LOCAL	EPA	USFWS	NMFS	USCG	FDA
NATURAL ENVIRONMENT													
Sediment & Benthos	X	X			X				X		X		
Water Quality	X	X					X		X				X
Phytoplankton	X	X					X						
Chemicals	X	X		X					X				X
Fish & Shellfish	X			X	X					X	X		
Importation of New Species	X			X						X			
Genetic Issues	X			X									
Disease	X			X									
Marine Mammals & Birds			X							X	X		
BUILT ENVIRONMENT													
Visual Quality		X						X					
Navigation		X			X			X				X	
Commercial Fishing	X									X	X		
Human Health				X			X	X					X
Recreation	X	X	X			X		X		X		X	
Noise		X						X	X				
Odor		X						X					
Upland & Shoreline Use		X						X					
Local Services								X					

State Agencies:

WDF	Washington Department of Fisheries
WDOE	Washington Department of Ecology
WDW	Washington Department of Wildlife
WSDA	Washington Department of Agriculture
DNR	Washington Department of Natural Resources
WSPRC	Washington State Parks & Recreation Commission
WDOH	Washington Department of Health

Local Agencies:

LOCAL	Local County Government

Federal Agencies:

EPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish & Wildlife Service
NMFS	National Marine Fisheries Service
USCG	U.S. Coast Guard
FDA	U.S. Food & Drug Administration

NOTE: Any of the listed agencies can participate in the environmental review of these issues through the SEPA process.

Table 3. List of abbreviations and acronyms used in this FEIS.

ACOE	Army Corps of Engineers
AHD	Acoustic Harassment Devices
BOD	Biochemical Oxygen Demand
BMP	Best Management Practice
dBA	Decibel (A-weighted)
DEIS	Draft Environmental Impact Statement
DNR	Department of Natural Resources
Ecology	Department of Ecology
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FCR	Food Conversion Ratio
FDA	Food and Drug Administration
FEIS	Final Environmental Impact Statement
FICUN	Federal Interagency Committee on Urban Noise
HPA	Hydraulic Project Approval
L_{eq}	Equivalent Constant Sound Level
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
MMPA	Marine Mammal Protection Act
MT	Metric tons
mV	Millivolt
NMFS	National Marine Fisheries Service
NPDES	National Pollution Discharge Elimination System
NTU	Nephelometric Turbidity Units
OTC	Oxytetracycline
PEIS	Programmatic Environmental Impact Statement
PSP	Paralytic Shellfish Poisoning
PSWQA	Puget Sound Water Quality Authority
RCW	Revised Code of Washington
RPD	Redox Potential Discontinuity
SCUBA	Self-Contained Underwater Breathing Apparatus
SEPA	State Environmental Policy Act
SMA	Shoreline Management Act
TOC	Total Organic Carbon
VHS	Viral Hemorrhagic Septicemia
WAC	Washington Administrative Code
WDF	Washington Department of Fisheries
WDOH	Washington Department of Health
WDW	Washington Department of Wildlife
WPRC	Washington Parks and Recreation Commission
WSDA	Washington State Department of Agriculture
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service

1. BACKGROUND AND OBJECTIVES OF THE EIS

1.1 BACKGROUND

Raising fish in floating fish farms has been practiced in Puget Sound for almost twenty years by public agencies and private individuals. Much of this early culture was experimental and concentrated on raising Pacific salmon. Commercial culture began in the early 1970s and one very large salmon farm has operated near Manchester in Kitsap County for the entire time. Salmon fish farms now common in Europe, were based upon this early work in Washington State.

In Norway, the national government saw the farming of Atlantic salmon as a means to economically stimulate the more rural and economically depressed coastal areas of the country. Many of these areas depended largely on commercial fishing, which had declined severely. Consequently, a major effort was directed at developing salmon farming as a cottage industry, especially for former fishers. The success of this effort is now well documented. Norway has become a major exporter of salmon, with anticipated production exceeding 100,000 metric tons (220 million pounds) annually. (By comparison, the Washington commercial salmon fishing industry produces about 2,950 metric tons [6.5 million pounds] of Pacific salmon each year.)

The success of these efforts, and the dominance of the United States as the market for salmon, led to rapid growth of salmon farm culture in Washington State. This growth was unexpected, and has resulted in numerous conflicts between culturists and other users of the State's shores and waters. Numerous environmental concerns have also been raised that have not been adequately answered.

To address these concerns, the Washington Department of Fisheries (WDF), with funding from the Department of Ecology (Ecology) through the *Coastal Zone Management Act*, contracted the University of Washington to review fish and shellfish culture around the world to assess its possible impacts to the aquatic environment (Weston 1986). On the basis of this information, Ecology, WDF, the Department of Natural Resources (DNR), and the Department of Agriculture (WSDA) developed a set of recommended guidelines. These guidelines, the *Recommended Interim Guidelines for the Management of Salmon Fish Farm Culture in Puget Sound*, were intended to assist State and local decision makers in assuring that fish farms were located in areas that would avoid significant adverse impacts to the aquatic environment (SAIC 1986).

These efforts, however, did not completely address the issue of fish farms. Shoreline residents, the commercial fishing industry, and other citizens expressed concern about the possible effects of an expanding fish farm industry on other traditional uses of the State's waters. In response to these concerns and the growing controversy, the Washington State Legislature directed WDF to prepare an environmental assessment of the impacts of fish farm culture in Puget Sound (see Appendix J). WDF elected to prepare this assessment as a programmatic environmental impact statement (EIS) following the procedures of the State Environmental Policy Act (SEPA) for non-project EISs. WDF also contracted to complete a separate report (not a SEPA requirement) on the economics of salmon farming (see Appendix E).

On September 30, 1987, WDF issued a Determination of Significance for the evaluation of fish culture in floating fish farms. Pursuant to WAC 197-11-408, WDF requested written comments on the scope of the programmatic EIS. In addition, WDF held three public meetings to receive public comments. The dates and locations of the meetings were:

October 13, 1987: Port Townsend
October 14, 1987: Port Orchard
October 15, 1987: Mt. Vernon

Written comments received in response to the scoping notice and audio tapes of the public meetings are on file with WDF in Olympia.

WDF issued the Draft EIS (DEIS) on February 6, 1989, and invited written comments from agencies, local governments, tribes, and interested citizens. Because of the complex nature of the document, WDF extended the 30-day SEPA review period to two months and accepted comments until April 7. In addition to inviting written comments, WDF held two public meetings to receive comments on the DEIS. The dates and locations of these meetings were:

March 1, 1988: Silverdale
March 9, 1988: Mt. Vernon

Responses to the written comments received by WDF are included in this Final EIS (FEIS) in a separate volume.

1.2 OBJECTIVES

The objective of the FEIS is to assess the potential environmental impacts of fish farm development in Puget Sound (see Figure 1) under the following two alternatives: (1) the No-Action Alternative evaluates the potential impacts from floating fish farm development under the existing regulations and guidelines currently affecting the fish farming industry in Washington, and (2) the Preferred Alternative evaluates the potential impacts from fish farms under existing regulations with recommended additional measures that can be taken by State agencies and local governments to avoid significant adverse impacts. See Section 4 for a further discussion of the alternatives.

The intent of this FEIS is to provide information to regulators, the public, and the Legislature for assessing the adequacy of existing regulations that affect the fish farming industry in Washington, as well as presenting a Preferred Alternative that identifies actions that State and local governments can undertake to avoid significant adverse environmental impacts.

While no activity can occur without some level of impact, it is the goal of this FEIS to ensure that all reasonable efforts be made to limit impacts from fish farms. However, any impacts to food fish and shellfish or their habitats must be fully mitigated. The ultimate goal of the WDF is to ensure the continued viability of Puget Sound as a resource to be used and appreciated by a wide variety of users.

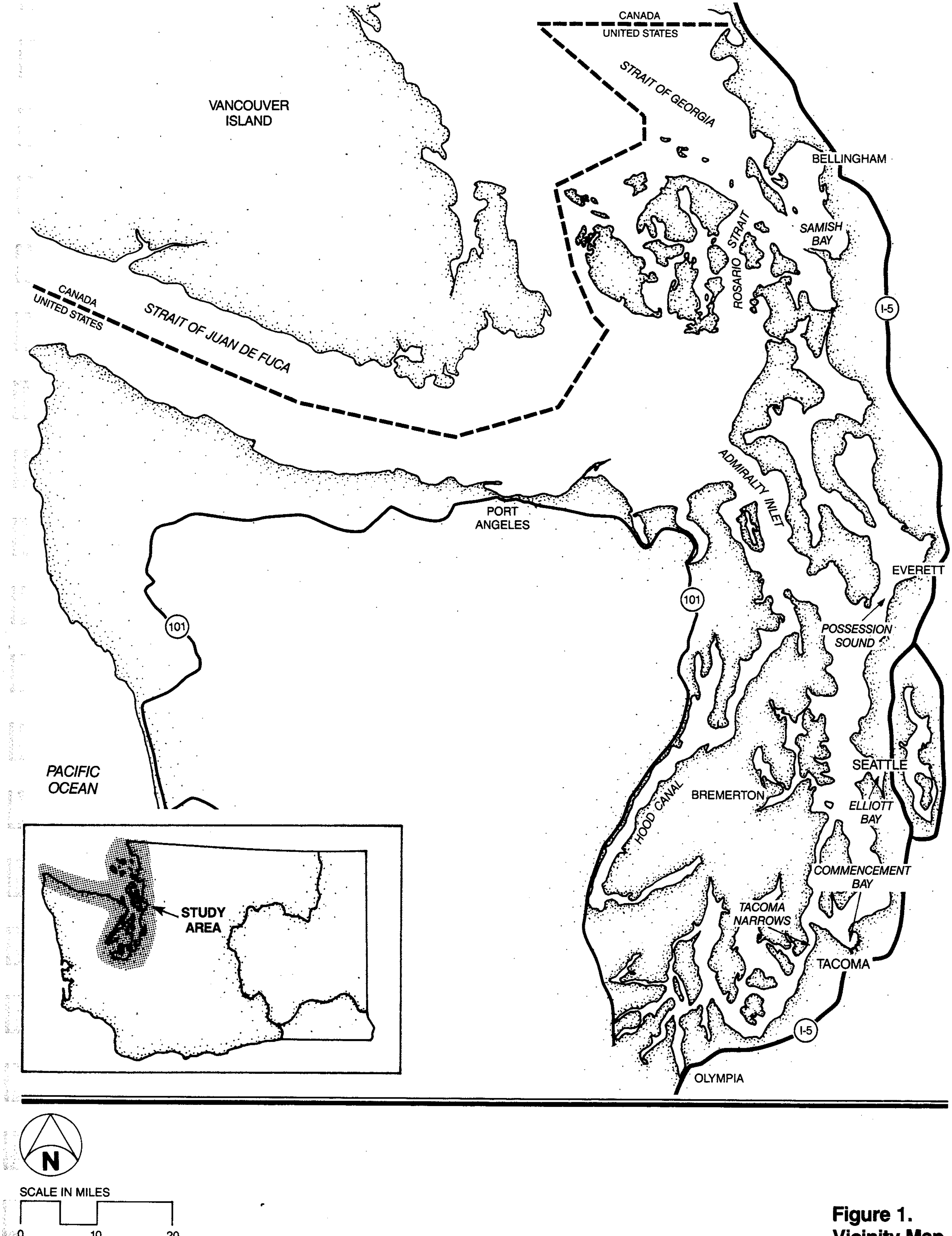


Figure 1.
Vicinity Map

2. BACKGROUND OF THE FLOATING FISH FARM INDUSTRY

Floating salmon farms have been in Washington waters since the early 1970s. In Puget Sound, commercial farms are primarily used to raise coho (*Oncorhynchus kisutch*) or Atlantic (*Salmo salar*) salmon. Presently, there are 13 floating commercial fish farms facilities operating in Puget Sound (see Figure 2). There are also nine research and delayed-release facilities used by agencies, tribes, and private recreational sports groups to enhance Puget Sound salmon populations. Delayed-release farms are used to hold salmon for one to six months before release into the wild after the fish have lost their inclination to migrate out of State waters. This FEIS does not specifically evaluate the impacts of delayed-release farms. However, many of the environmental impact discussions in this FEIS also pertain to delayed-release facilities though their smaller size and temporary nature will result in proportionally reduced impacts.

A typical floating commercial fish farm operating in Puget Sound receives young fish from a freshwater hatchery. These fish are placed directly in pens floating in Puget Sound. The fish are fed daily with pelleted dry food until they reach a marketable size. Harvest size and timing depends on the fish species and market demands. Proper husbandry practices, vaccination, and the periodic use of antibiotics in the food protect the fish from disease. Extra nets surround the pens to protect the fish from predators.

For the purpose of the impact analyses in this FEIS, a typical floating fish farm is described below. This farm is modeled after the farms currently used in Puget Sound.

A cross-section of a typical floating fish farm is illustrated in Figure 3. The primary component of a floating fish farm is a group of pens that float in the water separated by walkways 1 to 2 m (3-6 ft) wide. The number of pens at a fish farm, and the amount of surface water they cover, varies considerably. Currently, all new fish farms in Washington are limited to a total surface area of less than two acres (8,100 m^2). Examples of a wide variety of pen configurations are shown in Figure 3, but most farms in Puget Sound are either square or rectangular structures consisting of up to 50 pens. The most typical size is a complex 30 by 300 m (100 by 1,000 ft). Recently, fish farms have been proposed using circular pens of up to 30 m (100 ft) in diameter, arranged in clusters of three or four pens. For the purposes of assessing the impacts of fish farms in this FEIS, it is assumed the pens are arranged in a 30 by 300 m (100 by 1,000 ft) rectangle.

Floating fish farms are typically constructed with galvanized steel, plastic pipe, or wood. Railings around each individual pen support the net about 1 m (3-4 ft) above the water. Some farm operations in Puget Sound have a maintenance building on the farm site to store food and equipment, provide temporary shelter for workers during inclement weather, and provide security. These buildings vary considerably in color and shape, but most are roughly 3 m (8-10 ft) high and 9 to 12 m^2 (80-120 ft^2) in size.

Nets, hung from the pen railings, have a 10 to 30 mm mesh (depending on the size of the fish), and are commonly about 12 m (40 ft) square and 5 to 8 m (16-25 ft) deep. This size net provides a total volume of 40,000 to 65,000 m^3 in the typical farm. A net is commonly placed over the top of nursery pens to prevent birds from eating

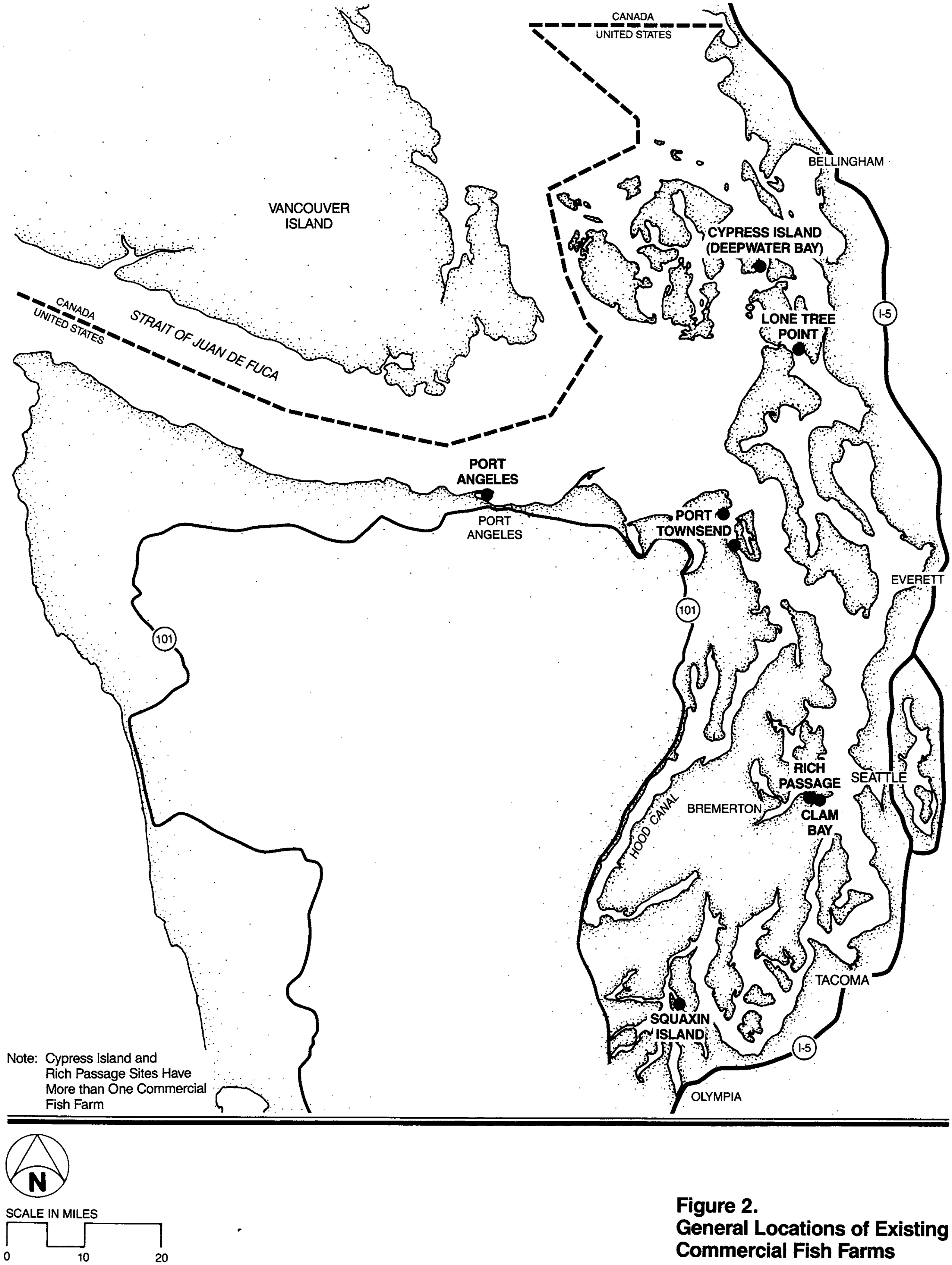


Figure 2.
General Locations of Existing Commercial Fish Farms

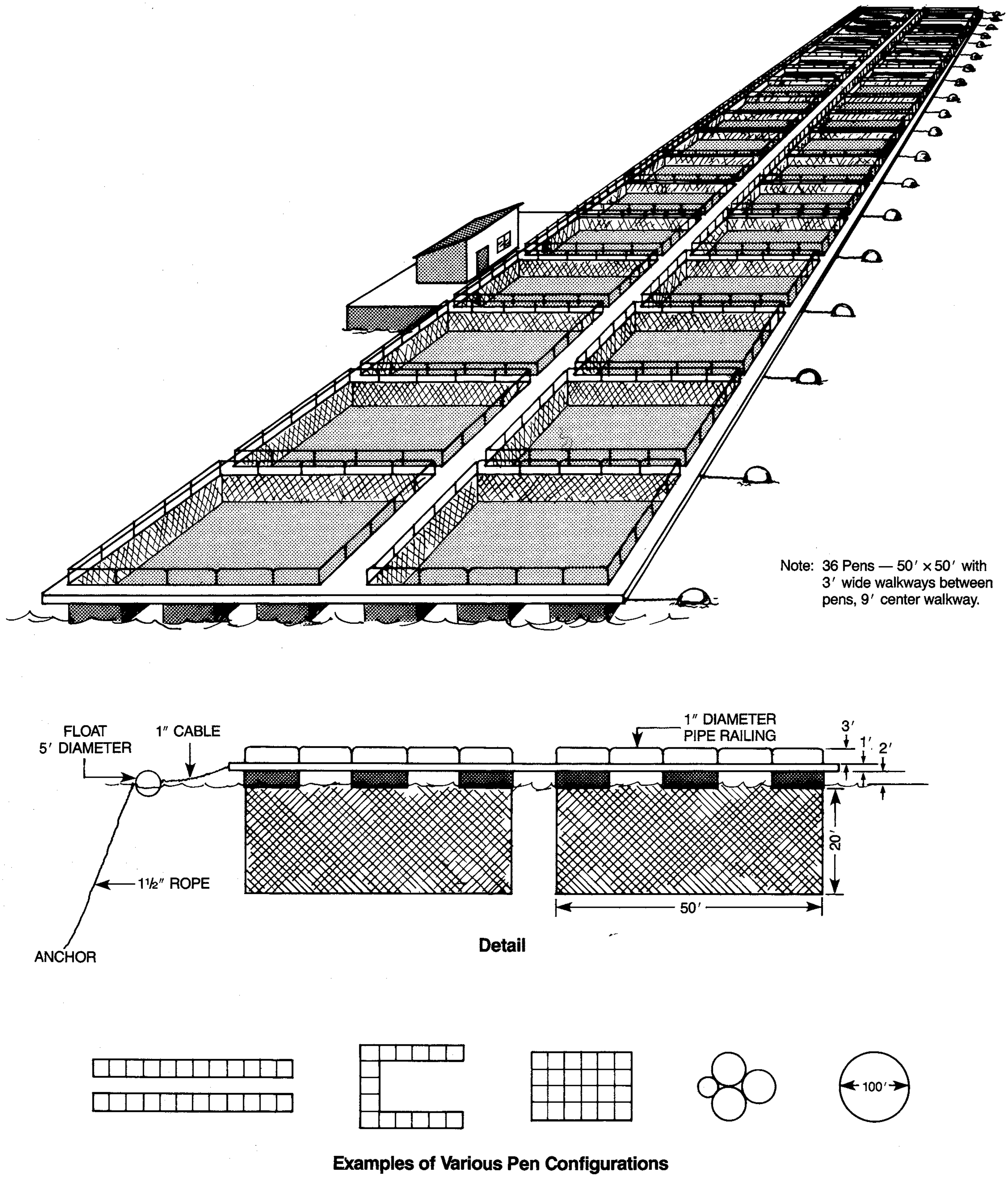


Figure 3.
Example of a Fish Farm and Various Pen Configurations

small fish. A larger mesh perimeter net is used around the farm for protection from potential aquatic predators.

The pens are held in place by a series of anchors, anchor lines, and floats. A short length of cable or rope attaches the pens to a large float from which a long piece of cable, chain, or rope connects each float to a 1,360 to 2,270 kg (3,000-5,000 lb) anchor on the bottom. The floats moderate the effects of weather or tidal currents that may tend to pull the pens down. Although the number and placement of floats and anchors at an individual facility varies by site, anchors are usually placed four times the water depth away from the pen's perimeter. Of the farms currently operating or proposed in Puget Sound, the area typically occupied by the anchors is five to ten times the surface area of the farms.

Most fish farm operations in Puget Sound are located away from shore, necessitating the use of boats. Boats at farms are used to transport personnel, fish, fish food, and all other supplies needed at the site. Boats are typically in the 5 to 11 m (16-36 ft) range with varying amounts of horsepower.

Presently, the predominant species cultured at farms is Atlantic salmon, which have been semi-domesticated and may be stocked at relatively high densities. In Norway, where pen sizes have been limited to 8,000 m^3 to encourage a small cottage industry, pens are stocked to maximum densities that may exceed 40 kg/m^3. In Washington, where larger farms are allowed, fish are stocked at optimal densities for growth and disease prevention. These stocking densities are generally 5 to 7 kg/m^3. Thus, a two-acre farm would produce 225 to 450 MT (metric tons) (500,000-1,000,000 lb) of salmon annually. For the purpose of this EIS, it is assumed the average farm is two acres in surface area and produces 340 metric tons (750,000 lb) of fish per year.

3. LOCATION

The geographical focus of this document is on all marine waters of Washington State from the west end of the Strait of Juan de Fuca, north to the Canadian border, and south to Olympia (see Figure 1). This area includes Hood Canal and all marine bays, harbors, passages, and inlets of the Strait of Juan de Fuca, Strait of Georgia, Admiralty Inlet, and "Puget Sound". Unless otherwise qualified, the term Puget Sound in this document refers to the greater Puget Sound marine area just described.

4. DESCRIPTION OF ALTERNATIVES

The two alternatives evaluated in this FEIS are:

No-Action - Existing Regulations and Guidelines. This alternative evaluates the potential environmental impacts from floating fish farms under the existing regulations and guidelines that affect the fish farming industry in Puget Sound. These regulations include relevant State and federal regulations, local shoreline master programs; and guidelines such as the *Recommended Interim Guidelines for the Management of Salmon Net-Pen Culture in Puget Sound*, and the *Aquaculture Siting Study*.

A brief discussion of some of the permits and approvals necessary for a fish farm proposal is included in Section 4.1. A list of government groups that regulate the fish farming industry are briefly described in Section 4.2, and Table 2 lists the agencies with authority and/or expertise in relation to specific elements of the environment discussed in this FEIS.

Preferred Alternative. This alternative evaluates the impacts of floating fish farms under existing regulations with recommendations for expanded regulations, and additional guidelines and scientific research. This alternative recommends additional measures that should be taken by State agencies and local governments to avoid significant adverse environmental impacts as a result of fish farm development.

4.1 PERMITS AND APPROVALS

While existing rules and regulations form the regulatory framework for the No-Action alternative, they would continue to apply to future development. However, these rules may be modified as the result of this FEIS. A brief summary of the primary regulations affecting fish farm development follows:

***State Environmental Policy Act* (RCW 43.21C, WAC 197-11).** The *State Environmental Policy Act* (SEPA) was implemented to ensure broad consideration of the social and environmental impacts of proposed actions before approval is granted by State or local governments. SEPA requires the lead agency (usually local government in the case of fish farms) to consult with agencies with specific expertise in the environmental issues involved. If a proposal is likely to have significant adverse environmental impacts, then the lead agency shall require preparation of an EIS. Determining that a project has significant adverse impacts does not preclude that project. However, an EIS is required to allow the agency making the decision to be fully informed of the possible environmental consequences of that decision. Most permits issued by State and local governments are subject to SEPA.

***Shoreline Management Act* (RCW 90.58).** The *Shoreline Management Act* (SMA) of 1971 was implemented to assure appropriate and orderly development of the State's shorelines, and provide for State shoreline management by planning for and fostering all reasonable and appropriate uses in a manner that enhances the public interest, protects against adverse environmental impacts, and preserves the natural character of the shorelines.

The SMA was established as a cooperative management program between local governments and the State. Within State guidelines, each local jurisdiction is responsible for developing and administering its own local shoreline master program with goals, policies, and regulations adjusted to fit local conditions. Ecology provides technical assistance, reviews shoreline permits, and approves master program amendments and conditional use and variance permits to ensure that state-wide issues are addressed.

Substantial development activities within the shoreline environment, which are not exempt from shoreline permit requirements, are subject to local shoreline master programs and the SMA. Projects must demonstrate compliance with both local and State regulations through the substantial development permitting process.

Aquatic Lands Lease **(RCW 79.90-.96).** The Department of Natural Resources (DNR) acts as the proprietary manager for State-owned public lands. Aquatic land uses, such as fish farms, require ground leases from DNR. Leases specify location, structural development, operational practices, lease terms, environmental monitoring, rent, and other requirements. Lessees must obtain all local, State, and federal permits.

Hydraulic Project Approval **(HPA) (RCW 75.20.100, WAC 220-120).** All construction projects are subject to approval by WDF or the Department of Wildlife (WDW) to ensure that food fish and shellfish, and their habitats, are protected. Projects must demonstrate that they are designed to provide for the adequate protection of fish life which includes fish habitat.

Finfish Import/Transfer Permits **(WAC 220-77-030).** Under the authority of RCW 75.58, Aquaculture Disease Control, permission is required from the Director of WDF for anyone who wishes to import aquatic organisms into State waters for culture purposes, or transfer these organisms from one area to another. The purpose of this permit is to assure that diseases, pests, or predators are not introduced into State waters. All introductions of new species will be assessed during SEPA review to determine their potential environmental impact.

Waste Discharge Permit **(RCW 90.48).** Any activity discharging waste that may adversely affect water quality must have prior approval from Ecology. Ecology currently requires waste discharge permits for commercial fish farms producing less than 20,000 lbs of fish per year. Also, see *National Pollution Discharge Elimination System* Permit. In addition, Ecology is developing sediment standards for activities in Puget Sound. When implemented, these standards will also apply to fish farms.

***Recommended Interim Guidelines*.** These guidelines were developed by Ecology, DNR, WDF, and WSDA to provide guidance to State and local agencies concerning proper siting of fish farms to avoid significant adverse impacts to the aquatic environment. These *Guidelines* were the best available knowledge of the agencies at the time of publication (1986). Parts of these *Guidelines* may be adopted into Washington Administrative Codes (WACs) as State regulations based on information presented in this FEIS.

***Section 10 Permit*.** The U.S. Army Corps of Engineers (ACOE) reviews projects in State waters for their probable impact on the public interest. Factors that are considered in their review include: general environmental concerns, historic values, economics, conservation, aesthetics, fish and wildlife values, land use, navigation, recreation, water quality, safety, energy needs, and in general, the needs and welfare of the people. As part of the *Section 10* permit review, State agencies and other federal agencies such as the National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), U.S. Coast Guard (USCG), and the Environmental Protection Agency (EPA) also review the permit request.

National Pollution Discharge Elimination System Permit **(NPDES) (40 CFR 122.21).** NPDES permits are required for all point source discharges. The permit system for fish farms will include siting and monitoring requirements to ensure that farms are in compliance with State and federal water quality laws. NPDES permits will be required for all commercial fish farms producing over 20,000 lbs of fish per year. The NPDES permit system is administered in Washington State by Ecology, but EPA issues NPDES permits for federal facilities and Tribal projects on Tribal lands.

4.2 STATE AGENCIES

In addition to the specific regulations, there are a number of different State, federal, and local agencies involved with regulating the fish farm industry. A brief description of these agencies follows:

Department of Fisheries. It is the responsibility of WDF to preserve, protect, perpetuate, and manage the food fish and shellfish in the waters of the State (RCW 75.08). This jurisdiction includes all species taken commercially and recreationally from marine waters, except for steelhead and cutthroat trout, which are managed by WDW. In addition, WDF is responsible for disease control and prevention for all aquatic organisms cultured commercially, and registration and maintenance of statistics on the aquaculture industry.

Department of Natural Resources. DNR acts as the proprietary manager for State-owned aquatic lands. These lands are managed for a balance of public benefits including environmental quality, public access, water-dependent uses, renewable resources, and revenue (RCW 79.90.455). In addition, DNR is charged with fostering the commercial and recreational use of the aquatic environment for the production of food, fiber, income, and public enjoyment (RCW 79.68.080).

Department of Ecology. Ecology was created in 1970 as the central State agency concerned with protection of the environment. It consolidated the regulatory programs involving air and water resources, with the influx of environmental legislation in the early 1970s, such as the *State Environmental Policy Act* and the *Shoreline Management Act*. In addition, Ecology is responsible for planning for the accommodation of competing interests in the use of these resources. Ecology is the primary agency responsible for controlling pollution, ensuring water quality standards are maintained, and enforcement of federal and State environmental laws.

Department of Wildlife. While WDW has no direct management function related to fish farms, they are responsible for managing and protecting game fish and animals including steelhead and cutthroat trout, marine mammals, and birds. WDW reviews proposed projects through SEPA, SMA, and the ACOE Section 10 permitting process. They may also require permits for planting, holding, and importation of steelhead or other game fish, except when used in aquaculture operations.

Washington Parks and Recreation Commission. The Washington Parks and Recreation Commission (WPRC) does not issue permits for aquaculture activities, but does review project proposals. WPRC administers many of the public parks along the shores of Puget Sound for recreation and protection of scenic and natural attractions. The WPRC specifically reviews projects via SEPA and the SMA for compatibility with boating and other recreational activities.

Department of Agriculture. WSDA prohibits the sale of fish which are decomposed or contain antibiotic residues (RCW 69.04). WSDA does not issue permits, but is responsible under RCW 15.85 for fostering the development of the State's aquaculture industry and providing market assistance. WSDA jointly developed disease control and prevention rules with WDF.

Puget Sound Water Quality Authority. The Washington State Legislature established the Puget Sound Water Quality Authority (PSWQA) in 1985 in recognition that Puget Sound is a "unique and unparalleled resource" and that its utilization carries a "custodial obligation for preserving it" (RCW 90.70.001). The Legislature charged this agency with preparing the *Puget Sound Water Quality Management Plan*, to be implemented by existing State and local government agencies. The Puget Sound plan was originally adopted in December 1986 and was recently revised and adopted in October 1988. While this plan imposes no additional permitting requirements on floating fish farms or other aquaculture facilities, State agencies, and local governments are required to carry out their own statutory mandates in a manner consistent with the plan. The goal of the plan is to prevent increases in the introduction of pollutants to the Sound and its watersheds and to reduce and ultimately eliminate harm from the entry of pollutants to the waters, sediments, and shorelines of Puget Sound.

4.3 LOCAL GOVERNMENT

Local governments review fish farm proposals through SEPA and local shoreline master programs. Any upland portion of a proposal would be reviewed under the existing zoning and building codes, comprehensive plans, and other regulations. See Section 8, Relationship to Land Use Plans and Regulations, for a further discussion of existing plans and regulations pertaining to local governments.

4.4 FEDERAL AGENCIES

Federal involvement in regulating and permitting fish farms is initiated through the ACOE Section 10 permitting process. If a federal permit is required, review of the project by other federal agencies is required under the *National Environmental Policy Act* (Public Law 91-190) and the *Fish and Wildlife Coordination Act* (16 USC Sec. 661).

U.S. Army Corps of Engineers. ACOE administers the Section 10 and Section 404 federal permitting programs. Permits are required under Section 10 of the *Harbors and Rivers Act* of 1899 (33 USC 403) for any activity that may affect navigation, and under Section 404 of the *Federal Water Pollution Control Act* (33 USC 1251) for any activity that discharges materials.

U.S. Fish and Wildlife Service. USFWS reviews ACOE permits and makes recommendations to ensure that the proposed projects are compatible with protection of freshwater and anadromous fish, marine fish, shellfish, marine birds and mammals, and their habitats.

National Marine Fisheries Service. NMFS also reviews ACOE permits to assure protection of marine mammals and fish.

Environmental Protection Agency. EPA is responsible for overall protection of the nation's water quality. EPA oversees Ecology's administration of the NPDES permit program, and issues NPDES permits for federal projects and tribal projects on tribal lands.

Food and Drug Administration. The Food and Drug Administration (FDA) is responsible for ensuring the safety and quality of food entering interstate commerce. Consequently, they are responsible for approving any chemicals, such as antibiotics used in fish farm operations.

U.S. Coast Guard. The USCG reviews ACOE permits to ensure fish farm proposals will not be a hazard to navigation. The USCG may require the farmer to supply aids to navigation to help achieve that goal.

sediments ranging from fine silts to rock cobble in environments with very little available nutrients to those that have substantial added organic material (Lie 1968). The type of community will depend upon the interaction of these two components. In some areas, the type of sediment can vary over a few meters, yielding several different benthic assemblages in a relatively small geographic area (Shimek 1983).

Habitats. The marine habitats potentially affected by fish farms are generally close to shorelines in relatively shallow-water. Depending upon physical conditions, each of these habitats can support a range of biological communities (known as assemblages) of animals and plants. Areas affected by fish farms could contain examples of virtually every shallow marine benthic community found in the greater Puget Sound region. Generally, these areas contain a mosaic of at least several assemblages. Although these communities have often been described in the technical and popular literature, specific ecological relationships within most of them are poorly understood.

The following is a general description of these habitats:

Soft Substrates. Clay and silt together with variable quantities of sand, gravel, and shell fragments form unconsolidated or "soft" sediments. This general substrate type is typical of most of the flatter portions of Puget Sound. It is inhabited by a wide variety of marine invertebrates. Although shallow portions (less than 15 m [50 ft] MLLW) may have eelgrass (*Zostera marina*), the deeper areas do not typically have aquatic vegetation growing on these soft substrates. A large variety of macro-invertebrates and fishes also live in these areas.

The invertebrates that live within the surface layer of soft sediments are generally of three major groups: polychaete worms, bivalve molluscs, or crustaceans. These groups include many different forms and sizes of organisms ranging from microscopic crustacea and worms to the geoduck clam (*Panope abrupta*). Most of these invertebrates are important to society because they provide the food sources that support many of the economically important fish, crab, and shrimp harvested in Puget Sound.

The small invertebrates that live on and within the soft substrates feed by filtering particles of organisms from the overlying water (suspension feeders), or by collecting organic material from the sediment (deposit feeders). Both require organic material and some oxygen in either the overlying water or the interstitial water (water in the pores of the sediment). Thus they may benefit from additions of organic material or be eliminated by large quantities of organic sediment. The types of organisms present and their relative numbers are determined by historical factors and ecological interactions (Birkeland 1974; Woodin 1974) in addition to organic concentrations.

Soft substrates are also commonly inhabited by a variety of large, mobile invertebrates that include primarily shrimp and crabs. Although crabs and shrimp may burrow into sediments, they move on the surface for feeding and reproduction. Some species undergo daily or seasonal migrations of considerable distances (hundreds of meters to kilometers). The shrimps include the spot prawn (*Pandalus platycerous*), coonstripe shrimp (*P. danae*), and the sidestripe shrimp (*Pandalopsis dispar*) which are harvested by commercial and recreational fishers. The economically important Dungeness crab (*Cancer magister*) and other species are found throughout Puget Sound on soft substrates.

Several other invertebrates also inhabit soft substrates. These include organisms such as sea pens (*Ptilosarcus gurneyi*), heart urchins (*Brisaster latifrons*), and many members of other taxonomic groups that are not of direct economic importance but which form basic parts of benthic communities.

Many fishes, including flatfish and cod, feed in these soft bottom areas on the invertebrates described above. The potential effect of fish farms on these fish are discussed in Section 5.5, Fish and Shellfish.

Hard Substrates. Gravel, cobble, and rock substrate occur in Puget Sound in areas of relatively high current velocity and/or steep slopes. In general, these substrate types occur in areas not particularly suited to fish farms. Some of the areas considered for fish farms might have hard-packed sand or gravel substrates or other hard substrates nearby.

Hard substrates support a different group of organisms than the soft substrates. Generally, these substrates are populated by organisms that live on the surface or in crevices in the surface. They include sea cucumbers, sea urchins, anemones, snails, abalone, chitons, barnacles, and many other invertebrates. Both the pink scallops (*Chlamys hastata*) and the rock scallop (*Hinnites giganteus*) are common in such areas.

Kelp such as the bull kelp (*Nereocystis luetkeana*) occur only in hard substrate areas. Many varieties of kelp provide food sources, reproductive sites, and refuge for a wide variety of invertebrates and fishes. Herring commonly spawn on some of these algae as well as on eelgrass. Most of the kelp are found in relatively shallow water, few occur deeper than 30 m (100 ft) in the north Pacific region. In Puget Sound, most occur in areas no deeper than 15-20 m (50-66 ft).

5.1.2 Impacts of Fish Farms on Benthic Communities

The following are factors that determine the impacts of fish farm on the bottom sediments and benthos:

- **Loading**. The poundage of fish reared in the farm is proportional to the amount of organic matter deposited from the farm. The greater the density of fish, the more concentrated the deposition of organic waste.
- **Pen size**. In comparing two different size farms with the same amount of loading, the larger farm will deposit sediments over a proportionally smaller area than the smaller farm (Earll et al. 1984).
- **Water depth and current velocity**. In deeper water and faster currents, the dispersion of wastes will be greater.
- **Pen configuration**. Pen configuration and orientation to the predominant currents can significantly affect the dispersion of wastes (Fox 1988, see Appendix B).
- **Bottom current velocity**. High bottom current velocities can erode and disperse sediments regardless of dispersion in the total water column.
- **Feed type**. Different feeds have different settling rates. Slower rates allow greater dispersion. In addition, feed that has lower carbon and nitrogen levels and higher digestibility will produce less organic matter on the bottom.
- **Feeding method**. Feeding methods can affect both wastage of feed and utilization of that feed by the fish. In one study, hand feeding resulted in 3.6% wastage, and up to 27.0 $g/m^2/day$ organic matter deposition on the bottom. The use of automatic feeders resulted in wastage of 8.8% and a maximum deposition of 88.1 $g/m^2/day$ (Cross 1988).
- **Bottom sediments and community**. The benthic community will also affect the impact. Areas of high biological productivity can assimilate higher organic deposition. However, adverse impacts may have greater significance due to the importance of such productive areas.

Sedimentation effects are the result of two major factors, additional particulate organic input from uneaten food and fish feces, and inorganic sediment deposition. Another source of sedimentation is organic matter that grows on nets and is dislodged from the net during cleaning. This source contributes relatively little to the total sedimentation generated by a fish farm operation (Weston 1986). The organic input from these sources affects both the chemical composition of the sediments and the responses of the organisms in the sediment (Pearson and Rosenberg 1978). However, due to lack of knowledge and the diversity and variability of habitats, qualitative predictions can be made, but predictive quantification of responses in the benthic community is impossible.

Particulate Organic Input - Uneaten Food. A typical fish farm producing 340 metric tons (748,000 lbs) of fish annually will utilize 340 to 680 metric tons (748,000-1,496,000 lbs) of food. Fish are fed a variety of foods, ranging from minced fish, to semi-moist pellets of minced fish and various binders, to dry pellets. Semi-moist or dry pellets are used exclusively in Puget Sound fish farms and consist of a combination of fish meal and vegetable matter, mixed with vitamins and other organic material. If the fish become diseased during culture, antibiotics may be added to the feed for treatment.

Fish farmers measure the effectiveness of their feeding by calculating a food conversion ratio (FCR). An FCR is the ratio of food fed (dry weight) to fish produced (wet weight). Typically, average FCRs range from 1:1 to 2:1. That is, for every pound of fish produced, 1 to 2 lbs of feed were introduced into the water. The amount of food used depends primarily upon the type of food used, the size of the fish, and the water temperature. It may be assumed that fish feed includes about 7.7% nitrogen (Edwards 1978) and 44% organic carbon (Gowen and Bradbury 1987). A major research goal for the fish farming industry is to develop lower-cost food that provides maximal digestibility and food conversion, and minimal environmental impacts. Because of this research, there has been a steady decline in the FCR values. In some laboratory experiments, FCRs of less than 1:1 have been achieved, and most fish farmers now claim values between 1 and 1.5.

Even with the best FCRs, a portion of fish food is not eaten and settles to the bottom. Food wastage has proven difficult to determine in field conditions. However, several studies in Europe have suggested that a range of 1-30% of the feed may be lost (Gowen et al. 1985; Pencsak et al. 1982). Dry food consistently showed the least amount of wastage (1-5%) while 5-10% of moist fish foods were lost (Gowen and Bradbury 1987). In Puget Sound farms, fish growers report that food wastage is typically less than 5% (Weston 1986). Specific studies of food wastage at a commercial (chinook) salmon farm in Sooke Inlet, B.C., showed that hand feeding, the most common practice in Puget Sound, resulted in wastage of 3.6%. The use of automatic feeders increased wastage to 8.8% (Cross 1988).

Since food pellets do not decompose appreciably as they settle to the bottom, their nitrogen and carbon is unlikely to be reduced either through solution or microbial activity, before depositing on the bottom (Collins 1983, in Gowen and Bradbury 1987). Thus, any food particles or pellets lost during feeding will retain their nutrients essentially unaltered. Development of slower settling food, which is available to the fish in the farm for longer periods, and food with more uniform size have reduced wastage. However, the amount of wastage is still highly dependent upon the care used by the fish farmer during feeding.

Particulate Organic Input - Fish Feces. Of the food consumed, about 26% is lost as feces (Butz and Vens-Capell 1982). Fish feces are smaller and less uniform in size than food pellets. Consequently, the settling rate of these particles will vary greatly, but will be less than that of food pellets. The composition of the feces depend on the chemical composition of the food and its digestibility. Gowen and Bradbury (1987) estimated from the literature that about 30% of the consumed carbon would be excreted in the feces, along with about 10% of the consumed nitrogen.

From the information presented in the above paragraphs, estimates of the total particulate matter emanating from fish farms, for eventual deposit on the sea bed, have been calculated. Weston (1986), assuming a FCR of 2 with 5% wastage and one-third of the consumed food being lost as feces, estimated that 733 kg (1,600 lbs) of sediment would be produced for every metric ton (2,200 lbs) of fish grown. The Institute of Aquaculture (1988) estimated sediment production of 820 kg (1,800 lbs), assuming 20% wastage and 30% feces loss.

Review of these calculations indicate that they are very sensitive to changes in the FCR and wastage rate, factors over which the grower has some control through his selection of feeds and feeding procedures. Reducing the FCR from 2 to 1.5 (which may better represent current practice) would reduce the total sediment production by 25%. Using the Institute of Aquaculture's estimate of sediment production as one extreme, the total sediment production from one typical, 340-metric-ton farm would be 279 metric tons (307 tons) annually. Assuming a FCR of 1.5 and 5% wastage, sediment production could be reduced by 40% to 171 metric tons (188 tons). Organic carbon introduced to the sediments range from 84 to 51 metric tons (92-56 tons) and nitrogen would range from 11 to 7 metric tons (12-8 tons) with 81% of the carbon and 71% of the nitrogen coming from the feces.

<u>Organic Enrichment of the Benthos</u>. Pearson and Rosenberg (1978) present a very comprehensive review of the impacts of organic enrichment on bottom sediments and the associated benthic community. Sources of this enrichment include deposits of natural organic matter from seaweed or from terrestrial sources, and organic matter introduced from human activities, such as sewage, pulpmill effluent, and sediment from log storage.

Organic sediments affect the seabed and benthos by two mechanisms. One is the physical effect of the continual deposition of organic or inorganic fine particles. At high rates, these may clog the filtering apparatus of filter-feeding organisms such as clams. At low sediment rates, the organic matter may provide an additional food source for these animals. However, at higher rates the energy cost to clean the filtering apparatus can exceed the energy derived. At very high rates, these animals may actually be buried.

Sedimentation from fish farms decreases benthic sediment oxygen levels by increasing the demand for oxygen, and by decreasing both diffusion and water flow into the interstitial spaces of the sediment. As increasing amounts of fine sediment accumulate, the depth to which oxygen penetrates is reduced, and the underlying sediment layers become devoid of oxygen (anoxic) and unable to support animal life. The only organisms found in such sediments will be those that have access to the surface waters for respiration via burrows or siphons, and anaerobic bacteria, which can utilize organic material in the absence of oxygen.

Chemical change due to organic enrichment is the other major mechanism affecting the benthos. As previously discussed, fish food and feces are high in organic carbon and nitrogen. At low levels of nutrient enrichment, these particles may enhance the abundance of the established benthic community by providing an additional food or energy source for deposit- and filter-feeding organisms and for scavengers. At higher rates of deposition, organic matter will accumulate on the substrate surface and be subject to biological decomposition by bacteria and chemical decomposition. Both processes, along with respiration by infaunal animals, consume oxygen. Consequently, oxygen available for exchange into the sub-surface sediments is reduced.

<u>Oxygen Depletion of the Benthos</u>. In undisturbed sediments, oxygen is only able to penetrate a short distance. How far oxygen may penetrate in undisturbed sediments depends upon sediment porosity, the presence of burrowing organisms, and current velocity, which controls the rate at which oxygen is renewed at the sediment surface. Oxygenated sediments are typically light tan to light grey. Below this oxic layer, sediments are oxygen depleted (anoxic). Anoxic sediments are

characterized by their dark black color, and the distinct aroma of hydrogen sulphide. As the amount of organic enrichment and sedimentation increase, the anoxic layer moves closer to the surface. In areas of high organic deposition, the anoxic layer will reach the sediment surface, coloring it black. In these cases, the organic material often forms a layer over the original sediments. In stagnant areas of poor circulation, oxygen demand by the anoxic sediments will reduce the dissolved oxygen in the overlying water. Anaerobic decomposition of the organic matter under these conditions may lead to production of methane in sufficient quantities to produce visible bubbles at the surface. At this point hydrogen sulfide (H_2S) will reach concentrations that allow its distinctive "rotten egg" smell to be detected in the water. H_2S is highly toxic, making these sediments toxic, and at higher concentrations can lead to mortality of the fish in the fish farm.

Determination of Benthic Organic Enrichment. Several methods are used by researchers to quantify organic enrichment. The most direct methods of measuring enrichment are to collect bottom sediment samples and analyze these for various nutrients. Since organic carbon controls the productivity of the benthic community, increases in total organic carbon (TOC) result in increased oxygen consumption. Levels of nutrients, nitrogen compounds and phosphates, and sulfides are useful indicators of enrichment, and can be measured chemically in sediment samples. Benthic oxygen consumption is a direct measure of the oxygen demand by respiration and chemical decomposition of the sediments. Benthic oxygen demand is expressed as milliliters of oxygen consumed per square meter per hour (mL $O_2/m^2/hr$).

Another method for assessing the impact of organic deposition is the reduction oxidation (redox) potential. The redox potential measures sediment oxygen content at different depths to determine the depth of the boundary between aerobic and anaerobic sediments. At this point (the redox potential discontinuity or RPD), oxygen consumption by the decomposing material is in equilibrium with the oxygen supply from surface waters. In enriched sediments, the RPD moves closer to the surface and the depth of this boundary can be used as an estimate of organic enrichment (Pearson and Stanley 1979).

The redox potential (positive = oxic; negative = anoxic) gives a relative indication of the degree of enrichment. Pearson and Stanley (1979) used the redox potential measured at 40 mm to characterize the degree of enrichment and relate these to changes in the benthic community. In a study around an alginate factory discharge, the redox potentials of undisturbed sediments were typically 300 to 400 mV while potentials less than -150 mV corresponded to anoxic sediments devoid of animals. Potentials between -150 and 200 mV were sediments dominated by opportunistic species and potentials of 200 to 300 mV were "transitional" or enhanced. The specific values for a particular habitat will largely depend upon the sediment particle size. Weston and Gowen (1988) recommend use of redox potential in soft sediments to measure enrichment impacts beneath fish farms because it is effective, relatively inexpensive, and can be conducted in the field. They caution that in fine sediments (mud) the RPD is so close to the surface that the probes used for measurement could not reliably measure the variations in redox potential.

In addition, visual observations provide indications of the area affected by enrichment. Food pellets are readily detectable, and feces produce a flocculent deposit. Sediment color also changes with enrichment. In addition to the normal oxic light grey, and the highly enriched anoxic black, intermediately enriched sediments may show areas of orange or red. A common indicator of enrichment is the filamentous, sulphide-reducing bacteria, *Beggiatoa*. *Beggiatoa* is commonly found in dense whitish mats on surface sediments or decomposing plant material. It grows in the presence of oxygen and H_2S, and is thus found in the transition zone between oxic and anoxic sediments (Jorgensen 1977).

Changes in the Benthos due to Organic Enrichment. Pearson and Rosenberg (1978) related general changes in the benthic communities as the result of increasing organic enrichment (Figure 4). The figure does not provide units of measure for the organic enrichment because the level at which these changes occur is highly dependent upon the nature of the benthic community affected. The following discussion follows the progression of changes as an observer proceeds from an affected environment to the fish farm. It must be noted that transitions from one zone to another occur along a continuum, generally with no clear boundaries. Depending upon the amount of organic material deposited and the existing benthic community, the more affected zones may or may not be present under any specific pen.

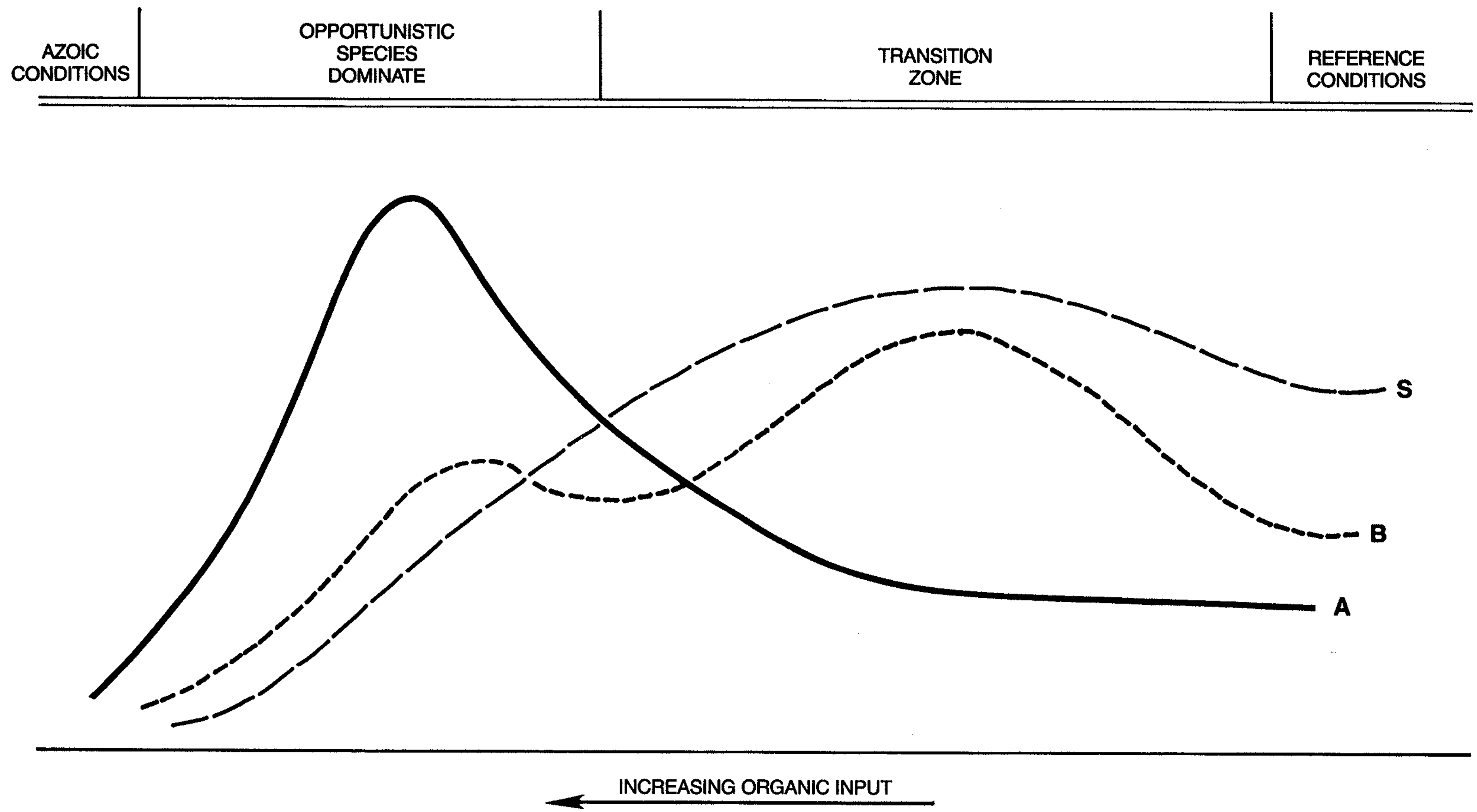
A stable, diverse benthic community comprised of filter-and sediment-feeding organisms and predators exists in undisturbed sediments. Many of these animals are large and live in the sediment. As organic matter is introduced into an undisturbed environment, it provides an additional source of nutrition for the benthic organisms. This additional organic matter benefits the existing filter- and deposit-feeders, and encourages colonization by additional species. Thus, both species diversity and biomass (total weight) of the benthic organisms increase, and the benthic community is enhanced. Pearson and Rosenberg (1978) refer to this as the "transition zone."

Pearson and Rosenberg (1978) observed that as the level of organic input increases, the normal community changes as many species, especially filter feeders, are displaced. The sediments become progressively dominated by various opportunistic deposit feeders, which flourish under these conditions. The most notable deposit feeder is the small, common polychaete worm *Capitella capitata*, indicative of organic enrichment. Under these conditions, the abundance of these opportunistic species can reach very high densities, to the exclusion of other species. Elimination of the larger, deeper borrowing animals further reduces the ability of oxygen to penetrate the sediments. Thus, while the number of organisms increases dramatically, the diversity of species declines (Figure 4).

At higher rates of sedimentation, even the opportunists cannot survive. At this point, the anoxic layer reaches the sediment surface, depriving the animals of oxygen and exposing them to toxic H_2S. In these sediments, the surface is black and devoid of any animals (azoic). Methane and toxic H_2S are produced and escape as bubbles into the water. Gowen et al. (1988) estimated that input of organic matter at rates greater than about 8 g carbon/m^2/day resulted in the production of methane and azoic conditions. At low concentrations, H_2S can reduce fish health through gill damage and at higher concentrations be toxic to fish in the farm above the sediments (Braaten et al. 1983). Such effects have only been reported in stagnant areas with little water circulation.

Azoic zones (zones devoid of any animals) are reported under most fish farms, except those in areas of depth greater than about 60 ft and/or high currents and the affected area is limited to that immediately below the farm (Weston 1986). Earll et al. (1984) found dark, black sediments under most fish farms observed. This zone was usually demarcated by a "halo" of dense *Beggiatoa* mats, which covered and stabilized the underlying sediments. The absence of *Beggiatoa* under the farm was attributed to its need for both oxygen from surface water and H_2S from the anoxic sediments. In areas of poor water circulation, the water immediately above the substrate may become anoxic, precluding *Beggiatoa* growth. No live animals were observed in this zone, although occasional dead starfish, nudibranchs, and sea cucumbers were observed on the surface. Gas bubbles (methane) were evident in the sediment and redox potentials were severely depressed. Stewart (1984) observed these conditions to extend to about 3 m (10 ft) from the farm perimeter.

Examples of Benthic Impacts - Scotland. Earll et al. (1984) observed benthic conditions below 25 fish farms facilities in Scotland located in



Source: Pearson and Rosenberg 1978

S Number of Species

B Biomass

A Total Macrofaunal Abundance

Figure 4.
Generalized Trends in Organism Diversity

relatively shallow water (mean depth 9.5 m). He noted that the redox potentials were reduced within a distance of 20-30 m (66-99 ft) from the farm and that *Beggiatoa* first appeared 10-15 m (33-49 ft) from the pen perimeter. Outside this zone, the sediment surface appeared normal and was light brown with a thin covering of diatoms. Predator species such as crab, flatfish, nudibranchs, and anenomes were abundant. Scallops, starfish, and sea cucumbers were also observed. Stewart (1984) noted that organic loading, carbon:nitrogen ratios, and redox potentials were essentially normal beyond 40 m (131 ft) of a pen site. He concluded that the transition zone extended 37-100 m (121-328 ft) from the farm.

High species abundance and diversity, representing both pre-existing species and newly colonized species, were found in a zone 15-120 m (49-393 ft) from farm by Brown et al. (1987). Gowen et al. (1988) observed that total organic carbon, redox potentials, and dissolved oxygen levels were normal beyond 15 m (49 ft) of the farm. He also found that opportunistic species dominated the zone between 15 and 120 m (49-393 ft), with the inner boundary of the transition zone being 20-25 m (66-82 ft) from the farm boundary.

Gowen et al. (1988) reported an azoic zone extending 3 m (10 ft) from the farm. In this zone, total organic carbon levels are about twice background levels and redox potentials were consistently less than -100 mV, despite seasonal variations. Dissolved oxygen in the overlying water was reduced and gas bubbles were observed. Hall and Holby (1986) measured chemical changes below a small fish farm. Both total organic carbon and nitrogen concentrations were increased ten-fold above background levels, and benthic oxygen consumption was increased 12 to 15 times. Deposition under these farm was 50 to 200 $g/m^2/day$ total solids, about 20 times higher than background.

<u>**Examples of Benthic Impacts - Washington**</u>. In studies conducted at Clam Bay, Kitsap County, Weston and Gowen (1988) estimated that normal benthic communities extended to within 150-450 m (492-1,475 ft) of the farm. This site is of one of the world's largest fish pen facilities and has been in operation for 17 years. Other observations at the same site (Pease 1986) noted an increased abundance of geoducks in the area, and abundant congregations of anemones near the farm wherever objects provided solid substrate for attachment. They noted that in rocky areas having stronger currents, this zone apparently extended to the boundary of the farm. The only deposits of food occurred in the lee of protruding rocks. Elsewhere, the rocks were almost totally covered with anenomes, and kelp was also abundant. Mobile predators are also abundant in this area, including flat fish (Pease 1988) and crab (Cross 1988). Weston and Gowen (1988) concluded that changes in the biological community extended beyond the zone where chemical changes were detectable. This observation indicates the increased biota consumes the organic matter, not allowing it to accumulate.

Gowen et al. (1988), and Brown et al. (1987) observed that the area between 3 and 15 m (10-50 ft) was almost exclusively dominated by opportunistic polychaete worms, especially *C. capitata*. The total number of species in this zone was about 20% of that in undisturbed sediments. However, the number of individuals was 2 to 3 times normal with total biomass slightly below normal. All of the organisms were polychaete worms, with *C. capitata* representing 80% of the total organisms. Gowen et al. (1988) observed that the total organic carbon was slightly elevated while the redox potentials at 40 mm were near zero. Dissolved oxygen in the overlying water was not affected. Seasonal changes were observed, with increased effects being noted during the summer. The authors concluded these severely disturbed conditions existed when the rate of organic loading exceeded 1.8 to 4 $gC/m^2/day$. It was estimated that the total area affected below this fish farm (540 m^{2-}) was 6,000 m^2. Similar observations from studies of pulp mill and sewage treatment plant discharges reported an affected area of 5 to 23 km^2.

Earll et al. (1984) observed that redox potentials were depressed within 20-30 m (66-98 ft) of the farm. Sediments were brown to grey without the diatom covering noted outside this zone. The inner boundary was frequently indicated by a mat of *Beggiatoa*. The only large organisms observed in this zone were occasional anemones and small crab and fish which foraged into the area. The presence of anemones was explained by their ability to extend above the sediments into unaffected water. Stewart (1984) concluded that this zone extended from 3-37 m from the farm. This relative smooth zone did not have mounds and burrows typical of animal activity in undisturbed sediments (Institute of Aquaculture 1986).

Weston and Gowen (1988) observed increased concentrations of carbon and nitrogen, and reduced redox potentials between 15 and 60 m (50 and 200 ft) down current (east) from fish farms at Clam Bay. These changes extended only 15 m (50 ft) to the south, and 30 m (100 ft) to the northwest. Redox potentials in undisturbed sediments were about 350 mV at the sediment-water interface and 250 to 300 mV (millivolt) at 40 mm depth. Redox potentials remained positive to within 30 m down current. Up current, these potentials were positive to the pen perimeter.

The abundance of organisms was approximately 4 times greater than background at the farm perimeter and declined to background levels at about 45 m, with *C. capitata* the dominant species. Biomass was reduced to about 45 m and increased moderately between 90 and 150 m. Normal conditions were reached between 150 and 450 m from the farm. Pease (1984) reported that geoduck abundance increased in this area away from the farm. No geoducks were found in the area occupied by *Beggiatoa*. However, in a more recently developed site in British Columbia, geoducks were observed within the more distant area occupied by *Beggiatoa* (Cross 1988).

An azoic zone has been observed beneath the fish farm complex at Clam Bay (Weston and Gowen 1988; Pease 1984). Pamatmat et al. (1973) conducted an extensive study of benthic oxygen consumption (BOC) in Puget Sound. Typical BOC for Puget Sound sediments was 4 to 56 mL $O_2/m^2/hr$. Under one fish farm complex, BOC averaged 125 mL $O_2/m^2/hr$. Pease (1984) observed that the area under the farm was completely covered by *Beggiatoa* and food particles, overlying a layer of black sediment 1 to 2 inches deep. Under this layer, was a substrate suitable for geoducks, which are abundant in the area. However, no geoducks were observed under the farm. The covering mat of *Beggiatoa*, unlike the bare sediment reported by Earll et al. (1984), suggests that the current velocities over the sediments are strong enough to maintain sufficient dissolved oxygen levels near the sediment surface for bacterial growth.

Weston and Gowen (1988) (see Appendix A) found the greatest benthic impacts in the direction of the dominant current. Sediment traps under the farm estimated deposition of 52.1 kg dry wt./m^2/yr and 29.7 kg dry wt./m^2/yr at the farm perimeter. This deposition equates to 36.4 and 9.9 kg carbon/m^2/day, respectively. According to Gowen et al. (1988), this enrichment rate should result in methane gas and H_2S production that would affect oxygen levels in the water. However, Weston and Gowen (1988) reported no measured effect on dissolved oxygen.

The redox potential at the southeast corner was strongly negative at 15 m (50 ft) downstream at both the sediment surface and at 40 mm. Under the pens, toward the upcurrent end of the farm, redox potentials were still positive at the surface. These potentials corresponded with the pattern of enrichment shown by carbon and nitrogen, with the greatest enrichment occurring at the eastern end of the complex.

Not all fish farms will have an associated azoic zone. Weston and Gowen (1988) also observed a small (20 metric tons [22 tons]) pen complex near Squaxin Island. This complex is located in only about 10 m (33 ft) of water, yet no significant chemical changes were observed. Increased numbers of opportunistic species were observed, indicating that biological changes were beginning. The impacts of the farm may have been limited by their recent operation (18 months) and/or the relatively high current velocities over a relatively smooth bottom which may tend to disperse deposited matter. Maximum currents were 31 cm/sec and 23 cm/sec measured at two nearby locations. Currents greater than 24 cm/sec have been observed to scour waste from fish tanks (Institute of Aquaculture 1988).

Duration of Organic Enrichment Impacts. The effects of organic enrichment of the sediments begins quickly after installation and operation of the fish farm. Weston and Gowen (1988) observed only limited changes in the community at the Squaxin Island site after 18 months of operation. Recovery of affected benthic communities may take months or years. However, the benthic sediment chemistry appears to recover to normal levels relatively rapidly. In Puget Sound, Pamatmat et al. (1973) observed normal benthic oxygen consumption 2 months after pen removal. Dixon (1986) noted that bottom sediments appeared normal at two pen sites in the Shetland Island, 12 months after removal of the farm. Biological recovery may take longer depending on the successional colonization of the area by different species and normal recruitment cycles (Pearson and Rosenberg 1978). Species abundance will recover more quickly than biomass due to the growth rates of the larger animals. Rosenberg (1976) observed that the recovery of the area surrounding a pulp mill discharged required three to eight years to recover.

5.1.2.1 Modeling of Benthic Impacts

General. While the previous information describes the types of impacts that have occurred at various farm sites, they do not allow prediction of sediment impacts at a specific site. Weston (1986) concluded that the primary factors determining the probable pattern of sediment enrichment were current velocity, water depth, and loading (pounds of fish).

Weston (1986) reviewed several sediment models and concluded that none were adequate to predict the fate of particles deposited from a fish farm. As part of a multi-year study of fish farm impacts in Scotland, Gowen et al. (1988) presents a conceptually simple model that divides a farm into 1-meter squares and calculates where particles of food and feces from each square will accumulate on the sea bed after several tidal cycles. Tests of the model at six relatively small (672-2460 m^2) fish farms in Scotland showed good correlation between predicted and observed redox potentials at all six farms. Predictions correlated with species diversity in 4 of 5 farms. Weston and Gowen (1988) also tested this model at two farm sites in Puget Sound -- a very large (14,560 m^2) farm at Clam Bay, Kitsap County and a 1184 m^2 farm at Squaxin Island. Again, predicted redox potentials correlated well with observed values at both farms. Measured carbon levels correlated well with predicted values at Clam Bay. Possible resuspension of sediments at Squaxin Island, the short time of operation (18 months), and problems with the use of sediment traps may explain the lack of significant correlation at the Squaxin Island site, where the model estimated a greater impact than was observed.

In general, the model has proven a good predictor of general sediment impacts at farm sites, despite its inherent limitations. The model's limitations include using only single settling velocities for excess feed and for feces, not allowing for turbulence or changes in current velocity and direction at depth, and assuming a level bottom below the farm. In addition, the model must rely on assumed data for feed wastage. However, the model's ability to evaluate the effects of different pen sizes and configurations in different siting conditions makes it valuable for predicting sediment impacts, for selecting suitable sites, and for optimizing the deployment of farms (Gowen et al. 1988). See Appendices A and B for further discussions of this model and comparison with other models.

<u>Methods For Minimizing Impact</u>. Potential methods of minimizing impacts to benthic communities can be classified as either technological or siting methods.

Technological methods that minimize impacts to the benthos below farms include vacuuming the sediments under the farm, "diapers" under the pens, and blowers. Vacuuming under the pens on an annual basis, for example, could remove wastes that accumulate under the farm. However, the vacuuming process would likely remove more than just the farm waste, and would probably have an impact on the benthic community. A system of tarps under the farm to collect wastes could also be used to reduce the potential impact to benthic communities. This technology is relatively unproven though some sites in Europe have used it with mixed success (Braaten et al. 1983). There are problems associated with upland disposal of the farm waste from a collection system. The waste collected in a "diaper" system would have to be dewatered before disposing in a landfill, and the salt content in the waste would have to be removed to avoid water quality problems at the landfill. A system of blowers beneath the farm could be used to increase dispersion of the waste. This technology is also unproven, but could probably be used in areas with marginal circulation. If the blowers failed, waste from the farm could have an impact on benthic communities. Siting farms in areas of sufficient tidal currents would achieve the same effect as blowers.

Siting methods to reduce potential impacts to the benthos below farms include selecting areas of deep water and/or high currents, siting farms in areas with low biological productivity, avoiding sites above important biological communities, rotating farms between different sites, and different orientations and configurations of the farm. Using models to select areas with sufficient depth and currents to avoid impacts to the benthos is feasible, and the models are currently available. Avoiding sites above important biological communities and siting farms in areas of low biological productivity would avoid significant impacts to the benthos. These areas have been identified by the environmental surveys included in the *Interim Guidelines* discussed below under Section 5.1.2.2. Rotating farms between multiple sites would allow an area to recover, or the rotation could be timed to move the farm before impacts could occur. Rotating farms would minimize potential impacts to the benthos. However, the possibility of obtaining all the necessary local, state, and federal permits for numerous sites associated with one farm is remote and this would not be a feasible alternative in most cases.

Methods to minimize benthic impacts that involve orientation and configuration of the pens tend to increase the possibility of increasing impacts in other areas such as navigation and aesthetics. Although orienting the configuration of the farm so that its long axis is perpendicular to prevailing currents will reduce benthic impacts, it would increase potential navigation conflicts. Using individual clusters of pens rather than a single array, and using single-point moorage to allow a farm to swing over a larger area would reduce benthic impacts, but would increase the potential for aesthetic and navigation conflicts.

Other potential methods for reducing impacts to the benthos are related to the operation of the farm. The use of feeding methods that maximize ingestion and the use of slow-settling, highly digestible feed to maximize food conversion would reduce benthic impacts. These practices are in the best financial interest of the farmer and would be expected to be incorporated into standard operating procedures at each farm. One last potential method for reducing benthic impacts would be to spread out the concentration of waste deposition from a farm over a wider area by establishing a maximum density of fish in the pens. For example, instead of a farm raising 1,000,000 lbs a year under the current two-acre maximum size guideline, the same level of production could be achieved in a three-acre farm. However, this measure would increase the potential for navigation and aesthetic conflicts.

5.1.2.2 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the potential impacts of fish farms on benthos:

- Ecology is presently developing sediment quality standards for adoption by June 1990. These standards will specify the degree of effects allowed in sediments throughout Puget Sound, including sediments occurring below fish farms. The goal of these standards is to ensure that "no acute or chronic adverse affects on biological resources and no significant human health risk" occur as a result of any outside interference (Ecology 1989).

  The standards will include a rule addressing sediment contamination cleanup. If an abandoned or "out-of-operation" fish farm is responsible for unacceptable historic contamination of the sediments, Ecology may determine the need for sediment cleanup. Sediment cleanup action or the designation of a "sediment recovery zone" may be required (Ecology 1989). These standards will be implemented through the NPDES permit for fish farms.

- The *Interim Sediment Quality Evaluation Process* is a set of Ecology guidelines containing chemical and biological criteria, as well as instructions to other Ecology programs regarding the use of the interim criteria. Developed as outlined in the *Puget Sound Water Quality Management Plan*, the interim criteria will be subject to "best professional judgement" requirements associated with nonadopted guidelines. These criteria are implemented through NPDES permits for fish farms. These interim criteria will be replaced by the sediment quality standards discussed above in June 1990.

- WDF has the authority to "preserve, protect, perpetuate, and manage..." food fish and shellfish resources in Washington (RCW 75.08). WDF requires a Hydraulic Project Approval (HPA) permit for virtually all work within the ordinary high water mark of marine waters in Washington (RCW 75.20 and WAC 220-110). The HPA process provides WDF with permitting authority to ensure that food fish and shellfish habitats are protected from any significant adverse impacts.

- The SEPA review process provides WDF with the opportunity to evaluate individual fish farm proposals on a case-by-case basis. This mechanism allows WDF to evaluate each farm proposal for its potential impact to the benthos with the most current, available information.

- The *Interim Guidelines* (SAIC 1986) present minimum depth and current recommendations for siting fish farms of various sizes, based on reported observations of sediment accumulations reported in Weston (1986). These recommendations provide a "best guess" of the conditions under which sediment dispersal by currents would prevent any significant accumulations of organic material below the farm. In general, the *Guidelines* recommend that large, commercial fish farms be located in areas with a minimum average current of 5 cm/sec (0.1 knot), and at least 60 ft between the bottom of the farm and the sea bed.

- The *Interim Guidelines* recommend a bathymetric survey be performed as part of an overall site characterization survey in order to apply the guidelines pertaining to depth and current, and to identify the presence of any bathymetric feature which might affect bottom accumulation of excess feed and feces. The area covered by this survey is the seabed directly beneath the farm site and within 300 ft of the farm perimeter. This survey provides initial environmental information before permitting the farm.

- The *Guidelines* recommend a diver survey be included in the site characterization study. This survey would identify important biological communities to be avoided.

- The *Guidelines* also recommend a baseline survey for farms with annual production amounts greater than 100,000 lbs per year. This survey takes place after the farm is sited, but before fish are placed in the pens. This survey should include sediment chemistry and benthic infauna sampling, and could include a diver survey as well. This information "characterizes" the seabed before fish are placed in the pens.

- In addition to the surveys discussed above, the *Guidelines* also recommend annual monitoring of potential changes in the sediments below farm sites. This annual monitoring would assess the extent of solids accumulation on the bottom near the farm and the biological effect of this accumulation.

- Reports produced under the *Guidelines* are submitted to DNR for distribution and review to other appropriate state agencies.

5.1.2.3 Preferred Alternative

The site surveys and annual monitoring in the *Interim Guidelines* provide an adequate framework for determining potential impacts to the benthos. The *Guidelines* take a conservative approach to preventing benthic impacts. Given the existing data, the present depth and current guidelines should continue to be used. It is recommended that the surveys and annual monitoring identified in the *Interim Guidelines* be adopted into WACs. With the State sediment quality standards, Ecology's implementation of the NPDES permit system will provide adequate regulatory control to avoid significant impacts to the benthos.

It is recommended that data collected by DNR from annual monitoring reports from farms be reviewed annually by the Ecology, WDF, and DNR to determine if the depth and current guidelines should be revised.

5.1.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

In addition to implementing the NPDES permit system, adopting the site surveys and monitoring requirements in the *Interim Guidelines*, the State sediment quality standards, and the annual review of farm monitoring data by DNR, WDF, and Ecology into WACs will avoid significant adverse impacts to the benthos. The SEPA review process and the HPA permit will allow proposals to be reviewed on a case-by-case basis and no additional programmatic mitigation measures are necessary.

5.2 WATER QUALITY

Fish farming depends on high water quality but has the capacity to adversely influence water quality. The successful culture of fish requires clean, oxygen-rich water. On the other hand, the intensive culture of fish introduces large quantities of nutrients that can alter existing water quality conditions. The effect of this nutrient introduction, and the measure of its significance, is the biological response of plankton and eventually fish and shellfish to these changes.

5.2.1 Affected Environment

Puget Sound Water Circulation. To understand the potential water quality impacts of floating fish farms in Puget Sound, it is desirable to understand the basic water circulation patterns of Puget Sound.

For this EIS, Puget Sound includes all marine waters of Washington State inland from and including the Strait of Juan de Fuca. Puget Sound is a large sunken valley connected to the Pacific Ocean by the Strait of Juan de Fuca. It consists of several interconnecting fjord-like basins often separated by relatively shallow sills that transverse the entrances to these basins (see Figure 5). The main basin of Puget Sound, inland from Admiralty Inlet, has an average depth of 64.1 m and a maximum depth between Point Jefferson and northwest Seattle of 283 m. The main basin alone covers an area of 2,630 km^2 (768 square nautical miles) at high tide with a volume of about 169 km^3 (26.5 cubic nautical miles).

Puget Sound is strongly affected by the force of tides, which provide most of the energy for movement of water in the Sound. Tidal exchanges, from low to high tide, can be as great as 5 m (16 ft) resulting in an average of about 3.25 km^3 of water moving in and out with each of the twice-daily tidal changes. This daily tidal displacement represents over 9 billion tons of water (Metro 1988). The movement of this water also produces strong currents in many channels which commonly exceed 3 knots (1.5 m/sec) and may exceed 6 knots (6 m/sec) in narrow channels such as Deception Pass and the Tacoma Narrows. Figures 6 and 7 show generalized surface water movement at flood and ebb tides.

As is typical of estuaries, Puget Sound is dominated by a two-layer flow of water with a mid-depth oceanic inflow and a less saline surface water outflow resulting in a continual, slow replacement of these waters. The inflowing oceanic waters are characterized by low temperature, high salinity, and low dissolved oxygen.

Freshwater inflow drives the flow of water out of Puget Sound. Freshwater is supplied to the Sound by surface runoff, with two-thirds coming from the Skagit, Stillaguamish, and Snohomish Rivers. Smaller amounts are contributed by Lake Washington and the Duwamish, Puyallup, Nisqually, Deschutes, and Skokomish Rivers (Strickland 1983; Duxbury 1988).

Freshwater is less dense than saltwater and floats on the surface. Tidal currents gradually mix the freshwater with saline oceanic water to create a brackish surface layer extending down 10-50 m (32-160 ft). The brackish layer flows by gravity towards the ocean with assistance from winds from southerly storms. The saltwater layer beneath flows inward from the Pacific to replace the saltwater lost by mixing with the upper brackish layer that flows seaward. This seaward movement at the top and landward at the bottom exists throughout the Sound and is typical of fjords with river-dominated circulation. As a result of this seaward movement, surface current velocities are generally stronger on ebb tides than on flood tides, which tends to carry dissolved materials out of the Sound and to the ocean (Figure 8).

In addition to tidal driven water exchanges, meteorological conditions can cause large intrusions of saline, coastal water. According to Cannon (1983), "in the Strait of Juan de Fuca, the waterway connecting the Sound with the Pacific Ocean, winter storms with predominantly southerly winds along the coast are capable of significantly reversing the normal estuarine flow and causing large intrusions of coastal water lasting several days." This phenomenon can also occur during the summer when low-pressure systems may persist off the coast long enough to change the circulation pattern in the Strait (Cannon 1983).

Another important feature of Puget Sound is the presence of major sills such as those at the entrance of Admiralty Inlet and at the Tacoma Narrows. These shallow areas cause turbulent mixing of deep and surface waters as tidal action forces the water back and forth over the sills. South of Admiralty Inlet, this mixing tends to restrict the flushing of surface waters by forcing the seaward-moving surface water to partially mix with deeper water and to partially recirculate. Surface waters of the main basin (Admiralty Inlet

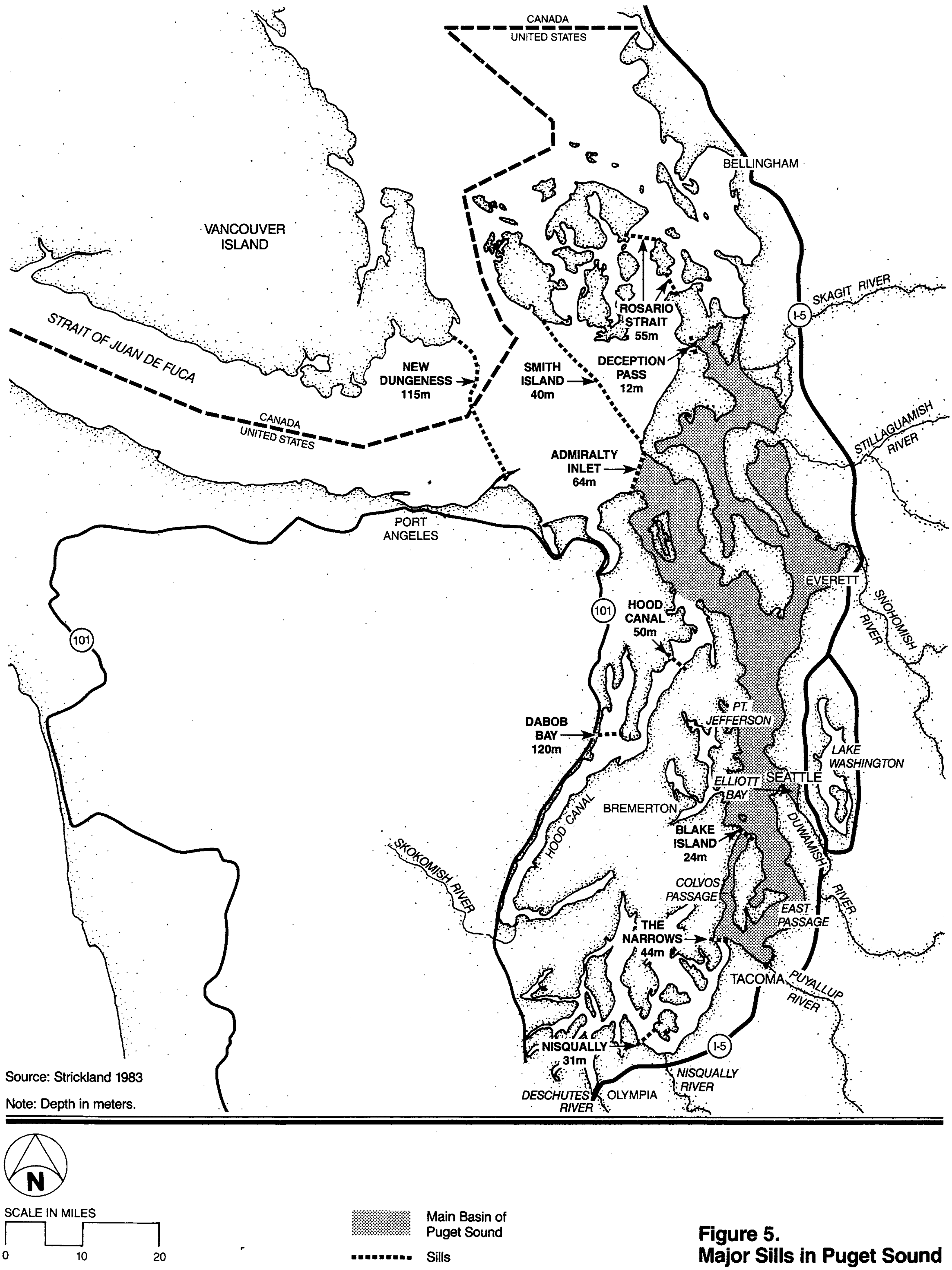


Figure 5.
Major Sills in Puget Sound

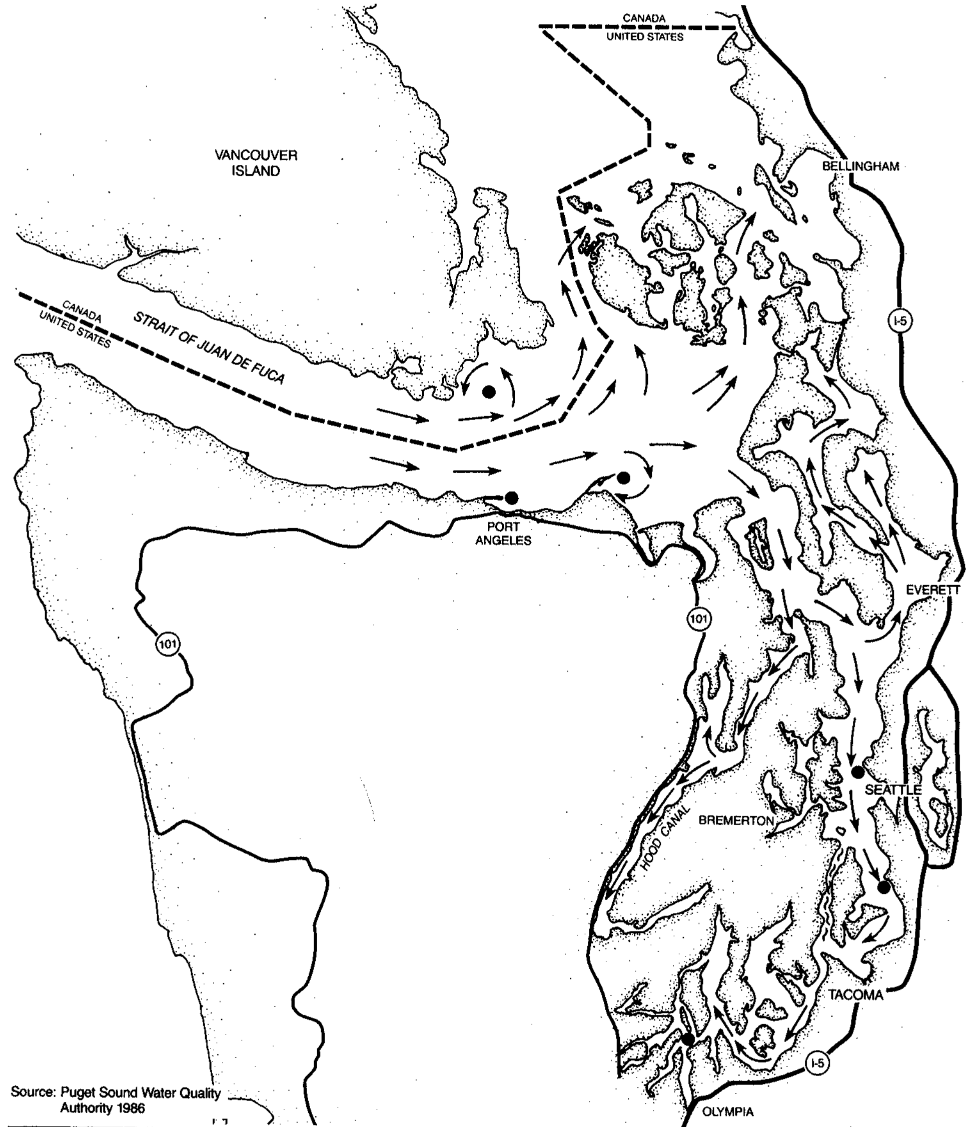


Figure 6.
Generalized Surface Water Movement at Flood Tide in Puget Sound

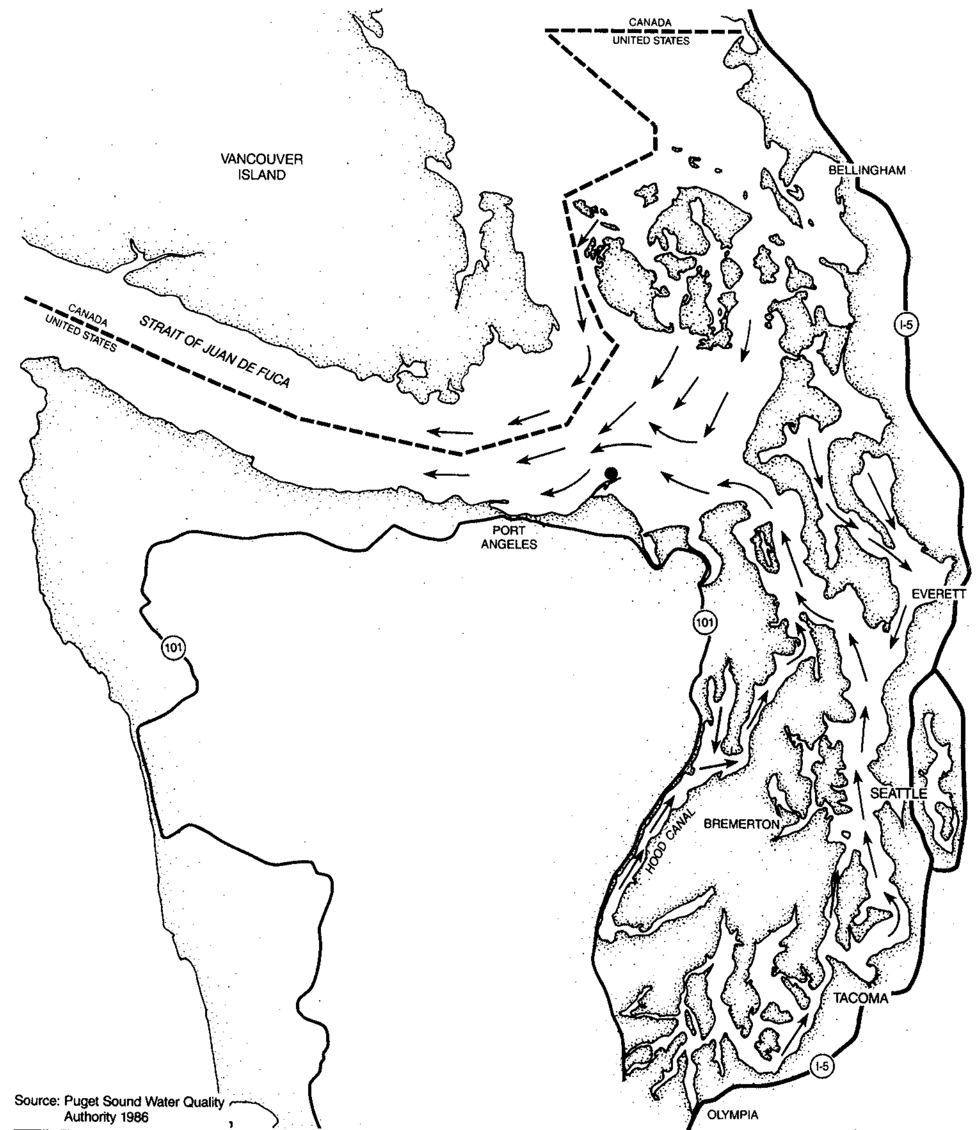
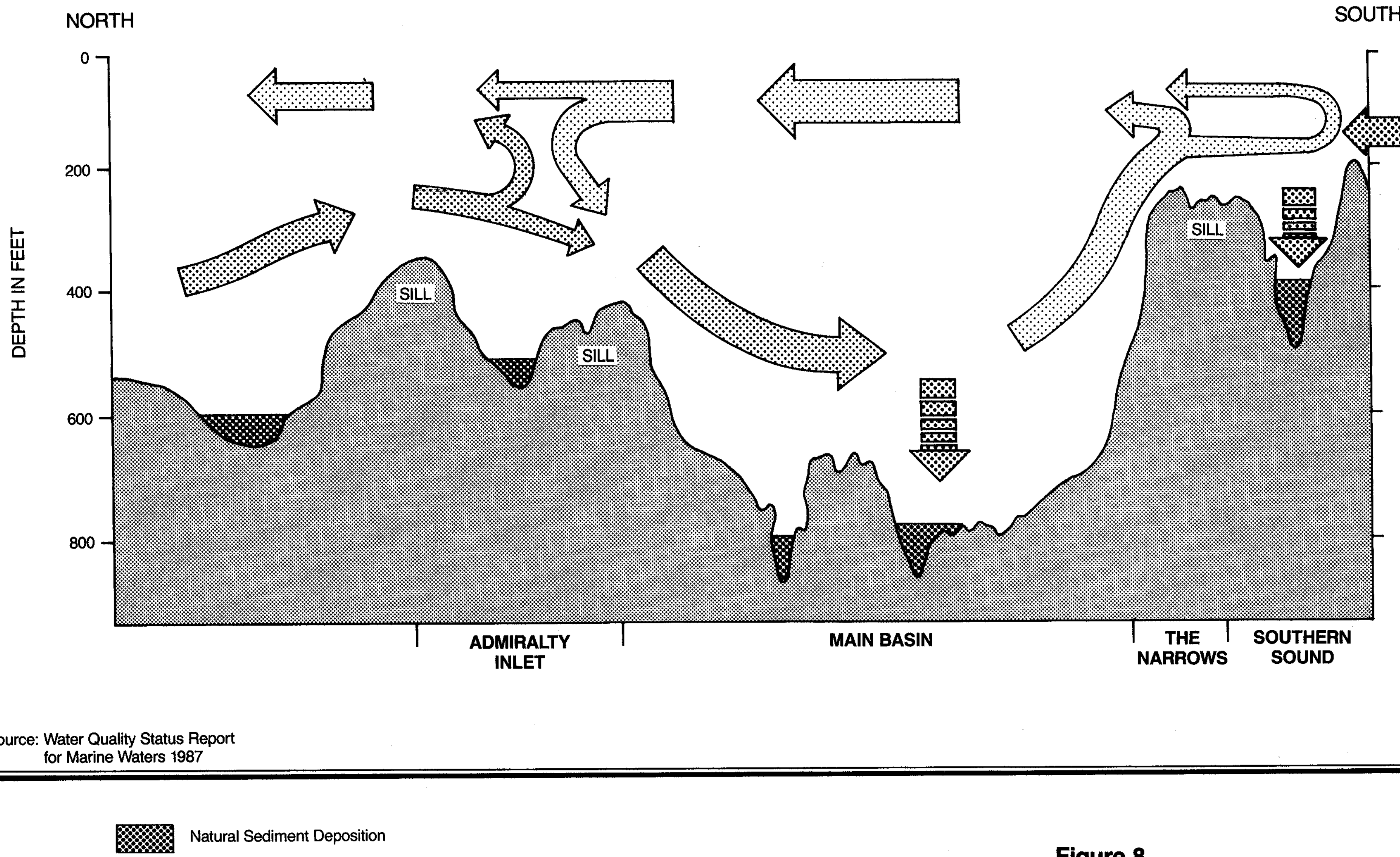


Figure 7.
Generalized Surface Water Movement at Ebb Tide in Puget Sound



Source: Water Quality Status Report for Marine Waters 1987

Figure 8.
Simplified Diagram of Circulation and Sedimentation in Puget Sound

to the Tacoma Narrows) take about a week to travel from Elliott Bay to the sill at Admiralty Inlet. After mixing, a portion of this water will travel back to Elliott Bay in about 10 days. On average, the seaward-moving water must go through this cycle twice before clearing the sill and reaching the Strait of Juan de Fuca (PSWQA 1986). This finding agrees with a 50% average recycling of surface water at the Admiralty Inlet sill (Duxbury 1989 personal communication).

The course of 400 computer modeled parcels of water instantaneously released into the Sound and carried by currents is shown in Figure 9. Approximately half of the parcels are left in the south after three months. Six months after the water parcels are released, 25% remain. After a year, 5% of the parcels are still in the south. These numbers indicate how portions of the parcels are recycled at the sill (PSWQA 1986).

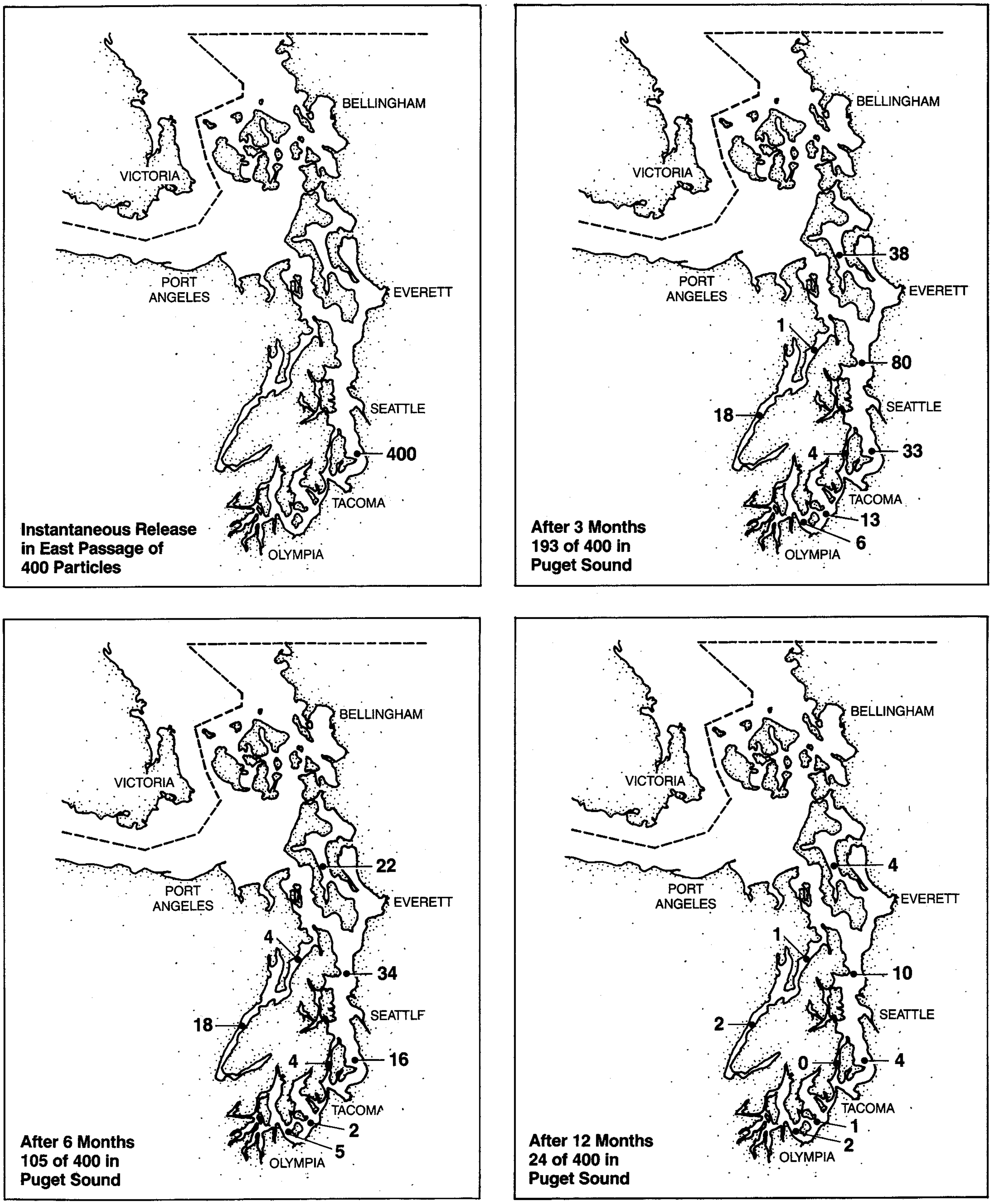
Another effect of this mixing results in a continual replenishment of nutrients into the surface waters (this mixing is also demonstrated by Puget Sound's typically cold surface water temperatures). During summer, many fjords are characterized by strongly stratified layers with little exchange between deep and surface waters. Surface layers are typically low in nutrients and salinity, overlying nutrient-rich, oceanic waters. Consequently, the productivity of these fjords is often limited. Locally, this situation is typified by central and south Hood Canal. By comparison, surface waters in the main basin of Puget Sound are rich in nutrients and relatively saline. These conditions support abundant and sustained phytoplankton growth (the basis of the aquatic food chain) and also support a great variety of both oceanic and estuarine organisms. Consequently, Puget Sound is considered one of the richest, most productive estuaries in the world.

Differences in the degree of mixing in different basins play a major role in the biological nature of individual bays and inlets. For example, the main Puget Sound basin is characterized by a high rate of tidal flushing and turbulent mixing from tide and wind-induced currents. The result is a deep stratification that limits the intensity of algal production by mixing phytoplankton to depths where the light levels are too low to sustain photosynthesis. However, this constant mixing also maintains high levels of nutrients, which produce phytoplankton, and result in a high rate of annual primary production.

In terminal areas of some bays, such as Budd Inlet, the lack of flushing combined with shallow waters and summertime stratification, provide stable conditions for phytoplankton growth. Phytoplankton populations are maintained in the surface layer until the nutrients become exhausted. In extreme cases, death of these cells may consume the available oxygen, contributing to fish kills typical at the head of Budd Inlet.

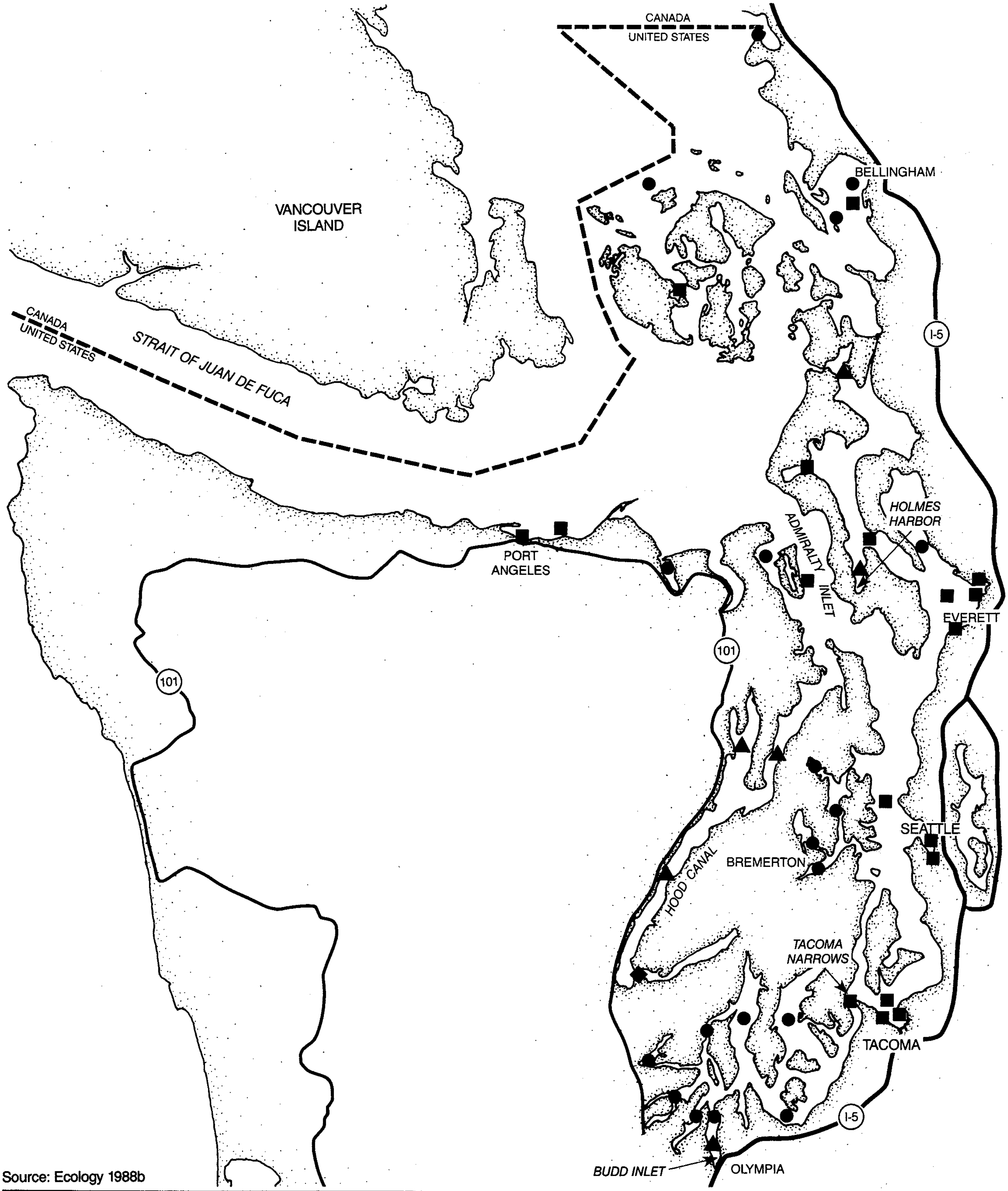
Hood Canal is adjacent to, but separate from, the main basin of Puget Sound with a 51 m (167 ft) deep sill near its entrance. The Canal extends about 80 km (50 miles) to the south. Hood Canal has received relatively little study compared to some of the other areas of Puget Sound, but the water in the central and southern Canal appears to be slowly flushed (Cannon 1983). Despite the presence of a sill near the entrance, relatively little turbulent mixing occurs and the central and southern Canal has typical fjord characteristics–nutrient poor surface waters overlying nutrient-rich waters. Consequently, primary production is relatively low, as demonstrated by the growth rates of oysters that feed on this phytoplankton. In Hood Canal, oysters typically attain harvest size in about five years, while in south Puget Sound only about three years is required.

Water Quality Monitoring in Puget Sound. Ecology water quality monitoring stations in Puget Sound are presented in Figure 10. This figure identifies monitoring stations that have fallen below State standards in the last five years. Whether a station meets the dissolved oxygen standard is based on the 1988 Water Quality Index calculated by Ecology from data collected at the surface and depths of 10 and 30 m (30-40 ft) during the summer months of the last five



Source: Puget Sound Water Quality Authority 1986

Figure 9. Theoretical Dispersion of Water Parcels in Puget Sound



Source: Ecology 1988b

Figure 10. Washington Department of Ecology Water Quality Monitoring Stations and Their Relation to Dissolved Oxygen Standards

years (Ecology 1988b). This five-year average masks unusually low or high values in the data set. In other words, stations that do not meet State standards on rare occasions are not identified as such in Figure 10.

Twenty-five of the 46 monitoring stations do not always meet the Class AA standard for dissolved oxygen (see Figure 10). This means that dissolved concentrations less than 7.0 mg/L have been observed at over half of the monitoring stations on several occasions in the past five years. Only 10 of these stations do not meet the standard for their class of waters. Four stations do not meet the Class A standard of 6.0 mg/L. They are Holmes Harbor at Honeymoon Bay, Hood Canal at Pulali Point, Hood Canal at Eldon, and inner Budd Inlet. One station, Hood Canal at Sisters Point, does not meet the Class B standard of 5 mg/L.

In summary, dissolved oxygen problems in Puget Sound most commonly occur in certain embayments that have poor circulation, such as southern Hood Canal, Budd Inlet, and Holmes Harbor. These problems typically occur during periods of low tidal exchange in late summer and autumn, and are related to phytoplankton blooms.

5.2.2 Impacts on Water Quality

General. The primary causes of water quality impairment in the State's estuaries are bacteria, organic enrichment, and low dissolved oxygen. The primary sources of bacteria problems are from agricultural runoff, failed onsite wastewater disposal systems (septic tanks), municipal wastewater (sewage) treatment plants, and stormwater. Other sources of water quality impairment include erosion from forest practices and streambank alteration and loss of water quality functions due to degradation and destruction of wetlands. Natural factors such as phytoplankton blooms and the upwelling of bottom waters are the primary source of organic enrichment and dissolved oxygen problems in Puget Sound. Toxic metals and organic chemicals from urban and industrial sources are a serious problem in certain portions of Puget Sound (Ecology 1988a).

Exacerbation of organic enrichment and dissolved oxygen problems are a potential water quality concern for the operation of fish farms. These problems are interrelated in that organic enrichment fuels bacterial decomposition and results in oxygen depletion. This depletion occurs primarily by microbes in the water and sediment consuming oxygen as they decompose organic matter. In addition, inorganic nutrients (nitrogen, phosphate) are a cause of organic enrichment because they are converted to organic matter by algae and bacteria that consume them. It is the rapid consumption of nutrients by phytoplankton that results in excessive phytoplankton growth (blooms) in shallow or stratified embayments.

Phytoplankton blooms may increase dissolved oxygen through photosynthesis during the day, and decrease oxygen levels by respiration during the night. Oxygen levels may decrease in the surface waters when the surface waters mix with oxygen-deficient bottom waters. This may occur in the summer and autumn from the upwelling of very deep water during incoming tides. It also occurs in stratified embayments that are vertically mixed in the autumn by winds and tides (Collias et al. 1974).

A decrease in dissolved oxygen becomes a problem when marine organisms are subjected to stress. The degree of stress depends on both the level of oxygen and the length of time an organism is exposed to low oxygen levels. It is also dependent on many other physical, chemical, and biological conditions, such as temperature, toxicity, and food availability.

The following is a discussion of the potential impact that a fish farm may have on several water quality variables:

Turbidity. Turbidity is a variable that indicates the clarity of water. During net cleaning, turbidity could significantly increase downcurrent of farms. The degree of turbidity increase would depend on the amount of material washed off the nets, which in turn would depend on the accumulation rate of material on the nets and on how often the nets were cleaned. Cleaning severely fouled nets could possibly increase turbidity by more than 5 NTU (nephelometric turbidity units) over background and violate the State standard in the immediate vicinity of the farm. The loss of fish food and feces from farms would also increase turbidity, but to a much lesser degree than net cleaning. It is unlikely that food and wastes will increase turbidity sufficiently to cause a turbidity exceeding water quality criteria. Higher turbidity levels during net cleaning activities would not adversely impact aquatic organisms, but would reduce the clarity of the water.

A study in Clam Bay, Washington, reported that floating fish farms did not affect turbidity (NMFS 1983). Although turbidity ranged from 0.5 to 2.0 NTU throughout the study, measurements were not taken during net cleaning (Damkaer 1988).

pH. pH is a water quality variable that indicates how acidic or basic the water is. The range of possible values is 1 to 14 with lower numbers being categorized as acidic. Fish excrement includes the passage of carbon dioxide and ammonia through the gills, as well as feces and a very small amount of urine (Lagler et al. 1962). Since carbon dioxide is a weak acid and ammonia is a weak base, the net pH effect of fish excrement through the gills is neutralized. The pH of feces is buffered by pancreatic secretions (Lagler et al. 1962). Because of tidal dilution and the relatively high buffering capacity of Puget Sound waters, fish excrement would not result in a measurable change in pH down current of farms.

Pease (1977) reported that a fish farm in a poorly flushed, log rafting area (Henderson Inlet, Washington) did not affect pH. He made five monthly observations (May through September) of pH at three sites near farms and at a control site. On one occasion the pH was between 0.15 to 0.3 units less at the three farm sites than at the control site. The pH was within 0.15 units at all sites on all other occasions. Some pH changes may also have been due to tannic acids and other acidic products of wood decomposition in the log rafting area. Pease reported that tidal factors were the primary factor regulating pH at all sites. His observation of the daily variation of pH showed that it was between 0.1 and 0.2 units higher at high tide than low tide.

Temperature. The operation of fish farms would not affect water temperatures in Puget Sound. Fish farms have no features that would measurably change heat loss or heat gain by Puget Sound.

Fecal Coliforms. Fecal coliform bacteria are produced in the intestines of warm-blooded animals and are a relative measure of sanitary quality (APHA 1985). Fish farms do not directly affect ambient (existing) fecal coliform concentrations in Puget Sound because fecal coliforms are not produced in fish. However, fecal coliform levels could indirectly increase near farms from increased marine bird and mammal activity (See Section 5.9, Marine Mammals and Birds). Or fecal coliform levels could possibly increase from the failure of a facility's sanitary holding tank.

Nutrients. Nutrients are primary substances organisms require for growth. Some of the essential nutrients include nitrogen, phosphorus, hydrogen, and carbon. The operation of farms releases nutrients into the water from fish feces and from uneaten feed. The primary nutrients of interest in relation to fish farms are nitrogen and phosphorus. Both may cause excess growth of phytoplankton and lead to both aesthetic and water quality problems. Generally in marine waters, phytoplankton growth is either light or nitrogen limited, and phosphorus is not as critical a nutrient as it is in fresh water (Ryther and Dunstan 1971; Welch 1980).

Nitrogen may be categorized as: (1) inorganic (nitrate, nitrite and ammonia and nitrogen gas); and (2) organic (urea and cellular tissue). Most of the waste food and feces from fish farms is composed of organic carbon and nitrogen (Liao and Mayo 1974, Clark et al. 1985). About 22% of the consumed nitrogen is retained within the fish tissue and the remainder (78%) is lost as excretory and fecal matter (Gowen and Bradbury 1987). Approximately 87% of the metabolic waste nitrogen is in the dissolved form of ammonia and urea; the remainder (13%) is lost with the feces (Hochachaka 1969).

Salmon will produce approximately 0.22 to 0.28 grams of all forms of dissolved nitrogen per day per kilogram of fish produced annually (Ackefors and Sodergren 1985; Penczak et al. 1982; Warren-Hansen 1982, as cited in SAIC 1986, or that cited by Weston 1986). Ammonia and urea are essentially interchangeable as phytoplankton nutrients. Immediately downstream of most farms (6-30 m [19-90 ft]) the concentration of ammonia diminishes greatly. This decrease is probably due to the natural microbial process of nitrification (oxidation of ammonia to nitrites and nitrates). Rapid rates of nitrification are expected in any well-oxygenated aquatic environment (Harris 1986).

The effects of nutrients will not be discussed here, but will be covered in Section 5.3, Phytoplankton.

Toxicity. Toxic chemicals would not be introduced into the fish farm from fish food. The potential impact of toxicants leaching from treated nets and of antibiotics is discussed in Section 5.4, Chemicals.

Ammonia in the un-ionized form (NH_3) is toxic to fish at high concentrations depending on water temperature and pH (Trussel 1972; EPA 1986). High ammonia levels in fish excrement have raised ambient (existing) ammonia concentrations. Normal concentrations of ionized and un-ionized ammonia in Puget Sound are very low, with some variability. A small percentage of the ammonia originating from farms in Puget Sound, typically about 2%, will be toxic and un-ionized.

Excess ammonia, which is undesirable for sensitive coldwater species such as salmonids, has not been an acute problem for typical flow through fish hatcheries. It is a condition that requires treatment in reuse water systems (Burrows and Combs 1968; Liao and Mayo 1974). Salmon and many freshwater fish are considered more sensitive to the effects of ammonia toxicity than most invertebrates, including bivalves such as clams and oysters (EPA 1986). Although exposure to low concentrations of ammonia may occur in freshwater facilities and not produce lethal effects, if sufficiently high, it causes chronic adverse effects including reduced stamina, growth, and disease resistance (Burrows 1972).

At pH 7 and below, ammonia is never a limiting factor in freshwater salmon production. Near a pH of 8, loading limitations (limitation of nitrogen output from fish farms) are necessary when the density of fish is great (above 8 lbs per gallon per minute). The pH of Puget Sound waters is generally about 8 (on a scale of 1 = very acidic to 14 = very basic) and varies little due to the natural carbonate buffering system of seawater (Stumm and Morgan 1981). Saltwater rearing of salmonids is affected by many of the same biological restraints common to freshwater hatchery culture, except relatively greater volumes of water per unit of fish production typically pass through farms. This results in much greater dilution of waste products such as ammonia in farms when compared to freshwater hatcheries or municipal sewage discharges (Weston 1986).

Recent nearfield studies in Washington (Milner-Rensel 1986; Rensel 1988b,c) have shown increased concentrations of ammonia immediately downstream or within the farms. Total ammonia values typically have increased from 3 to 55% above the low background levels. The highest observed concentrations were only a small fraction of the maximum four-day, chronic exposure level recommended by EPA (1986). These studies have shown variable amounts of dissolved nitrogen produced from salmon farms (ammonia plus nitrate and nitrite) not explained by variations in water velocity. Additional studies, at larger facilities, are presently being completed and may allow more accurate estimation of rates of dissolved nitrogen production indexed to the size of the facility, biomass of the fish, and rate of water flow through the farm.

A long-term study, under worst-case conditions in southern Puget Sound, found that the greatest concentration of total ammonia observed at any time was 0.176 mg/L, equivalent to 0.006 mg/L un-ionized ammonia, well below chronic exposure threshold (Pease 1977).

In summary, increases in dissolved nitrogen (including ammonia) are typically seen within salmon farms. Immediately downstream, nitrogen or ammonia levels may also be elevated compared to ambient, upstream values. However, results are variable. In some cases, concentrations were greater or much less than expected compared to predicted values based on freshwater hatchery data. However, even within the fish farm, un-ionized ammonia levels remain well below toxic concentrations.

Dissolved Oxygen. Dissolved oxygen consumption by fish, and by microbial decomposition of fish wastes and excess food, could significantly reduce dissolved oxygen concentrations near the farm. Depending on feeding rates, the oxygen consumed by microbial decomposition may equal or exceed that of fish (Institute of Aquaculture 1988). Most of the microbial decomposition is associated with solids that settle to the bottom (Institute of Aquaculture 1988). Thus, the greatest potential for oxygen consumption would be from fish respiration near the surface and microbial decomposition near the bottom.

The total effect of oxygen consumption from farm operations on dissolved oxygen concentrations near the farm is highly variable. The loss of dissolved oxygen depends on the water exchange rate near the farm, fish density, and fish feeding rate. If the water exchange rate near the farm is high, there will be less reduction of dissolved oxygen. If the fish density and fish feeding rate are high, there will be decreased dissolved oxygen.

In general, the dissolved oxygen requirements of salmon raised in farms limit the impact fish farms can have on the environment. Water quality criteria for oxygen are based in large part on the oxygen requirements of rearing salmon. The lowest oxygen levels caused by fish farms are likely to occur within the farm and immediately downcurrent. Thus, the impact of low dissolved oxygen is likely to affect the farm before having an effect on the surrounding environment.

The impact of fish farms on dissolved oxygen have been estimated by mathematical modeling and field measurements at existing sites. Model predictions indicate a decrease in dissolved oxygen concentration of less than 0.3 mg/L (Weston 1986). Field studies of dissolved oxygen concentrations near several farm sites have shown a decrease in dissolved oxygen ranging from near 0 to 1.5 mg/L. These farm sites were located in Port Angeles Harbor (Milner-Rensel 1986; Rensel 1988), Deepwater Bay off Cypress Island (Rensel 1988), Clam Bay (NMFS 1983; Damkaer 1988, see Appendix A), in Henderson Inlet (Pease 1977), Squaxin Island (Fraser and Milner 1974; see Appendix A), and in Sechelt Inlet, British Columbia (Black and Carswell 1986). Generally, the decrease was less than 0.35 mg/L and did not exceed State water quality standards. Instances in which the State standards were exceeded occurred in areas of poor circulation and naturally occurring low oxygen levels during August and September.

Cumulative Impacts of Multiple Farms. The presence of more than one fish farm in an embayment may cause a greater reduction of dissolved oxygen if the area of decreased oxygen from one farm overlaps the area of decreased oxygen from another farm. In this case, both farms may be capable of operating without a significant reduction in dissolved oxygen, but the proximity of one farm to another could result in localized dissolved oxygen reductions in violation of State standards.

Field measurements around individual farms indicate that the region of dissolved oxygen impairment around a farm is less than 50 m (165 ft). Consequently, the potential of one farm affecting the dissolved oxygen near a second farm is highly unlikely if the farms are placed even 100 m (330 ft) apart. It is highly improbable that sediment impact requirements and aesthetic considerations would allow siting farms closer than a few hundred meters apart. As previously discussed, a single farm rarely reduces dissolved oxygen concentrations to the point of violating State standards. Consequently, the potential for five farms violating the dissolved oxygen standards is no greater than for one farm unless the farms are placed extremely close together.

In summary, most studies have shown that fish farms do not have a significant adverse impact on dissolved oxygen. Exceptions to this have occurred during summer or autumn at sites that had low background dissolved oxygen levels and did not have adequate current flow through the nets.

5.2.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the potential impacts of fish farms on water quality:

- In May 1989, EPA determined that NPDES permits would be required for certain salmon farms in Washington. Ecology is currently incorporating this determination into policy and developing a draft NPDES application for marine fish farms. When issued, NPDES permits will satisfy both federal and state laws.

  The NPDES requirement will apply primarily to fish farms producing over 20,000 lbs of fish per year and using more than 5,000 lbs of food per month. A State waste discharge permit will be required for commercial farms producing less than 20,000 lbs of fish per year. For non-commercial facilities, the NPDES permit will be discretionary. However, all fish farms must meet the substantive requirements of the policy, regardless of procedural requirements.

  The NPDES permit application will provide the specific information needed to make permitting decisions on fish farms. Proposed guidelines include both siting and monitoring requirements. Siting requirements will include compliance with existing and subsequent revised siting guidelines and recommendations. Environmental monitoring will also be required to characterize any environmental impacts from farm operations, and demonstrate that operations do not violate water quality standards or applicable sediment quality standards. Specific monitoring requirements will be developed by EPA and Ecology, and may include bathymetric and hydrographic surveys, water quality measurements, sediment chemistry, and biological sampling.

- Fish farming operations must comply with State water quality regulations. Water quality in Puget Sound is monitored, assessed, and protected by Ecology. Water quality criteria have been established in WAC Chapter 173-201, Water Quality Standards for Surface Waters of the State of Washington. Marine waters are classified as Class AA (extraordinary), Class A (excellent), Class B (good), and Class C (fair). The water quality criteria associated with this classification are summarized in Table 4.

Most of Puget Sound is classified as Class AA or A. Everett Harbor, inner Commencement Bay, Budd Inlet, and Oakland Bay are classified as Class B. The Tacoma City Waterway is the only marine water classified as Class C.

Table 4. Marine water quality standards in Washington state.

Criteria	Waterbody Classification			
	AA	A	B	C
Fecal Coliforms (#/100 mL)				
upper limit	14	14	100	200
Dissolved Oxygen (mg/L)				
lower limit	7.0	6.0	5.0	4.0
decrease limit[a]	-0.2	-0.2	-0.2	-0.2
Temperature (°C)				
upper limit	13	16	19	22
increase limit[b]	+0.3	+0.3	+0.3	+0.3
pH				
range limit	7.0-8.5	7.0-8.5	7.0-8.5	6.5-9.0
inc./dec. limit[c]	+/-0.2	+/-0.5	+/-0.5	+/-0.5
Turbidity (NTU)				
increase limit	+5	+5	+10	+10
Toxicity, Aesthetics	See Chapter 173-201 WAC for narrative and numeric criteria.			

[a] decrease limit if background is less than lower limit
[b] increase limit if background is greater than upper limit (see Chapter 173-201 WAC for specific equations for increase limit)
[c] increase or decrease limit for man-caused activities

- Water quality standards for dissolved oxygen have been developed from an extensive data set on the effect of oxygen on freshwater fish and invertebrates. EPA (1986) reported that a minimum dissolved oxygen concentration of 8 mg/L would not impair the production of juvenile or adult salmonids, or of invertebrates. Light-to-severe production impairment would occur at 6 and 4 mg/L, respectively. The limit to avoid acute mortality is 3 mg/L. Thus, according to federal water quality standards, dissolved oxygen problems could occur when the concentrations are sustained below 6 mg/L.

- Water quality concerns are addressed in the *Interim Guidelines* (SAIC 1986). The primary issues raised are changes in nitrogen and dissolved oxygen concentrations near fish farms. No recommendations are made in the *Guidelines* concerning specific changes in the concentration of dissolved oxygen or nitrogen. Instead, the *Guidelines* evaluated monthly Ecology water quality data and identified areas that already have low dissolved oxygen concentrations at depth and persistent nitrogen depletion in the surface waters. From this assessment, the *Guidelines* recommended that fish farm development be restricted in these areas unless the applicant can demonstrate that the biochemical oxygen demand from the farm will not depress dissolved oxygen concentrations and the nutrient input from the farm will not affect phytoplankton blooms.

- In addition to the restriction of certain areas in Puget Sound from fish farm development, the *Guidelines* also recommended production limits in defined geographic areas. These areas and production limits are defined in the *Guidelines*, but the production limits range from 50,000 lbs per year in Sequim Bay to 5,900,000 lbs per year in Skagit Bay. In areas where there are no water quality-based limits on production levels, the *Guidelines* recommended a maximum production level of 1,000,000 lbs per year per square nautical mile.

- The *Guidelines* also recommend that a hydrographic survey of the site be completed before starting the permitting process. The hydrographic survey should include three components: (1) current velocity and direction; (2) circulation patterns using drogue tracking techniques; and (3) vertical profiles of temperature, salinity, and dissolved oxygen. This information provides initial information to apply the depth and current guidelines and to predict the dilution and dispersion of excess feed and waste.

- Annual monitoring for changes in water quality near the farms is also recommended in the *Guidelines*. Water quality parameters included in the sampling program include: dissolved oxygen, temperature, salinity, pH, ammonia, and nitrite/nitrate. Results from these annual reports are submitted to DNR for distribution and review by other State agencies.

5.2.2.2 Preferred Alternative

The hydrographic surveys and annual monitoring in the *Interim Guidelines* provide an adequate framework for determining potential impacts to water quality. In establishing areas where farms should be restricted, and limiting production amounts for specific geographic areas, the *Guidelines* used a conservative approach to ensure that water quality would not suffer significant impacts. It is recommended that the surveys and monitoring requirements outlined in the *Interim Guidelines* be adopted into WACs.

Ecology's implementation of the NPDES permit system for fish farms will provide adequate regulatory control to ensure that fish farms will be in compliance with all state and federal water quality laws.

It is recommended that the following measure be required of fish farmers:

- During periods of naturally high turbidity, farmers should monitor turbidity during their net cleaning operations. If this monitoring identifies turbidity levels over State water quality standards, then the farmers should increase the frequency of their net cleaning to assure that State standards are not exceeded.

5.2.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Adoption of the *Guidelines* and the monitoring requirement for net cleaning operations identified in the Preferred Alternative into WACs with the implementation of the NPDES permit requirements will ensure that no significant adverse water quality impacts occur as a result of floating fish farm development. No additional mitigation measures are necessary.

5.3 PHYTOPLANKTON

Phytoplankton, small plants suspended in the water, form the base of the marine food chain. There are generally three major forms of phytoplankton in Puget Sound: diatoms, dinoflagellates, and flagellates. Most larger phytoplankton cells in Puget Sound are diatoms or dinoflagellates. Diatoms are free-floating plant cells or chains of cells and are the most abundant phytoplankton group in central Puget Sound (Anderson et al. 1984). Typically, they are most abundant in any area where there is a moderate amount of vertical mixing. Dinoflagellates are protozoan, able to move in the water column, and some have plant-like qualities. A few species of phytoplankton, mostly dinoflagellates, may have adverse effects upon man or marine animals. Other forms of marine algae include macroalgae (or seaweeds) such as kelp and marine flowering plants such as eelgrass.

In many marine environments, there is a general seasonal succession of phytoplankton types. This begins with diatoms in the spring, shifting to dinoflagellates in the late summer and early fall, and returning to diatoms in the late fall and early winter. The succession is influenced by seasonal water column stratification and overturn. In many areas of Puget Sound this seasonal succession is not observed. For example, in main channel areas, diatoms tend to dominate all year, while the inner portions of restricted embayments tend to be dominated by dinoflagellates during summer and fall. Although studies of phytoplankton species dynamics are limited in Puget Sound, there have been several studies of discrete sub-areas (Johnson 1932; Phifer 1933; Thompson and Phifer 1936; Chester et al. 1978) and studies using chemical measures of phytoplankton abundance (Campbell et al. 1977; Chester et al. 1978; Anderson et al. 1984). Additionally, Ecology maintains regular monitoring of chlorophyll a (chemical measure of phytoplankton density) at many stations throughout marine waters of Puget Sound.

Phytoplankton populations in marine waters are regulated in part by nutrients. Salmon farming produces nutrients that could stimulate phytoplankton blooms if phytoplankton growth is nutrient limited. This potential effect is different from the dissolved oxygen effects discussed in the previous section. Phytoplankton blooms would be a secondary, biological effect caused by a water quality change, not a direct effect of fish farms.

It is universally agreed that the primary growth-limiting nutrient in marine waters for virtually all types of phytoplankton is dissolved nitrogen. Exceptions exist, such as in the Chesapeake Bay area where phosphate may be limited for short periods in the spring (Taft and Taylor 1976, McCarthy et al. 1977). When seasonal depletion of nutrients occurs in semi-restricted marine areas, the limitation found has always been nitrogen (URS 1986, SAIC 1986, Tetra Tech 1988). Nitrogen depletion is caused by the physiological requirement for this nutrient, which is many times greater than the need for phosphate.

Although not documented, increased plankton growth from fish farms would not necessarily be an adverse effect since phytoplankton are the base of the marine food chain. However, greatly increased growth of marine phytoplankton could have adverse effects on dissolved oxygen concentrations, on fish and shellfish survival, and, in rare cases, on aesthetics of nearshore waters.

5.3.1 Affected Environment

General. Phytoplankton are present in Puget Sound throughout the year, although their winter abundance is normally reduced. Winter et al. (1975) found that growth rates of phytoplankton populations were high in the central basin of Puget Sound compared to coastal waters worldwide. This high growth rate was partly attributed to Puget Sound's strong, persistent upwelling of nutrients and algal cells from depth.

When a combination of suitable physical and chemical factors occur simultaneously and sufficient seed stock is present, a "bloom" is possible. A bloom is an outburst of growth in the phytoplankton that produces a large crop. It commonly occurs in the spring in most temperate seas and in Puget Sound may reoccur throughout the summer. Exceptional blooms are those that are grossly noticeable or may have significant impacts on human activities and may be reoccurring over long time scales (Parker and Tett 1987).

The question of what factors limit the crop size of phytoplankton in natural waters may be difficult to answer for at least three reasons. First, the population of microscopic phytoplankton is very dynamic. Both growth rates and death rates are usually very rapid. Typically, phytoplankton live no longer than several days, thus, temporal changes in the crop size are determined by imbalances in the rates of growth and rates of death. Grazing by zooplankton also contributes to the dynamics of phytoplankton populations.

Second, the size of the phytoplankton crop may be directly controlled by the availability of materials necessary for the production of new cells. Direct control occurs solely by chemical factors such as the concentrations and rates of nutrients and trace metals supplied.

Finally, the crop size may be indirectly controlled by factors that determine the growth and death rates of the cells that comprise the population. Physical factors that exert indirect control on the size of the crop include light intensity, water temperature, and water movement (vertical mixing caused by tides and weather and transport to the ocean by horizontal flow). These factors are most important in controlling phytoplankton crop size in the main channels of Puget Sound (Winter et al. 1975).

Thus, depending on the physical, chemical, and biological state of the planktonic community, nitrogen loading can have several effects. It can lead to increases in either the concentration of dissolved nitrogen in the water, phytoplankton concentration, zooplankton concentration, or any combination of these three. The fate of discharged nitrogen is difficult to assess.

However, the fate of nitrogen discharged from farms will generally be the same as that of naturally occurring nitrogen. If the natural concentrations of organic nitrogen in a phytoplankton crop and zooplankton stock are high relative to the concentration of dissolved nitrogen in the water, then the waste or discharged nitrogen will be assimilated into the plankton. If organic nitrogen concentrations within the plankton are lower than natural nutrient concentrations in the water, then discharged nitrogen will not be assimilated. This rule-of-thumb may not be valid when rates of nutrient loading are large relative to natural rates of nutrient supply to the phytoplankton. Under such circumstances, the plankton community may be significantly altered, and the distribution of nitrogen between dissolved, phytoplankton, or zooplankton phases significantly changed.

Transitional or boundary areas between strongly stratified embayments and well-mixed main channel areas often have the greatest density of phytoplankton, based on chlorophyll a concentration (Pingree et al. 1978; Jones et al. 1982; Gowen 1984). While these areas are not provisionally mapped in western Washington, their occurrence is fairly predictable.

There have been several attempts to map the distribution of phytoplankton in portions of Puget Sound. These studies were based on short time scales (Munson 1969) and on an annual basis of total productivity in certain regions (Stockner 1979). Although phytoplankton may be inherently patchy in their distribution, replicate samples of chlorophyll a from the same station often show little more variability than can be attributed to statistical error (Platt et al. 1970). Anderson et al. (1984) found variation between nearby stations (not replicate samples at one station) on any specific day to average 15% for nutrients, 30% for plankton biomass measures (chlorophyll a), and 40% for species abundance.

Nutrient Sensitive Areas in Puget Sound. Certain portions of Puget Sound may have restricted water movement and other conditions that encourage the growth of phytoplankton. In these areas, surface waters may be measurably depleted of dissolved nitrogen for sustained periods during summer and early fall (SAIC 1986). At least four of these areas have been characterized in government sponsored reports as presently sensitive to nutrient enrichment. Sinclair Inlet, Budd Inlet, Oakland Bay and South Hood Canal have a combination of factors including relatively poor flushing, human sources of nutrients, and a degree of density stratification in summer months that combine to make them sensitive to nutrient enrichment (Tetra Tech 1988). Other areas of Puget Sound (south Puget

Sound inlets and some of its passages, Dyes Inlet, Liberty Bay, Agate Passage, marine waters east of Whidbey Island, Northern Hood Canal, Discovery Bay and Sequim Bay) have varying degrees of flushing, density stratification, and flux rates of nitrogen. These areas vary in their ability to assimilate additional nutrients.

EPA sponsored a study of water quality trends in 13 of the potentially sensitive subareas of Puget Sound (Tetra Tech 1988). In recent years the concentration of nitrate has declined in Port Gardner (surface and near surface water), Carr Inlet (surface water), and possibly central and southern Hood Canal (near surface and sub-surface water). The cause of the reduced levels in central and southern Hood Canal may be related to sub-surface phytoplankton activity in southern Hood Canal. The decrease in Carr Inlet is possibly related to phytoplankton use. Ammonia is rapidly converted to nitrate in most oxygenated aquatic environments (Harris 1986) and occurs at low concentrations in most of Puget Sound. Thus, there were no analyses of ammonia concentration trends.

Another nutrient required by phytoplankton is phosphate. Long-term phosphate concentrations decreased since the 1950s in seven of nine areas, both urban and rural (Tetra Tech 1988). Recent increases were seen in six of the study areas, all near urban centers. The significance of these changes is unknown, but such increases are likely insignificant due to the abundant natural nutrient concentrations.

The shallow, nearshore environment has had less attention in oceanographic and routine water quality sampling programs in the past. One study suggests conditions in very shallow, nearshore waters of central Puget Sound may be extensively depleted of dissolved nitrogen during late spring and early summer (Thom et al. 1984, 1988). The depletion occurred during a period of increasing light intensity coupled with enrichment from several sources, especially an urbanized creek that flowed onto the beach. The enrichment resulted in excessive seaweed growth and odor when the algae began to decay. The published literature for Puget Sound suggests that nearshore eutrophication is not a serious problem in most of Puget Sound at this time. However, it was suggested that increased discharge of nutrients due to population growth would possibly first be noticeable in the shallow, nearshore waters of embayments less subject to strong physical mixing processes. Physical processes (water currents and circulation) are the prime determinant of the degree of nutrient trapping and potential for eutrophication (Thom et al. 1984, 1988).

<u>Existing Marine Phytoplankton Problems</u>. Although in most areas, including Washington State, there has been no systematic attempt to assess the trends, the incidence of noxious or harmful phytoplankton blooms may be increasing worldwide. Historical records are limited in scope and of little statistical value, although most observers agree that the increase is actually occurring (Ayres et al. 1982; Tangen 1987; White 1987). Because noxious or toxic blooms may adversely affect shellfish and finfish aquaculture, there is a continuing and increasing monitoring effort worldwide (Tangen 1987), and specifically in the Pacific Northwest (Rensel et al. 1989).

The term "red tide" refers to toxic and non-toxic blooms of phytoplankton, bacteria, ciliates or even small zooplankters (Steidinger and Haddad 1981). Often, red tides are dominated by one or just a few species. Although dinoflagellates cause most of the red tides, only 20 of the more than 1,200 described dinoflagellates cause toxic red tides. For example, commonly seen red tides in southern and other parts of Puget Sound are related to blooms of a large heterotrophic dinoflagellate, *Noctiluca miliaris*. This organism may alter surface water coloration to a very noticeable orange-red tomato soup like color, and may accumulate along beach areas, but it is generally considered non-toxic to fish and marine life.

In areas of Puget Sound with restricted water movement, dinoflagellates are the dominant phytoplankton in nutrient-depleted areas during calm weather periods (Cardwell et al. 1977, 1979). Dinoflagellates often migrate vertically in the water column to obtain nutrients at depth during the night and use sunlight near the surface during the day. Another possible reason for this dominance is that they avoid being eaten by zooplankton by this migration. Estimates of dinoflagellate migration rates for many species range from about 0.5 to 2.0 m/h (Darley 1982) to 20 m/h (Paerl 1988). To some degree, these dinoflagellates operate independently of nutrient-depleted surface water conditions, because they can obtain adequate inorganic nitrogen below the surface stratum. However, when there is an adequate concentration of inorganic nitrogen below the surface, self shading and available light may be more important limitations to growth than nutrient concentration.

Because it is the sole source of paralytic shellfish poisoning (PSP) in Washington, the most important species of noxious phytoplankton in Puget Sound is the dinoflagellate, *Protogonyaulax catenella* (formerly *Gonyaulax catenella*). PSP may occur throughout Puget Sound, but regular outbreaks are restricted to certain bays such as Sequim Bay and Quartermaster Harbor. Although coastal areas may be seeded from offshore blooms that move onshore, it appears that embayments are the source of PSP blooms in Puget Sound (Nishitani 1988 personal communication). Worldwide, there has never been any evidence that fish farms caused or increased a bloom of noxious phytoplankton. In many cases, noxious and exceptional blooms have originated offshore and drifted inshore where they are noticed (Steidinger and Haddad 1981; Parker 1982).

PSP-causing dinoflagellates may form resting cells (cysts) that fall to the bottom and later germinate under favorable conditions or with time (Anderson and Keafer 1987). *Protogonyaulax catenella* requires a stable water column (no wind or strong currents), light, nutrients, a seed population, and 13° to 17° C water temperature for optimum growth (Nishitani et al. 1988). In other cases, low concentrations in surface water of nitrogen and possibly phosphorus has been proposed as a growth limiting factor for this species in Quartermaster Harbor. However, site-specific conditions such as greater depth and existence of a underlying nutrient-rich layer make comparison to other areas with PSP difficult. Diurnal vertical migration has been demonstrated for *Protogonyaulax* spp. in Washington State (Nishitani et al. 1988) and elsewhere (Eppley and Harrison 1974).

Although trace nutrients such as iron, copper, zinc, boron, sodium, and vitamin B12, are also important for the growth of phytoplankton, for marine waters they are considered of secondary importance. This has been shown by culture experiments where major growth response is elicited by addition of nitrogen, not minor elements or vitamins (Welch 1980). Therefore, phytoplankton growth is essentially determined by the amount of one nutrient which is in shortest supply, not by a conglomeration of different nutrients (Raymont 1980).

Elevated concentrations of biotin, present in fish food in small amounts (1 gram in 1,000 kg of food), has been found in the laboratory to increase the toxicity of one species of dinoflagellate, *Gyrodinium aureolum*, which was responsible for fish kills in the north Atlantic ocean (Turner et al. 1987). The relative significance of this finding is small, since there would have to be virtually no water movement for many months to allow the necessary level of biotin to leach from uneaten food beneath a typical fish farm. Turner et al. (1987) noted that most of the biotin is metabolized by the fish and would accumulate locally only under "adverse hydrographic conditions." The organisms most at risk from biotin accumulation causing a possible bloom would be farm-reared salmon.

Noxious phytoplankton appear to have caused occasional kills of fish reared in farms in Washington State. Unlike fish kills in Europe, which are usually associated with dinoflagellates, most of the problems in Washington state have been related to blooms of diatoms, especially certain members of the genus *Chaetoceros* (Bell et al. 1974; Rensel et al. 1989). Although there has been no detailed research on the issue, it appears that simple mechanical clogging and abrasion of the gills may be the main source of this mortality rather than toxicity. Diatoms of the genus *Chaetoceros* are very common in Puget Sound. Most species of *Chaetoceros* are considered benign or beneficial as food for shellfish and zooplankton.

5.3.2 Impacts on Phytoplankton

Salmon farms may cause or increase blooms of phytoplankton by localized nutrient enrichment (Weston 1986; Gowen and Bradbury 1987). This enrichment could occur when excessive dissolved nutrients are discharged into semi-enclosed waters with limited tidal mixing and strong vertical stratification.

Impacts on Phytoplankton in Nutrient Sensitive Areas. The addition of nutrients to an embayment can increase the production of phytoplankton. Phytoplankton forms the basis for the aquatic food chain in all aquatic systems and moderate increases in primary production will usually increase the production of zooplankton, filter-feeding fish and shellfish, and the larger predator fish harvested by sport and commercial fishermen. Phytoplankton is also a major source of dissolved oxygen.

However, in unusual cases, eutrophication may result in excessive growth of phytoplankton. This occurs in poorly flushed, shallow bays where hydrographic conditions allow a high-density of phytoplankton growth. Eutrophic bays may have an accumulation of small attached algae near shore and decaying macroalgae and phytoplankton. This accumulation of organic matter results in the same sediment impacts as described under farms, with the reduction of organisms in the sediment and the production of oxygen-depleted sediments. Hydrogen sulfide from these anoxic sediments and the decay of organic matter can result in obnoxious odors, a naturally occurring situation in some small bays.

The above description represents an extreme situation that occurs only in very limited areas of Puget Sound for short periods. In the water, prolonged or successive intense algae blooms can result in (1) shading of the bottom which prevents the establishment of larger attached algae and (2) the buildup of high levels of organic matter on the bottom (phytoplankton cells). During nighttime, when there is no sunlight for photosynthesis and oxygen production, phytoplankton consume oxygen. Thus, there can be wide variations in the dissolved oxygen levels from day to night, and in extreme cases, nighttime respiration and decomposition of decaying phytoplankton may reduce dissolved oxygen to levels that cause fish kills. An example of this situation is the extreme southern end of Budd Inlet, which has experienced fish kills during the summer.

In all but a few localized areas of Puget Sound, limited increases in phytoplankton production would have no adverse effect and would merely contribute more food to the food chain. Even in situations such as Budd Inlet, fish and shellfish are abundant. Shellfish in the area grow rapidly, feeding on the phytoplankton. As a comparison, commercially grown oysters in the nutrient- and plankton-rich waters of south Puget Sound reach market size in two to three years, while those grown in the relatively nutrient- and phytoplankton-poor waters of Hood Canal reach market size in four to five years.

In the past, Puget Sound farms located in restricted embayments (Henderson Inlet in southern Puget Sound and Shoal Bay near Lopez Island) suffered severe losses of salmon and other aquaculture species in some years (Rensel and Prentice 1980; Bill 1988 personal communication). Such losses contributed to the eventual removal of those facilities. Presently, there are no large, commercial farms operating in restricted Puget Sound waters.

Since few fish farms have been located in nutrient sensitive areas of the state, there has been little study of the possible effects of nutrient discharge on phytoplankton. One detailed study, conducted under worst-case conditions in Henderson Inlet, suggested that there was no effect from salmon farms on phytoplankton populations (Pease 1977). The study area had very limited water circulation, a condition worsened by the study area location within a shallow log dumping and storage area. Establishing reference ("control") areas for these worst-case studies of fish farm impacts on phytoplankton is difficult. There is a possibility that the effects of this farm on phytoplankton were overlooked by selecting reference areas too close to the farm location.

The effects of a salmon fish farm on dissolved nutrient concentration, phytoplankton density, and growth rates were investigated in a shallow passage of southern Puget Sound, near Squaxin Island, Washington (Rensel 1988c). It was hypothesized that if background levels of dissolved nitrogen were low for long enough periods, excreted nitrogen from the fish could have enhanced the growth of phytoplankton. The fish farm complex was the largest in western Washington located in surface waters that were depleted of dissolved nitrogen for at least some period of the time. Accordingly, the site constituted a "worst-available case" for fish farm in western Washington.

Two experiments were conducted. The first measured phytoplankton density and growth rates at the farm site during a period of maximum fish biomass and one month later during similar tidal and weather conditions, but after release of 60% of the fish. Monitoring of reference stations at both ends of the passage, beyond the immediate area of the fish farm, was conducted to assess source water conditions and provide a comparison to the farm site.

The results of the first experiment suggested no consistent and significant effect of the fish farm. However, natural variation of dissolved nitrogen concentrations confounded possible correlation between phytoplankton density/growth rate and the fish farm or reference stations. Moreover, only two of twelve samples were collected when major dissolved nutrients could have been limiting to phytoplankton growth. Therefore, phytoplankton cells were usually not limited by the ambient nitrogen concentration, and addition of nitrogen from the farm could not have had a stimulating effect on their growth.

Although the timing and conditions of this study were appropriate to maximize the effects of the fish farm on phytoplankton, and some effects were observed, most of the statistical tests indicated that phytoplankton growth rate did not significantly vary among stations or times except during one monitoring period. The first experiment further served to illustrate the complexity of monitoring phytoplankton in the field.

The second type of experiment that Rensel (1988c) conducted involved nearfield monitoring of nitrogen produced from the fish farm. During the period of maximum fish biomass, minor increases in dissolved nitrogen ($NO3+NO2+NH4$) were seen downstream of the farm during one tidal period, but not the next. Although total ammonia was significantly elevated within the farm compared to ambient concentrations, concentrations were well below the chronic exposure concentration for salmonids and other sensitive coldwater fish. At a distance of 30 m downstream of the fish farm, approximately 80% of the ammonia was nitrate, presumably oxidized through microbial nitrification.

Recent studies in Scotland (Gowen et al. 1988) focused on phytoplankton density and growth rates in a restricted, fjord-like sea-loch that had slow water movement (maximum flow of 16 cm sec^{-1}) and a large, salmon fish farm. Additionally, water exchange into the 50 m (164 ft) deep Loch Spelve is restricted by a shallow sill, only 4 ms (13 ft) deep. Although localized elevated ammonia was seasonally observed immediately around the fish farm, study results indicate no measurable effect of the farm on phytoplankton density. Carbon-14 isotope productivity data did not show any effect of the farm, although the authors felt that this portion of their study was based on insufficient data. In spite of slow water flow near the farms, the residency time of water was too brief to allow measurable increases in phytoplankton density or growth rates.

Stockner (1979) has suggested that an observed increase of phytoplankton stocks in the Strait of Georgia, British Columbia, was correlated with increased nutrient discharge in Vancouver, B.C., municipal wastes. Nitrogen and phosphorus waste loading doubled during the period 1951 to 1977, and dispersion into the Strait was enhanced by locating the discharge in the Fraser River plume. Nutrients are limiting to phytoplankton growth in that area at some places and times from July through September. Although the author did not prove a causal relationship, he suggested that nutrient enrichment could produce a positive effect by providing an expanded base for the aquatic food web, which includes stocks of commercially valuable fish such as salmon.

Sensitive Area Management. There are a number of factors that contribute to the nutrient sensitivity of any specific sub-area of Puget Sound. In general, the area is more sensitive if the following conditions exist:

- Strong density gradient (salinity and to a lesser extent, temperature) during calm summer and fall periods
- Low rate of water exchange with an outside water source
- Low rate of dissolved nitrogen flux into and out of the system
- Low phytoplankton crop (low total nitrogen load that could be proportionately more perturbed by added nutrients)
- Dissolved oxygen depletion, usually at depth
- Presence of sufficient seed stock of noxious phytoplankton species such as *Protogonyaulax catenella*.

Sufficient data exist in many of the potentially sensitive sub-areas to rank the sensitivity for all but the last factor. However, a ranking is not included here, since the specific location of a proposed farm site within a sensitive area has a tremendous bearing on the probability of measurable impacts. These factors should be considered on a site-specific basis in potentially nutrient sensitive areas listed in the affected environment section.

5.3.2.1 Modeling Phytoplankton Impacts

Modeling (mathematical simulation of the biological processes occurring in a bay) can allow estimation of potential impacts. Modeling of the entire Puget Sound basin is highly impractical (Winter et al 1975). However, an incremental approach, addressing certain potentially sensitive sub-areas, is possible using the tools of physical, chemical, and biological oceanography. Modeling of environmental effects upon water quality, a science developed largely to study industrial waste discharge, has recently been adapted to salmonid aquaculture. Near- and farfield nutrient and phytoplankton modeling fish farming has recently been developed (Parametrix Inc. et al. 1988; Kiefer and Atkinson 1988).

Nearfield impacts (ammonia production and oxygen consumption) from farms may be easily modeled using models that conservatively approximate a pipeline passing through the farm. These models neglect lateral mixing that would tend to reduce the measurable effects. Farfield models are much more complex and have been developed for potentially nutrient sensitive areas. Calibration of these models must account for existing conditions of temperature, nutrients, hydrodynamics, mixing rates with outside waters, variability of phytoplankton standing stock, and other factors.

Phytoplankton enhancement models assume a two-layer (box) system commonly used by oceanographers to describe surface and deep layers of aquatic systems (Broeker and Peng 1982). Such box models are generally valid because of limited mixing between surface and deep waters (Brooks 1960). These models are useful to estimate both surface and nearbottom impacts on dissolved oxygen, sedimentation, and nutrient-phytoplankton interactions.

The most important component of these models is the physical oceanography of the area: flushing rates and circulation patterns. Estimates of flushing can be made based on drogue and current meter studies, studies of conservative properties of seawater such as salinity, and through the study of the biota that reflect the physical and chemical conditions. Once flushing rates are known, site-specific water chemistry data and laboratory-derived and predictable features of phytoplankton growth may be applied to estimate response of phytoplankton to added nutrients. Such models have been verified as effective in predicting nutrient and phytoplankton conditions in actual practice (Atkinson 1984; Atkinson et al. 1984).

The analysis of the impact of one farm on the phytoplankton population in an embayment previously discussed may not be an accurate estimate of the actual impact of a fish farm if other farms are in the same embayment. The area immediately around the farm (nearfield) is usually independent of other farms as long as the farms are adequately spaced as discussed in the dissolved oxygen section. The farfield consists of the remainder of the embayment and is affected by the cumulative effect of all the farms in the embayment.

To estimate the cumulative effect of several farms on phytoplankton in a nutrient sensitive embayment, knowledge of three factors is necessary. They are (1) the size of the embayment, (2) mean depth (or mean mixed layer depth for a stratified embayment), and (3) the dilution or flushing rate of the embayment. For this analysis, it is necessary to consider a hypothetical embayment. This embayment is tidally flushed, is relatively small, has five farms, and is vertically stratified with a relatively shallow mixed layer. A suitable model for this type of analysis was developed by Kiefer and Atkinson (1988) for use in western Washington.

The Kieffer-Atkinson model simulates the nitrogen cycle within an embayment (Figure 11). The model considers three nitrogen pools: aqueous nitrogen, nitrogen in phytoplankton, and nitrogen in zooplankton. The nitrogen is exchanged among the different nitrogen pools through photosynthesis, respiration, grazing, excretion, basal metabolism/mortality, and loss from the system through the zooplankton pool. Photosynthesis is either light or nitrogen limited, while zooplankton grazing depends on the concentration of phytoplankton. In the simulation of summer conditions, when biological activity is high, the model predicts the steady-state nitrogen, phytoplankton, and zooplankton condition of the embayment.

For the hypothetical embayment, a surface area of 1.7 x (10^7) m^2 was chosen to represent a smaller bay near full development with five farms in operation.

A dilution rate (D) of 20% was selected using an exchange rate with source waters outside the embayment of 27% per tidal cycle based on data from the 19 sub-areas of Puget Sound discussed in the *Interim Guidelines* (SAIC 1986). Assuming a reflux coefficient of 0.5, the flushing factor would be 13.5% per tidal cycle. With approximately 1.5 tidal cycles per day, this results in 20.2% flushing per day.

In winter, when biological conditions are low, the model simplifies to a single expression for the mass loading to the embayment and resulting change in the nitrogen concentration (δN) given by:

$$\delta N = \frac{J * F}{A * Z_m * D}$$

where: J = mass nitrogen loading from the farms (kg/day)

F = the fraction of nitrogen produced by the farms that enters the embayment

A = surface area of the embayment (m^2)

Z_m = mean depth or depth of the mixed layer (m)

D = dilution rate of the embayment by tidal exchange (day^{-1})

The fraction of nitrogen released from the farms and remaining in the embayment (F) was estimated at 95%. Normally, this nitrogen quantity would be based upon site specific studies and may range from a low value of 10% to as much as 95%. For this worst-case estimate, a value of 95% is very conservative.

Loading of dissolved nitrogen produced by fish per day was taken as 0.25 g/kg fish per day and for a typical 500,000 lb/year facility would be 56.8 g/day times the percent soluble (87%) for a total of 50 kg/day. The depth of the surface mixed layer was conservatively assumed to be 5 m.

Model results for five 500,000 lb/year farms in a single embayment are presented in Table 5.

For winter conditions, the average increase in nitrogen concentration throughout the embayment would be 0.0085 mg/L. The natural concentrations of nitrate plus nitrite and ammonia at this time of year is about 1.5 mg/L. Therefore, the increase in the concentration of dissolved nitrogen would be less than 1%. This one-percent nitrogen increase would be negligible as there are already abundant natural sources of nitrogen that are not utilized during the winter.

During the summer, the model used here assumes that 95% of the dissolved nitrogen excreted by the salmon will be incorporated by the phytoplankton within the embayment. In many areas, this would be too conservative an assumption, but it is used here as a worst-case approximation. Under nutrient limiting conditions, the concentration of dissolved nitrogen in surface waters may be very low during the summer in many of the embayments, less than 0.1 mg/L, and in many cases 0.05 mg/L or less. There may be large amounts of total nitrogen at this time in the standing crop of phytoplankton, particularly in the late spring and early summer.

During summer steady state conditions, the model assumes the partitioning of phytoplankton biomass into one-half as much zooplankton biomass. Non-steady-state conditions are included in the model, but the other calculations are elaborate differential and simultaneous equations that involve use of a mainframe computer. See Kiefer and Atkinson (1988, 1989) for a more detailed description of the model, including necessary equations.

Based on the model, the summer phytoplankton crop would increase approximately 2% from five farms. This run of the model assumes that nominal conditions of phytoplankton abundance are 3.0 μ/L chlorophyll a. Under normal conditions, there is a range of phytoplankton abundance varying from about 1 to 15 μ/L chlorophyll a.

This modeling assumes a well-mixed condition throughout the surface layer and ignores nearfield effects from the farms. It also conservatively assumes no mixing of nutrients from the deeper layer with the surface. The actual siting of fish farms could be determined from modeling embayments to determine their flushing rate and circulation patterns, and evaluate nearfield conditions around the proposed farm.

Modeling is more critical in the siting of more than one farm in an embayment. In particular, the farm should be situated such that the nearfield conditions from multiple farms do not overlap and cause high localized concentrations of nutrients and phytoplankton or low concentrations of dissolved oxygen.

In summary, the nitrogen added to a small embayment from five farms is not expected to adversely affect the embayment's phytoplankton abundance. Extremely small, shallow, or poorly flushed bays would be more sensitive to nutrient loading from fish farms, but proper analysis of proposed farm sites could identify such embayments.

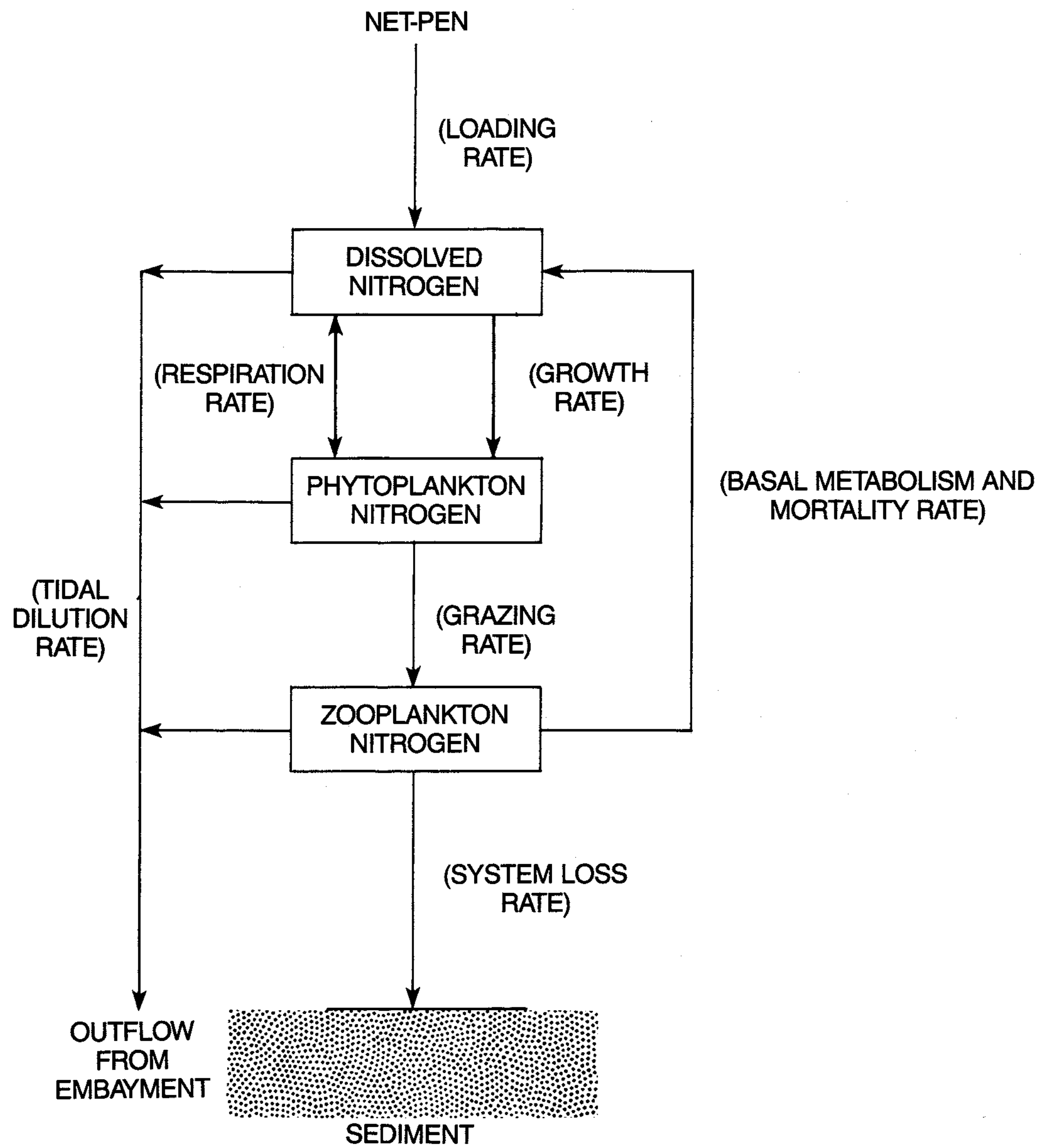


Figure 11.
Schematic Representation of the Processes Simulated in the Keiffer and Atkinson Phytoplankton-Nutrient Model

Table 5. Effect of five farms in an embayment on the nitrogen, phytoplankton, and zooplankton concentrations for summer and winter conditions based on the Kieffer and Atkinson model (1988).

	Dissolved Nitrogen (mg/L)		Phytoplankton (mg/L)		Zooplankton (mg/L)	
	Ambient	Increase	Ambient	Increase	Ambient	Increase
Winter	1.5	0.0085	0.012	0	0.003	0
Summer	0.012	0	0.186	0.004	0.186	0.004

5.3.2.2 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect potential impacts of fish farms on phytoplankton:

- The SEPA process provides the opportunity for State resource agencies to evaluate individual fish farm proposals at specific sites on a case-by-case basis using the most current, available information.

- State water quality standards do not set limits or targets for phytoplankton concentration. The *Interim Guidelines* (SAIC 1986) do not set specific values for phytoplankton production near fish farms. The *Guidelines* deal with the issue of potentially excessive phytoplankton productivity near farms by proposing limits on the dissolved nutrient production from farms. See Section 5.2, Water Quality.

  The limit on nutrient production from a farm relates to flux of nitrogen from a farm compared to the total tidal flux of nitrogen into an embayment. A maximum 1% increase in the flux (not to be confused with the concentration) due to fish farming is recommended. Yet, the situation is actually much more complex and the guidelines result in a very conservative estimate of nitrogen flux. Many of the embayments are relatively deep and may have a two-layer, stratified system with nutrient depletion only present in the surface layer. The *Guidelines* rely upon measurement of dissolved nitrogen in the surface layer only, and not the deeper, nutrient-rich layer which may be much larger (such as in central Hood Canal). The *Guidelines* result in a much more conservative estimate of the 1% flux because only data from the nutrient-depleted surface waters are considered. (Duxbury 1988 personal communication). Thus, the deeper the embayment, the more conservative the existing guidelines are for the true 1% flux of nitrogen.

  In addition, the calculation of nitrogen flux in the *Guidelines* does not consider the biological conversion of dissolved inorganic nitrogen (ammonia and nitrate) to organic nitrogen (plankton tissue). The rate of nitrogen cycling ("turnover time") within an embayment depends on several factors including phytoplankton crop size, phytoplankton growth rate, grazing by zooplankton, and to a lesser degree, sedimentation (Harris 1986).

The *Guidelines* legitimately did not consider these unquantified factors, and sought instead to use the existing Ecology database. That database includes dissolved inorganic nitrogen (that is, nitrate, nitrite and ammonia) and orthophosphate. While nitrogen to phosphorus concentration has been used as an indicator of nutrient depletion in surface waters, the method is complicated in coastal waters by the relative rates of water exchange through a restricted area and varying rates of internal biochemical processes acting to adjust the ratio of N:P availability (Smith 1984; Harris 1986; Paerl 1988).

5.3.2.2 Preferred Alternative

The *Guidelines* provide an adequate framework for establishing which embayments may be nutrient sensitive. By establishing areas where farms should be restricted, limiting production amounts for specific geographic areas, and using a conservative methodology for estimating a 1% flux of nitrogen; the *Guidelines* used a reasonable approach to ensure that fish farms would not create significant impacts on potentially nutrient sensitive areas. It is recommended that the areas defined as sensitive in the *Guidelines* (Holmes Harbor, Budd Inlet, and Hood Canal south of Hazel Point) be identified as such in WACs.

For areas so defined, it is recommended that the following additional guideline be adopted into WACs:

- Limit total fish production within a sensitive area to that which will not adversely affect existing biota. The use of predictive models to estimate allowable production levels in sensitive areas is recommended.

The maximum production levels for fish farm development in the 19 embayments identified in the *Guidelines* should be adopted into WACs with the following additional measure:

- Where the maximum production level is attained in any of the 19 embayments, subsequent fish farm proposals must demonstrate to State resource agencies by field and modeling studies that additional proposed development will not adversely affect existing biota.

5.3.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Adoption of the measures identified in the Preferred Alternative will provide a conservative approach to avoiding significant adverse impacts. The SEPA process allows a case-by-case assessment of fish farm proposals and their potential affect on nutrient sensitive areas, and no additional mitigation measures are necessary.

5.4 CHEMICALS

This issue involves the use of antibiotics and antifoulants in fish farm operations. Concerns include the environmental risks associated with chemical usage, accumulation of antibiotics in the environment or tissues of indigenous biota, and whether the use of antibiotics encourages growth of bacteria resistant to antibiotics.

5.4.1 Affected Environment

Antibiotics. For fish farming applications, two antibiotics are currently registered by the U.S. Food and Drug Administration (FDA). These are (1) oxytetracycline (OTC), and (2) a potentiated sulfonamide marketed under the trade name Romet. Other antibiotics, such as oxolinic acid, may be used on a limited basis if special permission is granted by the FDA.

OTC, marketed under the trade name Terramycin or TM-50, is the most commonly used antibiotic in salmon farms. It is generally regarded as highly effective against vibriosis. It is also used to treat furunculosis. (See Appendix D for a further discussion of fish diseases.)

Romet is a relatively recently-licensed antibiotic for use in fish farming. It has been effective against furunculosis and enteric redmouth disease in freshwater fish hatcheries, and has also been demonstrated to be effective in saltwater pens against vibriosis.

The FDA practices a more conservative policy toward licensing drugs for use in aquaculture than do governments of many other countries. Thus, drugs such as oxolinic acid and chloramine-T, which are effective against certain bacterial diseases of salmon, are commonly used in other parts of the world, but are not used in the United States.

The digestibility of OTC, oxolinic acid, and chloramphenicol was tested in rainbow trout in freshwater by French scientists (Cravedi et al. 1987). These researchers found that the digestibility of OTC was 7 to 9%, in comparison with chloramphenicol's 99% and oxolinic acid's 14 to 38%. Chloramphenicol is not used in animal husbandry in the United States due to its high toxicity and, as noted above, oxolinic acid is not licensed for general use in aquaculture in this country. According to these authors, the relatively low level of digestibility of OTC may result from its affinity for calcium. Calcium is present in fish food in the form of shell or fish bone. The authors also note about 90% of OTC administered in fish feed is excreted in the feces as the parent compound (that is, as the chemical form added to the feed). That means use of the drug could contribute to the accumulation of OTC in the sediments below a farm and possibly to the development of antibiotic resistance in bacteria in these sediments. Austin and Al-Zahrani (1988) found that OTC and other antibiotics altered the number and type of bacteria in the digestive tract of rainbow trout fed antibiotics.

Austin (1985) discussed the effects of antimicrobial compounds used in fish farming that may escape into the environment. He noted that data are not available on the quantities of antimicrobial compounds entering the environment from fish farming. However, his research provides estimates of probable concentrations of antibiotics leaving freshwater fish farms. The estimated dilution of OTC, based on maximum allowable levels of administration, was 1 part in 50,000,000. This dilution was regarded as a worst-case estimate, based on no retention of the administered drug in the fish. Thus, Austin (1985) concludes that the concentrations of drugs reaching the environment are very small.

Austin (1985) noted that use of antibiotics in fish farms could lead to an increase in antibiotic resistance among bacteria in the farm effluent. Other authors have reported the phenomenon of antibiotic resistance of bacteria near fish farms in which the medications are applied (Aoki 1975, 1988; Aoki et al. 1971, 1972b, 1974, 1977, 1980, 1984, 1985, 1986a, 1987a; Aoki and Takahashi 1986; Takashima et al 1985; Bullock et al. 1974; Toranzo et al. 1983). Bacteria can gain antibiotic resistance through the selection of bacteria that contain resistance factors, or plasmids, some of which may be transferable from one fish pathogenic bacterium to another under certain conditions (Akashi and Aoki 1986b; Aoki and Kitao 1985; Aoki and Takahashi 1987; Aoki et al. 1972a, 1986b, 1987b, 1981; Mitoma et al. 1984; Toranzo et al. 1984). In addition, plasmids, or resistance factors, can confer resistance to more than one antibiotic when transferred from one bacterium to another (Aoki et al. 1987a). The presence of plasmids has been documented in both fish pathogenic bacteria (see above citations) and in native aquatic bacteria (Burton et al. 1982).

A FDA study to evaluate the use of OTC for aquatic applications, analyzed the environmental impact of the antibiotic on disease control in lobsters held in impoundments (Katz 1984). Based on seawater dilution and lack of long-term selective pressure favoring the persistence of OTC resistant organisms, Katz (1984) concluded that "there should be no build up of antibiotic resistant populations of microorganisms from the use of OTC in treating gaffkemia in lobsters." In the same report, Katz concluded that "the potential of R-factor (resistance-factor) transfer between organisms should be minimal" as a result of dilution, low levels of nutrients, low temperatures, and high salinity of seawater.

The technical literature cited above indicates several factors. The occurrence of antibiotic resistant bacteria in association with aquaculture depends on the diversity, frequency, and dosage and type of antibiotic administration. Environmental factors including temperature and rate of dilution will affect the probability of generating antibiotic resistant bacteria.

Reports of antibiotic resistance from Japan (see citations above) are from very intensive aquaculture sites characterized by warm temperatures, high densities of fish grown in confined ponds, and the use of a variety of antibiotics not registered for use in the United States. As well, the dosage and duration of antibiotic treatment in Japan appears to exceed both legal and general practices in the United States. Thus, while these studies document antibiotic resistance in fish pathogenic bacteria as a result of the administration of antibiotics, they should not be interpreted to indicate that similar antibiotic resistance will occur under very different environmental conditions and fish husbandry practices.

Importantly, other studies have noted that the increased level of antibiotic resistance associated with antibiotic use around fish farms was soon reduced after antibiotic use stopped (Austin 1985; Austin and Al-Zahrani 1988; Aoki et al. 1984). This phenomenon has also been observed in human medicine (Forfar et al. 1966) where dramatic declines in resistance levels of bacteria occur after antibiotic treatments are stopped.

The possibility of transfer of drug-resistance factors from a fish disease-causing bacteria to a potential human disease-causing bacteria, Vibrio *parahaemolyticus*, was investigated in Japan (Hayashi et al. 1982). Using test tube conditions and temperatures of about 86°F to 96°F, these authors were able to transfer drug resistance to *V. parahaemolyticus*. These authors also noted that in Japan, where antibiotics have been extensively used in aquaculture, drug-resistant strains of the *V. parahaemolyticus* have never been found in the environment.

Toranzo et al. (1984) reported the transfer of drug resistance from several bacteria isolated from rainbow trout to the bacterium, *Escherichia coli*. The transfer of resistance was performed under laboratory conditions at 25°C (77°F). The studies demonstrated the potential for transfer under controlled laboratory conditions. These authors concluded that "Responsible use of drugs in aquaculture will aid in minimizing the development and spread of R^+ factor-carrying microorganisms that may confer drug resistance . . . ."

The accumulation of antibiotic residues in shellfish near fish farms has received some study. In the Puget Sound area, Tibbs et al. (1988) found that mussels, oysters, and clams suspended within a matrix of net pens in which coho salmon were being given food supplemented with OTC had no detectable levels of the antibiotic in their tissues. That study examined the phenomenon of antibiotic accumulation in shellfish under worst-case conditions for the distance between the fish pen and shellfish (the shellfish were placed within the matrix of fish pens). Weston (1986) noted the large dilution factor that would occur when antibiotics are used in a fish farm. He made conservative calculations and computed a diluted level of 3 parts per billion of OTC in a parcel of water passed through a fish pen receiving medicated feed. Given this dilution factor and the water-soluble nature of antibiotics like OTC, Weston concluded that there was little potential for bioaccumulation of antibiotics used in fish farming.

Jacobsen and Bergline (1988) reported the persistence of OTC in sediments from fish farms in Norway. These authors also conducted laboratory tests and concluded that the half-life (time required for a given concentration to decay to 50% of the starting concentration) for OTC in marine sediments was about 10 weeks, but would likely depend on sediment type and other factors. They examined sediments from underneath four farms, but did not report the duration or quantities of OTC applied at each location. OTC was found in sediments from the four farms at levels from 0.1 to 4.9 mg/kg (ppm [parts per million]) of dry matter at up to 12 weeks following the administration of antibiotic. This level would potentially be high enough to inhibit marine bacteria (1-2 ppm is considered inhibitory), including vibrios. However, since the concentration is reported relative to dry weight, it overestimates the actual concentration in hydrated sediment. The study does demonstrate that measurable OTC can accumulate below fish farms. Conservatively, the study can be interpreted to show the highest concentrations were just above inhibitory levels on a dry-weight basis. The authors also noted that the oxidation state of the sediments would affect the half-life of OTC. In a preliminary study conducted in the Puget Sound region, no OTC was found in sediments near fish farms (Wekell 1989).

The Wekell (1989) study included the analysis of shellfish tissues placed near fish farms in Puget Sound for the presence of OTC. In this preliminary study, no OTC was detected in the shellfish tissues.

An Environmental Assessment of OTC by the FDA (USFDA 1983) concluded that "the use of OTC is beneficial to control diseases in aquatic environment and does not pose adverse effects on this compartment. However, steps should be developed to avoid the emergence of drug-resistant organisms."

Accumulation of antibiotics in marine sediments is also a function of the dilution factor (which determines the level of antibiotic reaching the sediment), biotransformation of the compound in the sediment, oxidation state of the sediment, and water solubility of the antibiotic. Levels of OTC such as those calculated by Weston (1986) to reach sediments are not likely to have inhibitory effects on non-pathogenic bacteria, which are little affected at levels below 1 ppm (Carlucci and Pramer 1960). In their study of the microbial quality of water in intensive fish rearing, Austin and Allen-Austin (1985) note that while it is difficult to make generalizations, their study indicated that two freshwater fisheries they monitored did not produce "a major imbalance in the aquatic bacterial communities."

Romet is a relatively new antibiotic on the fish farming scene. The approved dosage and length of treatment is one-half that of OTC. Therefore, one would expect its effects to be significantly less than that of OTC. The use of vaccines has been effective in reducing the amounts of Romet or OTC used in fish farms.

Antifoulants. Organic tin compounds, known for their toxicity to marine invertebrates (Hall and Pinkney 1985) and salmon (Short and Thrower 1987), were once used in Washington. Their use for most purposes is now prohibited by State legislation. Therefore, organic tin antifoulants are no longer used by the fish farming industry in Washington. Their use has also been virtually eliminated in fish farming in other parts of the world. No other chemical means of reducing fouling on nets is in use.

In Norway, netting containing copper wire is used to reduce fouling, and in British Columbia, waxy antifouling compounds have been used recently for the same purpose.

5.4.2 Impacts of Chemicals

Although some technical details require further study, the issues surrounding antibiotic use in fish farming have received detailed study. Those studies demonstrate that antibiotics will be released into the environment when used as a medication for farmed fish. Antibiotics have not been detected in shellfish held near salmon farms. One Norwegian study found concentrations of one antibiotic close to inhibitory levels in four farms. The concentrations of antibiotics outside of the immediate proximity of the fish farm are regarded by most authors as being too low to have adverse effects.

The presence of plasmids, a mechanism by which bacteria transfer resistance, is documented in pathogenic and native aquatic bacteria. Antibiotic resistance has been recorded in bacteria around fish farms. Most of the technical literature describing antibiotic resistance in fish pathogenic bacteria is based on studies of aquacultural practices and environmental conditions not comparable with salmon farming in the Puget Sound region. These conditions include high temperatures, high densities of fish, close proximity of multiple farms, and use of a variety of antibiotics not used in fish farming in the United States. Conditions in the studies reporting antibiotic resistance favor the development of resistance. In comparison, salmon farming in the Puget Sound region is much less likely to favor development of antibiotic resistance due to lower densities of fish farms, fewer antibiotics in use, and lower water temperatures. In addition, federal regulations that apply to the use of antibiotics in fish farming in the United States appear to be much more stringent than those that apply in Japan and Europe, where most of the technical literature has originated.

Shellfish held within a fish farm did not accumulate detectable levels of OTC. This observation, and the calculated dilution of antibiotics away from fish farms, suggest that any quantities of antibiotics accumulated in shellfish, or other benthic or planktonic marine invertebrates would be below levels of concern.

The lack of antibiotic resistance in a potential human disease-causing bacteria such as *V. parahaemolyticus* in Japan, despite the extensive use of antibiotics in aquaculture there, indicates the transfer of drug resistance from fish to human pathogenic bacteria is unlikely. It appears such transfer is a laboratory phenomenon that requires highly controlled conditions and is not representative of phenomena that occur in the environment. The Toranzo et al. (1984) study further demonstrates the potential for drug resistance transfer under controlled conditions (77°F). The lower temperature range found in Puget Sound (and required for salmon farming), is one key environmental factor that will prevent the laboratory-documented resistance transfer from occurring in association with salmon farms in Puget Sound.

5.4.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the potential impacts of chemicals:

- FDA is charged with regulating the safety of food fish. FDA has an active research and regulation program aimed toward determining and implementing food safety requirements. Procedures involving efficacy, toxicity, and chemical residues are required for the licensing of antibiotics for use on food animals.

- The *Interim Guidelines* mention organic tin compounds and the use of FDA approved antibiotics. Other than the licensing of these antibiotics, there are presently no State standards for the use of antibiotics at fish farms.

5.4.2.2 Preferred Alternative

Some risk of adverse impacts exists. These impacts can be effectively managed by taking the following recommended steps:

- Vaccination by effective protocols currently in place will reduce the use of antibiotics. It is recommended that an educational program be undertaken for fish farmers on the use of vaccination.

- Fish farms should report antibiotic use to a State regulatory agency.

- Appropriate State agencies should present educational programs for fish farmers on the use of antibiotics.

- Further research should be undertaken to verify that shellfish held near fish farms in various environments do not accumulate significant levels of antibiotic, as well as research to establish any potential amounts of the antibiotic in sediments near fish farms in Puget Sound.

5.4.3 Mitigation Measures and Unavoidable Significant Adverse Impact

No significant environmental impacts were identified under the legal use of antibiotics in fish farming in Puget Sound. However, since some risk of drug resistance can result from improper and excessive antibiotic use, all use of antibiotics should be conducted in a controlled and documented manner.

If the recommendations in the Preferred Alternative are adopted, they, in conjunction with existing regulations, would be adequate to avoid significant adverse impacts. No additional mitigation measures are necessary.

5.5 FOOD FISH AND SHELLFISH

This issue concerns the potential effect fish farms may have on existing fish and shellfish resources in Puget Sound. There is concern that farms may cause a degradation of commercially valuable species and potentially affect sensitive habitat.

5.5.1 Affected Environment

There are several commercially valuable species of food fish and shellfish harvested in Puget Sound. Commercial landings of salmon average 44 million pounds (20,000 MT) per year in Puget Sound. Marine fish landings average 5000 metric tons (11 million lbs) and shellfish landings average 5.6 metric tons (13 million lbs). The total landings of all species in Washington have a process value of around $300 million (Ward and Hoines 1987). The size of commercial fishing industry and the potential impacts of fish farms on the industry are discussed in Section 6.3, Commercial Fishing.

In addition to the commercial fishing industry, recreational fishing is a major activity gaining increased emphasis. In 1986, about 1.2 million angler trips were made to catch 830,000 salmon, and 1.8 million trips were made to harvest 4.6 million lb of clams, oysters, crab, and shrimp. In addition, 756,000 marine fish were taken by boat-based sport fishers.

The following are some of the species and important habitats that could be affected by fish farms:

Clams and Oysters. A variety of clams are found on intertidal beaches and subtidally to about 21 m (70 ft) in Puget Sound. Butter clam (*Saxidomus gigantens*), littleneck clams (*Protothaca staminea* and *Tapes japonica*), and horse clam (*Tresus capax*) are found in dense beds in substrates of mixed mud, sand, and gravel. There are an estimated 84 million kg (170 million lb) of clams in beds covering about 5,400 acres. Geoduck clams are taken commercially from depths of 6 to 18 m (18-60 ft), but they occur at depths of at least 110 m (360 ft). Subtidal sand and mud provide major habitat for geoducks. About 34,000 acres of geoduck beds exist in Puget Sound containing approximately 30,000 metric tons of clams. Approximately 1,800-2,300 MT (4-5 million lb) of geoducks are harvested annually at a value of about $5 million.

Two oysters are found in Puget Sound, the native oyster (*Ostrea lurida*) and the imported Pacific oyster (*Crassostrea gigas*). Oysters are generally limited to intertidal beaches where they would not be directly affected by fish farms. All commercial oyster harvest is from farmed beds that also provide the basis for populations on recreational beaches.

Octopus. The giant octopus (*Octopus dofleini*) prefers rocky, high current areas for spawning and foraging. They appear to feed on any fish or invertebrate they can catch. They are commonly harvested from soft bottom areas by traps (Mottet 1975).

Sea Urchins. Two commercially harvested sea urchins occur in Puget Sound waters: the red urchin (*Strongylocentrotus franciscanus*) and the green urchin (*S. droebachiensis*). They occur at depths extending from intertidal to depths of several hundred feet, generally on rock and other solid substrates, but also use soft substrates. Urchins tend to eat algae, but use many food sources including dead animals and algae. They will also eat organic matter discharged in sewage (Mottet 1976).

Crab and Shrimp. Dungeness crabs (*Cancer magister*) and red rock crab (*Cancer productus*) are common predator/scavengers of Puget Sound feeding on small clams, worms and other organisms. Both use intertidal and nearshore areas as nursery areas with adults found in nearby water offshore. Dungeness crabs are the primary species harvested commercially and recreationally, and are most abundant north of Everett and in Hood Canal. Red rock crab are found throughout Puget Sound. Seven species of shrimp such as the spot prawn (*Pandalus platyceros*), coonstripe shrimp (*P. danae*), and sidestripe shrimp (*Pandalopsis dispar*) are harvested in Puget Sound. They are generally harvested from soft bottom areas although coonstripes are common in rock riprap areas. Shrimp are also predator/scavengers feeding on small organisms in the sediments.

Salmonids. Five species of Pacific salmon are present, at times, in Puget Sound. These include: chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*). Juveniles, after rearing in freshwater, forage on small epifaunal and planktonic organisms in shallow nearshore areas. Most salmon migrate out of Puget Sound as juveniles to forage in the open ocean, although some coho and chinook remain in Puget Sound year-round. Adults migrate through Puget Sound, concentrating near points of land and river mouths.

Two species of anadromous trout are present in Puget Sound waters: steelhead (*O. mykiss*) and searun cutthroat (*O. clarkii*). Steelhead follow the same basic rearing and migrational patterns of salmon but spend less time in Puget Sound as juveniles. Searun cutthroat are different in this regard since they normally remain in Puget Sound. They live primarily in and around river mouths as adults.

Herring. Pacific herring (*Clupea harergus pallasi*) occur throughout Puget Sound. These pelagic fish spawn from late winter through spring in eelgrass and algae beds at certain locations. Herring tend to spawn each year in the same areas, some of which have been mapped by WDF. All such areas are intertidal to shallow subtidal (about -20 ft MLLW) although herring spawn have been found as deep as 40 ft (Haegele et al. 1981).

Juvenile herring are commonly found in nearshore waters during spring and summer. These pelagic fish migrate in large schools, gradually moving into offshore waters as they grow. Adult herring occur throughout the deeper waters of Puget Sound at most times of the year. Herring are harvested for both food and bait.

Smelt. Surf smelt (*Hypomesus pretiosus*) are pelagic fish that spawn on some intertidal beaches in Puget Sound at tidal heights of about +7 to +13 ft MLLW. They spawn throughout the year on beaches of coarse sand to small gravel (Penttila 1978).

Pacific Sand Lance. Pacific sand lance (*Ammodytes hexapterus*) are common and live in a number of habitats in Puget Sound. They can be found offshore, in shallow water, and partially buried in beach sand. Adults feed mainly on copepods but also on other organisms of similar size (Hart 1980).

Lingcod. Lingcod (*Ophlodon elongatus*) spawn preferentially in rocky areas in the winter, and juveniles use nearshore areas as nursery grounds. They are found from intertidal depths to the deepest portions of Puget Sound. Lingcod are a bottom-oriented fish that prey on other fish and large invertebrates.

Rockfish. Rockfish of many species are taken both commercially and recreationally. Many species of rockfish are found in Puget Sound. They occur from shallow subtidal depths to the deepest portions of the Sound. Although they are often associated with rocky areas, they are found near all bottom types. They are predators of other fish and large mobile invertebrates. They are often attracted to submerged structures such as artificial reefs.

Perch. There are three seaperches that are common in Puget Sound, the pile perch (*Rhacochilus vacca*), the striped seaperch (*Embiotoca lateralis*) and the small shiner perch (*Cymatogaster aggregata*). Perch are harvested both commercially and by sports fishermen. Each of these species inhabits nearshore areas and are often attracted to submerged structures.

Cod. Pacific cod (*Gadus macrocephalus*) are harvested by sports fishermen in Puget Sound. Although they may be found at times throughout the deeper waters of Puget Sound, they are harvested primarily from channels where they congregate to spawn in late winter. The sports and commercial harvest of cod in Puget Sound is about 160,000 kg (350,000 lb) annually.

Flatfish. Flatfish of many species occur in Puget Sound. These fishes reside at essentially all depths on the mud and gravel bottoms. They are harvested by both commercial and sport fishermen. Many species use shallow nearshore areas of nursery grounds.

5.5.2 Impacts on Food Fish and Shellfish

The primary impacts floating fish farms are likely to have on food fish and shellfish populations are the result of the farm structure and sedimentation that may occur under the farm. The effects of sedimentation upon the benthic community have been discussed in Section 5.1, Bottom Sediment and Benthos. In general, at low rates of deposition, filter feeders such as clams will be enhanced, but at high levels immobile organisms will be displaced from the area below the farm. Weston (1986) reported that mobile predators/scavengers are attracted to the area around aquaculture facilities to feed on excess food and on the small organisms, including opportunistic worms, which are enhanced around the farm. Weston's review reported increased densities of crab, flatfish, starfish, perch, lobsters and other predators and surface feeders from sites around the world. In Puget Sound, Pease (1977, 1984) observed increased numbers of crab, and various fish around farms and mussel rafts. It is likely that shrimp numbers near farms will also increase.

The farm structures also provide a habitat in the open water environment to attract fish such as surfperch and rockfish in larger numbers than would normally be found in an open-water portion of Puget Sound. Fish farms and their floats also provide a substrate on which algae and invertebrates grow, providing a food source that increases the attraction of various fishes. These organisms, along with waste food, would provide an available food source attractive to many fish.

Floating objects apparently protect small fish from predation (Mitchell and Hunter 1970). In Japan, floating structures have been used intentionally to attract fish, and in Puget Sound, artificial reefs of rock and concrete have been constructed to provide vertical relief and substrate for benthic organisms. Fish associated with farms in Puget Sound include shiner perch and other surfperch, true cod, lingcod, dogfish, sculpins, and flatfish.

Fish and mobile invertebrates are expected to be attracted to the periphery of fish farms, unless organic deposition results in anoxic conditions in the water. This is only likely in areas with very poor circulation (Earll et al. 1984). This effect would be self limiting in that anoxic conditions would have the same adverse impacts to the fish farm as they would to wild fish.

Fish and shellfish could also be adversely affected by the deposition of organic sediments upon important habitats. Clams and geoducks occur in dense beds. A farm directly above such a bed in shallow water could create an azoic zone immediately below the farm, killing all the shellfish within this zone. In addition, sedimentation over spawning areas (such as for lingcod and octopus) could smother eggs and eliminate the area for future spawning use. For many species, the availability of spawning habitat determines the ultimate abundance of the species. Other species may have different habitats that are critical to specific life stages, which could be adversely affected by sedimentation.

The depths of water regulated for fish farms preclude direct impacts to intertidal shellfish and fish habitats.

5.5.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the potential impacts of fish farms on food fish and shellfish:

- WDF or WDW require a Hydraulic Project Approval (HPA) permit for virtually all work within the ordinary high water mark of fresh or salt waters in the State of Washington (RCW 75.20). The WDF issues nearly all permits in areas accessible to salmon. The HPA provides WDF with permitting authority to ensure that fish farm proposals do not have a significant adverse impact on food fish and shellfish species, or their habitats.

- The objective of WDF habitat management policy is to achieve a net gain in the productive capacity of food fish and shellfish habitat in Washington. This objective is achieved by pursuing three goals:

    1. Maintain the present productive capacity of all food fish and shellfish habitat.

    2. Restore the productive capacity of habitats that have been damaged or degraded by natural causes, or as a result of human activities.

    3. Improve the productive capacity of existing habitat and create new habitat.

- WDF has the authority to "preserve, protect, perpetuate, and manage. . ." food fish and shellfish resources (RCW 75.08). This authority can be used to protect habitat not explicitly covered under the Hydraulic Code.

- As proprietary manager of state-owned aquatic lands, DNR is concerned with impacts to shellfish resources on these lands. DNR evaluates the impacts of proposed leases to shellfish and other aquatic land uses. When necessary, siting and operational adjustments may be required to protect shellfish resources. In cases where shellfish productivity is lost, reimbursement will be required.

- Ecology administers a water quality anti-degradation policy through the NPDES or State Waste Discharge permitting programs. This policy prevents impacts to existing beneficial resources including existing food fish and shellfish resources (WAC 173-201-035).

- The SEPA review process provides all State resource agencies with an opportunity to review individual fish farm proposals on a case-by-case basis. This mechanism allows each proposal to be evaluated using the most current information available for a specific site.

- The *Interim Guidelines* recommend that fish farms should not be sited where they are likely to adversely affect habitats important to commercial or sport food fish or shellfish fisheries, that are of critical ecological importance, or that are especially sensitive to degradation by culture activities. The *Guidelines* identify WDF as the agency with expertise and responsibility for the designation of and assessment of impacts on plant, invertebrate, and fish habitats of special significance.

- The *Guidelines* establish a buffer zone around habitats identified by WDF as being of special significance. In areas where water depths are less than 75 ft, a distance of 300 ft in the direction of prevailing tidal currents and 150 ft in all other directions should separate farms from habitats of special significance. Habitats that have been defined by WDF as of special significance are listed in the *Guidelines*. These areas include eelgrass and kelp beds, rocky reef habitats, habitats with significant geoduck and hardshell clam populations, habitats important to Dungeness crab, herring, and other species of fish. Other habitats may be determined to be of special significance as determined on a case-by-case basis through SEPA review.

- In addition to the habitats of special significance, the *Guidelines* also address sedimentation impacts to the benthos which affects food fish and shellfish habitat. See the discussion of the depth and current guidelines in Section 5.1, Bottom Sediments and Benthos.

- The *Guidelines* also recommend that a diver survey be performed at a proposed farm site to help identify habitats of special significance. DNR presently requires information from this diver survey as part of its Aquatic Lands Lease application.

5.5.2.2 Preferred Alternative

In addition to the use of existing regulations, it is recommended that the following measures be undertaken:

- The habitats identified in the *Interim Guidelines* should be included in the appropriate WACs as habitats of special significance.

- A case-by-case evaluation of the need for buffer zones around habitats of special significance should be incorporated into WACs. The distances discussed in the *Interim Guidelines* should be used as a reference.

5.5.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

The SEPA process provides State agencies with an opportunity to assess potential impacts of floating fish farms on food fish and shellfish on a case-by-case basis using the most current available information for a specific site. In addition to the use of existing regulations, adoption of the measures identified in the Preferred Alternative would avoid significant adverse impacts to food fish and shellfish resources. No additional mitigation measures are necessary.

5.6 IMPORTATION OF NEW FISH SPECIES

Commercial farming of fish frequently involves the use of species not indigenous to the area or specifically bred for use in fish farms. There is a concern that Atlantic salmon would escape farms and compete directly with native Pacific salmon populations.

5.6.1 Affected Environment

Fish farming in Washington State is presently limited to coho, chinook and Atlantic salmon and steelhead trout. In the future, other species may be employed if market conditions and culture technology permit profitable culture. For example, culture technology for turbot, halibut, cod, eel and other cold-water species of fish are being developed in Europe and Asia. Some of these species may eventually be economically feasible for culture in Puget Sound. Atlantic salmon are presently the species of choice for the salmon aquaculture industry in Europe and Washington State. This preference is due to the established marketability of Atlantic salmon, and their adaptability to culture (for example, tolerance to high density stocking and resistance to disease).

As with all new introductions, the importation of any plant or animal, terrestrial or aquatic, may pose a threat to native species if released into the wild. Many introductions of new species worldwide have led to ecological disasters. Not only might the animal itself spread unchecked, but diseases these animals may carry might be spread to native species (see Section 5.8, Disease). Therefore, new species imported to Washington must be screened, evaluated, and monitored with the utmost precaution. The actual risk of harmful impacts to native species depends upon the species proposed for culture and the culture system. Given the number of species considered for culture it is impossible to examine their possible interactions with native fish stock. As an example of the possible genetic interactions and possible mitigation measures, the introduction of Atlantic salmon into Puget Sound will be evaluated.

While the introduction of new fish species into habitats far removed from their native ranges has provided man with many benefits, each introduction poses a risk to the indigenous aquatic organisms of the new environment. Fish and shellfish have been and continue to be introduced into new areas for several reasons. They increase sport and commercial fishing opportunities and replace native stocks decimated by disease, environmental changes, or over harvest. Fish and shellfish have also been introduced in new areas to control pests and for commercial culture.

Examples in Washington include the introduction of Atlantic trout and salmon species into freshwater lakes and streams for sport fishing, mosquito fish (Gambusia) for insect control in eastern Washington, grass carp to control aquatic plants in small lakes, and the Pacific (Japanese) oysters – the basis of the state's oyster industry, etc. Accidental introductions have also been common. For example, a variety of invertebrates have been introduced around the world as fouling organisms attached to the hulls of ships or released with the discharge of ballast water.

5.6.2 Impacts of Importation of New Fish Species

General. The introduction of a new species into an area always poses unavoidable risks. While risks can be minimized, all introductions involve a level of unpredictability and environmental risks cannot be completely eliminated.

Perhaps the greatest movement of fish species in history is occurring due to the development of fish farming. Rainbow trout, native only to the western United States, is the foundation of the European trout industry. African tilapia is grown all over the world. Pacific salmon from Washington are being farmed in eastern Canada, Chile, New Zealand, and Japan. Atlantic salmon, the basis for the salmon farming industry, is now grown in the northeast Pacific.

Atlantic Salmon. The potential for impacts from introducing Atlantic salmon to Puget Sound depend on two variables: (1) that significant numbers of fish escape from fish farms, and (2) the ability of fugitive fish to outcompete resident stocks of salmon and steelhead. Two hundred and five Atlantic salmon were reported captured in 1988, and only twenty-five have been reported thus far in 1989. There is a strong economic incentive to prevent this escape given that smolts are worth around $3 each and a harvestable fish may be worth over $60 to the grower. Technology in fish farm engineering is developed to the point where such catastrophic structural failure is rare. There are, however, uncontrollable events, such as ships straying from shipping lanes or perhaps a 1,000-year storm event, which may break up farms. However, fish farms are normally placed well out of shipping lanes and in relatively calm waters. The major source of escapement appears to be from "leakage" where a few fish at a time escape through small holes in the nets or during handling and transfer. The most critical stage may be as smolts, when there is a wide range in fish size, are introduced into the farm. If the mesh size of the net is too large, or if it is an old net with small holes, some of these small fish may pass through.

An ecological threat to Pacific salmon and trout is theoretically possible should Atlantic salmon establish a wild run in Washington waters. Atlantic salmon are reared commercially at 13 seawater sites in Puget Sound (DNR 1987). Additional freshwater hatcheries produce smolts used to stock these farms. All culture operations have the potential to make inadvertent releases. Theoretically, these releases could establish a wild population of Atlantic salmon in Washington.

There have been scattered, qualified successes in maintaining Atlantic salmon populations in fresh water (Lindbergh 1984; MacCrummon and Got 1979). Attempts to establish Atlantic salmon in lakes have been moderately successful in Washington and Oregon. However, Atlantic salmon have only become established in lakes when planted as the only salmonid species in the system or in combination with brook trout (*Salvelinus fontinalis*). Atlantic salmon are apparently unable to compete with rainbow trout (*Oncorhynchus mykiss* [formerly *Salmo gairdneri*]) effectively. Lindbergh (1984) interviewed a number of researchers with WDW, NMFS, and the Oregon Department of Fish and Wildlife involved with the lake planting programs in Oregon and Washington. The consensus was that rainbow trout clearly dominate the Atlantic salmon and that Atlantic salmon would be displaced by native trout, if not naturally, then from continual restocking by the various natural resource agencies.

In the past, WDF and WDW have released Atlantic salmon into Washington waters with the intention of establishing permanent runs. They released Atlantic salmon smolts into two Puget Sound tributaries: Chambers Creek in 1950 and Minter Creek in 1980 (Lindbergh 1984). In addition, over the past 12 years about 3,000 Atlantic salmon have escaped from NMFS research farm at Clam Bay in Puget Sound. These escaped fish were sea-conditioned Atlantic salmon weighing between 0.5 and 13 lbs (Waknitz 1988 personal communication). In 1988, commercial salmon boats reported picking up Atlantic salmon in their nets while fishing in northern Puget Sound and a few fish were reported caught by Canadian trollers of the west coast of Vancouver Island. All these fish weighed between 4 and 12 lbs. This indicates that Atlantic salmon are escaping from fish farms and surviving in the wild.

Occasionally, Atlantic salmon have also been observed in the Nooksak, Skagit, and Nisqually Rivers and are being monitored by WDF, WDW, and tribal fisheries biologists. Lindbergh (1984) estimates that government agencies have released about five million Atlantic salmon in British Columbia, Washington, Oregon, and California waters. Despite these propagation efforts, intentional and accidental releases of Atlantic salmon into Puget Sound and other northeastern Pacific waters have all been unsuccessful in establishing self-sustaining runs. Similar introductions to establish wild populations have also been attempted in 36 countries around the world. The only successful introductions have been in the Faeroe Islands near Iceland, which is in the natural range of Atlantic salmon, and in southern Argentina (Lindbergh 1984; MacCrummon and Got 1979). Based on this persistent lack of success in establishing Atlantic salmon where other salmonid populations exist, it is unlikely that they could establish self-sustaining runs in Washington rivers.

5.6.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the impact of introducing a new species.

- Federal law (CFR 16.13, Title 50) prohibits the entry of live fish or eggs of salmonids unless such importations are by direct shipment, accompanied by a certification that the importation is free of the protozoan Myxosoma cerebalis and the virus causing viral hemorrhagic septicemia (VHS). This certification must be signed by a fish pathologist recognized by the Department of Interior.

- In addition to Title 50 requirements, WDF prohibits importation of any live salmonid product, save that of inspected eyed eggs and sperm from outside North America. Where eggs are being imported into Washington, WDF also requires that the Title 50 inspector in the country of origin send laboratory tissue and fluid samples from the broodstock from which the eggs will be derived to WDF for examination for pathogens.

- WDF requires a Finfish Import/Transfer Permit for importation of any aquatic organism into the State for culture purposes, or for any transfer of these organism within the State (WAC 220-77-030). The purpose of this permit is to ensure that diseases, pests, or predators are not introduced into State waters. In addition, a Fish Health Certificate, issued by a WDF-recognized fish pathologist, must accompany all import or transfer operations. On-site inspections are made by WDF staff at fish farms to monitor compliance with provisions and conditions prescribed in import/transfer permits.

- WDF requires a Hydraulic Project Approval (HPA) permit for virtually all work within the ordinary high water mark of salt waters in Washington (RCW 75.20). The HPA process provides WDF with permitting authority to ensure that any species proposed for culture in a fish farm would not have a significant impact on indigenous populations.

- WDF has the authority to "preserve, protect, perpetuate, and manage..." food fish and shellfish resources in Washington (RCW 75.08). This authority can be used to prevent the introduction of species that could have an adverse impact on existing food fish and shellfish species.

- The SEPA process provides WDF with the opportunity to review individual fish farm proposals on a case-by-case basis. This mechanism allows WDF to evaluate each farm proposal with the most current, available information. In addition, the SEPA process allows WDF to assess potential impacts of the proposed fish stock to be raised in relation to a specific site.

5.6.2.2 Preferred Alternative

Existing regulations should continue to be used to manage the introduction of new species to Washington. No further recommendations are being made.

5.6.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

The use of existing regulations to control the introduction of new species for commercial culture in Washington is adequate to avoid significant adverse impacts to indigenous species of food fish and shellfish in the State of Washington. The SEPA review and HPA permitting processes allow case-by-case evaluation of proposals and no further programmatic mitigation measures are necessary.

5.7 GENETIC ISSUES

There are two major issues involved in the potential genetic impacts that fish farms may have on wild salmon populations. The first is the potential impact non-native species, specifically Atlantic salmon, may have on wild populations of native salmon. The second is the potential genetic impact of rearing native Pacific salmon in fish farms. The relationships of these two different situations to existing conditions are quite different, thus the potential for genetic impacts are quite different. The following discussion describes how these two situations relate to existing conditions.

5.7.1 Affected Environment

Only Pacific salmon and not Atlantic salmon are present as wild populations in the Puget Sound region. These wild populations are supplemented by State and federal hatcheries that release more than 100 million juvenile fish into Puget Sound waters each year. Nearly all wild populations have intermixed to some degree with hatchery-reared fish. Existing hatchery practices will allow this intermixing to some degree for the foreseeable future.

Local experts agree that widespread farming of Pacific and Atlantic salmon in Puget Sound poses a minimal threat to wild salmon populations in terms of genetic degradation (Mahnken 1988; Hershberger 1988; Waples 1988). The subject is somewhat complex, however, and will be discussed below in some detail.

Different river systems generally have genetically different stocks of Pacific salmon. Because the characteristics of each river are unique, selective pressures on the populations in those rivers have lead to genetic adaptations that favor their survival. For example, salmon that spawn in the upper reaches of long river systems (for example, the Fraser or Columbia) must make much longer journeys to spawn than salmon from shorter river systems, such as those of Puget Sound. Thus, fish from the upper reaches of longer river systems have become more robust and store larger amounts of energy in order to sustain the long journey. Because introduced fish lack the energy reserves to make the entire trip to spawn, attempts to stock these upper reaches with fish from shorter rivers have been unsuccessful. Therefore, there is concern that if distinct fish stocks mix, important adaptive genetic traits would be diluted.

Some interbreeding of Pacific salmon stocks occurs naturally as fish stray from one river system to another. Rivers are often naturally propagated with fish this way after major natural disasters in the river system, such as landslides and volcanic eruptions. In nature, the incidence of straying is limited, thus new genetic traits can be incorporated into an existing population without diluting the existing genetic traits. If large populations of genetically distinct fish were to interbreed, then such dilution could occur.

In some special cases, farmed Pacific salmon may or may not be grossly different from stocks in adjacent rivers. This variation could lead to interbreeding with indigenous populations. While speculative in nature, there are theoretical grounds for this concern.

One concern is the potential for wild populations to be genetically altered by genes from Pacific salmon farm escapees that are inappropriate for natural conditions. There are two potential sources of Pacific salmon for fish farms that may be grossly different genetically from wild fish. One source might be fish from a river system that is geographically distant and environmentally different from the river system closest to the farm site. The other source might be Pacific salmon from a nearby river system that are highly inbred due to long-term genetic manipulation within a hatchery environment.

In hatcheries, fish are actively or passively selected for many genetic traits suiting them to that environment. These traits may be useless or even harmful in the natural environment. Passive selection includes such traits as tolerance to crowding, stress, disease, low water quality, reduction in fright susceptibility and aggressive behavior, and adaptation to hatchery diets. For example, aggressive behavior is a waste of energy to a hatchery fish. In the wild, it is a necessary behavior pattern. Traits actively selected for in-breeding programs, such as egg size, flesh color and taste, fat content, and maturation rate, have no use in wild conditions. Traits such as rapid growth rates are only beneficial when food is very abundant. Where food is limited (as is usually the case in the wild), this trait might be detrimental. However, a large portion of salmon in the North Pacific are from hatchery stocks. In the natural environment, these fish are exposed to all the environmental pressures of wild fish, which will tend to select against genetically maladapted individuals. The successful return of these fish to their hatchery streams indicates the retention of sufficient beneficial traits for survival.

The interbreeding of two grossly different wild stocks can occur by transplanting eggs from one distant river system to another. In the natural environment, salmonids tend to evolve into genetically discrete stocks adapted to specific ecological conditions within nearby river systems with similar geography (such as southern Puget Sound). In fact, there are over 100 stocks of chinook salmon in North America identified as genetically discreet (Mahnken 1988; Hershberger 1988). Genotypes (the genetic makeup of an organism) adapted to one region cannot be expected to survive as well in a distant region as the genotypes of the resident population. Therefore, interbreeding of two distant wild stocks could reduce the fitness of the progeny.

Another concern is the high degree of genetic variability within salmon populations. Maintaining this variability may be important to the long-term fitness (reproductive ability) of wild populations by providing the plasticity they need to survive sudden changes in environmental conditions. Genetic variability may be reduced in hatchery populations even if random selection is practiced during spawning. Nonintentional (passive) selection occurs in the form of different survival rates, favoring fish best suited for hatchery conditions. Since hatchery conditions are relatively stable, genotypes capable of tolerating environmental extremes are gradually lost.

Several studies have demonstrated lower variability in hatchery trout stocks (*Salmo sp.*) compared to wild stocks (Allendorf and Phelps 1980; Ryman and Stahl 1980; Stahl 1983). In some cases, this condition causes development of undesirable traits, such as lower viability of gametes (cells capable of participating in fertilization). While this has been demonstrated in trout and Atlantic salmon (Aulstad et al. 1972; Kincaid 1976a and 1976b; Ryman 1970) it has not been documented in Pacific salmon (*Oncorhynchus sp.*) This lack of documentation may be due in part to the lack of totally captive (captive throughout their life cycle) populations of Pacific salmon. The exception is Domsea Farms in Clam Bay, Washington, which has genetically manipulated coho for over 10 years. However, this effort encompasses only seven generations.

The degree of genetic degradation in wild populations by farm Pacific salmon escapees depends on two basic factors: first, the extent of genetic difference between the farmed and wild fish. Second, the degree of interbreeding between the two groups. "Normal" hatchery fish (released into marine waters, growing to maturity in the wild) may be very different from wild populations in the vicinity. Frequently, wild fish are used as supplementary broodstock in WDF and WDW hatcheries; and hatchery fish are frequently planted into wild populations. This can result in homogenesis between the two groups.

Farm fish differ from "normal" hatchery fish in that natural selection in the ocean is replaced by artificial selection in the hatchery. This allows aquaculturists to genetically manipulate the stock more extensively. However, farm fish do not necessarily have to be very different from wild fish. Efforts can be made to infuse wild genes into the hatchery population if desired.

The degree of interbreeding between farm escapees and wild fish depends on the proportion of the two populations within a stream and the spawning times of the two groups. For the farm and wild populations to interbreed, the spawn timing of the two groups must overlap. The greater the overlap, the greater the potential for interbreeding. If the two groups are widely divergent in spawn timing, no interbreeding can occur. The following four factors affect the number of farm fugitives entering any particular stream are the following:

- the number of fish escaping

- the marine mortality rate (determining the number surviving to adulthood)
- the success of homing these fish to the farm site
- the proximity of the farm to the stream of interest.

Homing ability in salmonids is influenced primarily by imprinting on the water odor components at the release site (Hasler et al. 1978). Imprinting ability is greatest during the smolting period, when juveniles are typically transferred from freshwater hatcheries to farm sites. However, the homing/imprinting process in salmonids has a genetic factor (Bams 1976). This factor may either be diminished or inappropriate for successful homing in farm fish transplanted from distant locations. Such fish, fugitive from fish farms, would be expected to stray farther than strays from locally derived stocks (Quinn 1988). It should be pointed out that wild fish stray to some degree naturally. Quinn (1988) has proposed that straying is a evolutionary alternative to homing and that the two processes are in dynamic equilibrium.

Hatchery trout have demonstrated lower survival rates than wild trout in the natural environment (Chilcote et al. 1985; Reisenbichler and McIntyre 1977). In these experiments, hatchery/hatchery crosses survived best under hatchery conditions while wild/wild crosses survived best in natural streams (Reisenbichler and McIntyre 1977). Impacts to wild populations would then be temporary and in the form of wasted reproductive effort (less fit genotypes would be lost due to natural selective pressures).

5.7.2 Genetic Impacts

For farm-reared fish to have a genetic impact on wild salmon populations, three conditions must occur. First, significant numbers must escape from fish farms. Second, the escapees must survive and return to mix with a wild population on the spawning grounds in sufficient numbers to affect wild populations. Third, the escapees must have the genetic capacity to either breed with or outcompete the wild population if they have mixed in sufficient numbers.

Fish do escape from fish farms, but generally in very low numbers compared to adjacent wild and hatchery populations. Because of these relatively low numbers of escapes, there is little potential for genetic impacts in most situations. However, in the case of a major disaster that destroys fish farms, there is a theoretical potential for sufficient numbers of fish to escape to cause a potential genetic impact, if other conditions are also met.

Are escapees likely to survive and return to mix with a wild population on the spawning grounds in sufficient numbers to cause a genetic impact? It does appear that escapees from fish farms survive at rates roughly comparable to the survival of hatchery fish. However, few if any of these survivors are likely to reach spawning grounds of wild fish. In most cases, these escapees will return to the location of the farm from which they escaped. Only if this location is near a spawning stream could any appreciable portion of the survivors be expected to stray into the stream. If the escapees were reared in the stream water as juveniles, and held in pens near the stream, then major portions of the surviving population of escapees would be expected to enter the stream and mix with the wild population. Thus, only under unusual circumstances can a sufficient number of escaped fish be expected to mix with wild fish on the spawning grounds and provide a real potential of a genetic impact.

Should escapees mix on the spawning grounds in sufficient numbers the potential impact from Atlantic salmon and Pacific salmon would be very different. The Atlantic salmon cannot genetically mix with the wild population of Pacific salmon. Theoretically, they could establish a natural spawning population of this non-native species. Such a theoretical population could compete with the wild population. Thereby, reducing the wild population to a sufficiently low level that a genetic component is lost from this wild population. However, past experience indicates that Atlantic salmon are not capable of effectively competing for Pacific salmon even when the Atlantics are intentionally introduced into a stream.

Atlantic Salmon. Atlantic salmon, which belong to the genus *Salmo*, are genetically incapable of breeding with Pacific salmon of the genus *Oncorhynchus*. They are genetically very different from and genetically incompatible with Pacific salmon (chinook, coho, chum, pink, and sockeye), which belong to the genus *Oncorhynchus*. Thus, it is essentially impossible that Atlantic salmon pose any direct genetic threat to these species. Under the best conditions (laboratory experiments), researchers have been unsuccessful at crossing these two groups (Lindbergh 1984; Refstie and Gjedren 1975).

In addition, Atlantic salmon spawn several months earlier than Pacific Coast steelhead and cutthroat trout, and would have little opportunity to attempt such hybridization (Heggberget 1988; Mahnken 1988).

Pacific Salmon. At this time, nearly all Pacific salmon reared in the Puget Sound region are reared in hatcheries or delayed release facilities by the state or federal government, or tribal entities for release into Puget Sound. Few fish farms raise Pacific salmon in the Puget Sound region. To evaluate the potential genetic impact of future farms, we have conducted a reasonable worst-case escapement analysis as follows. To keep this analysis in perspective, the reader should recognize that even this theoretical condition is highly unlikely in terms of existing hatchery practices.

Assumptions:

- 40 farms in Puget Sound
- 750,000 lbs production per farm (approximately 750,000 fish [0.1 to 10 lb range])
- Escapement rate from "leakage" = 0.5% (Forster 1989 personal communication)
- Escapement to rivers = 0.2% (Rensel et al. 1989)
- One major escapement (75% loss) in a model year in farms raising coho or chinook salmon
- 10% of farms use native salmon species, 90% use Atlantic salmon.

Escapement to rivers:

- From "leakage losses": 30 adult fish in a normal year
- From major escapement: 1,125 adult fish in a model year
- Total salmon escapement to Puget Sound rivers in a bad year: 1,155.

The 5-year average escapement of wild coho and chinook salmon to Puget Sound rivers is 259,520 (Flint 1989 personal communication). Chinook average 51,700/yr and coho 207,820/yr. If all of the escapees were coho, the potential for interbreeding with wild fish in the rivers would range from 0.1 to 0.5%. If all were chinook, the potential would be from 0.6 to 2.2%. Impacts would not be significant unless the percentage of fish interbreeding with wild fish (assuming that the farmed fish were grossly maladapted for existence in the wild) reached the 10 to 20-percent range (Waples 1989 personal communication). The potential risk of an all-coho or all-chinook escapement in the model is reduced by 90%, considering only about 10% of the farms will have native species.

To put this in perspective, the present hatchery system (State, federal, and tribal) releases about 100 million chinook and coho smolts per year into Puget Sound waters (WDF 1988). If 1% return as adults, and 1% of those stray from hatchery release sites (Quinn 1988), then about 10,000 hatchery fish are straying. About 8.5

million chinook and coho smolts are intentionally released from fish farms in Puget Sound by WDF and tribal facilities (WDF 1988). From these, about 2,890 fish enter rivers to spawn (Rensel et al. 1988). Adding these two sources of strays, about 13,000 hatchery fish enter rivers to spawn every year. This amounts to about 5% as many hatchery fish as wild fish (coho and chinook). To date, no adverse genetic effects have been identified. The strays from the regular WDF hatchery system and the delayed-release program are not as genetically modified as future commercially farmed fish might be. However, there would be 10 to 1,000 times as many fish from the WDF hatchery system as there would be from commercial fish farms.

Considerable interbreeding has already occurred between wild stocks in Puget Sound and stocks of different origin. Transplantation of stocks between river systems has been a common practice for nearly 90 years in Washington. In addition, straying rates for transplanted fish are greater than wild or established hatchery populations (Bams 1976). As a result, few if any wild populations of coho, chinook, or steelhead in Puget Sound have escaped at least some interbreeding with fish of different genetic character.

Assessing the potential impact of farmed Pacific salmon or steelhead on wild populations is difficult given the speculative nature of the issue. However, local experts agree that significant genetic impacts on wild populations due to widespread fish farming in Puget Sound is unlikely (Seidel 1988; Mahnken 1988; Herschberger 1988). The worst-case scenario would be where many genetically maladaptive escapees ascended a stream with a relatively small wild population. The impacts to the wild population, if any, would be reduced fitness of the interbred progeny. Without constant infusion by many escaped fish, these hypothetical maladaptive genes would disappear gradually due to selective pressure, making any impacts temporary.

5.7.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the potential for genetic impacts to indigenous species:

- WDF has the responsibility to preserve, protect, perpetuate, and manage fisheries resources (RCW 75.08). WDF requires that all stocks used in the fish farming industry have prior approval from WDF to ensure that farm fish will not have an adverse genetic impact on indigenous species. This authority also allows WDF to deny any transfer or importation that poses a potential risk to native fish or other aquatic or marine organisms.

- The Hydraulic Code and the HPA permit system (RCW 75.20) provides WDF with the authority to ensure that fish farm proposals do not have a significant adverse impact on indigenous fish.

- The SEPA review process provides WDF with an opportunity to review fish farming proposals for any potential genetic impacts related to siting farms near streams with indigenous salmon populations. SEPA review allows WDF to evaluate proposals using the most current scientific information available for a specific site.

- WDF considers it undesirable to interbreed indigenous wild salmon populations with stocks of grossly different genetic character. Reasons for this recommendation are discussed above in Section 5.7.1.

5.7.2.2 Preferred Alternative

It is recommended that the following guidelines be used by WDF when reviewing fish farm proposals:

- When Pacific salmon stocks are proposed for farms in areas where WDF determines there is a risk to indigenous species, WDF should only approve those stocks with the greatest similarity to local stocks near the farm site.

- In areas where WDF determines there is a risk of significant interbreeding or establishment of harmful self-sustaining populations, WDF should only approve the farming of sterile or monosexual individuals, or genetically incompatible species.

- In areas where WDF determines that wild populations could be vulnerable to genetic degradation, WDF should establish a minimum distance of separation between farms and river mouths.

5.7.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

WDF and other local experts agree that the potential for significant genetic impacts resulting from farm escapees interbreeding with wild stocks is low. Existing regulations and the use of the guidelines indicated in the Preferred Alternative are adequate to avoid any significant adverse impacts and additional mitigation measures are not necessary.

5.8 DISEASE

Concerns about disease in the aquaculture industry involve the potential for introducing exotic harmful pathogens in eggs imported from other geographic areas, transferring of diseases from farmed salmon to wild salmon, and transmitting diseases from farmed salmon to shellfish near the aquaculture facility.

5.8.1 Affected Environment

Infectious Fish Diseases. Fish farm rearing of salmon is well established in Norway and Scotland and practiced in Chile, New Zealand, Japan and other countries as well. Coho salmon (*Oncorhynchus kisutch*) farming was developed in the Puget Sound region beginning in the 1970s by the National Marine Fisheries Service, the University of Washington, and at the commercial site near Manchester, Washington. Subsequently, farming of this species expanded in other countries, surpassing that practiced now in Puget Sound. Atlantic salmon (*Salmo salar*) is the species now most commonly reared commercially in marine fish farms in Washington state. Past research on diseases of salmonids has emphasized conditions occurring during their freshwater phase of development. With the increase in marine aquaculture, infectious diseases of salmon from farms in Washington waters have recently been described in the literature (Harrell et al. 1976; Hoffman 1984; Harrell and Scott 1985; Harrell et al. 1986; Elston et al. 1986, 1987; Kent and Elston 1987a; Kent et al. 1988a,b). The major issues are discussed in the sections immediately following this paragraph. See Appendix D for a discussion of the specific infectious diseases of salmon in the Pacific Northwest and Appendix G for a discussion of VHS disease of fish.

Introduction of Exotic Pathogens. Some fish diseases are restricted in their geographic distribution since the affected fish are limited to their natural geographic range. Thus, a risk of introducing exotic fish pathogens (that is, those that do not exist in an area receiving imported fish) exists when fish are transported to a new location. Occurrences of exotic fish pathogenic parasites (Becker and Brunson 1968; Hoffman 1970; Bauer and Hoffman 1976; Hoffman and Schubert 1984; Johnsen and Jensen 1988), bacteria (Whittington et al. 1987) and viruses (Sano et al. 1977) in new locations have been attributed to the transfer of fish. However, the actual geographic and host distribution of many fish diseases is unknown. Following more in-depth studies, some pathogens considered "new introductions" have been found to have been established for many years but previously unidentified (Hedrick et al. 1985).

The study of diseases of farm-reared fish has led to the discovery of previously undescribed diseases. Research on fish diseases has previously been directed toward those diseases occurring in freshwater because the major fish culture operations were freshwater hatcheries. The observations of new diseases in marine fish farms are indications that those diseases occur naturally in wild salmon during their seawater phase of development, or are a result of the intensive husbandry of the fish.

To prevent importation of exotic diseases, some states such as Alaska restrict aquaculture to indigenous stocks. Of specific concern in North America, are Atlantic salmon eggs imported from Europe and the potential risk of introducing viral hemorrhagic septicemia disease (VHS) (see Appendix G).

Transmission of Disease to Wild Fish. Wild animals act as reservoirs for several diseases of domestic animals. The most dramatic example is probably in Africa where one-third of that continent is unsuitable for rearing domestic livestock because of the reservoir of *Trypanosoma* parasites in wild game (Murray and Trail 1986). Conversely, there are a few examples of transmission of disease from domestic mammals to wild mammals. An example of this phenomenon is also in Africa, where the viral disease "Rinderpest" is transmitted from domestic cattle to wild hoofed animals.

In the aquatic environment, wild fish can act as reservoirs for serious diseases of cultured fish. These include bacterial kidney disease (Evelyn 1988) and infectious hematopoietic necrosis (IHN) virus. IHN infects returning sockeye salmon in all major production populations in Washington (Amend and Wood 1972). Examples of this phenomenon also exist in fish farms. Wild salmon and non-salmonid fish can be reservoirs for ectoparasitic sea lice (Copepoda) of pen-reared salmon, Cod are apparently the reservoir of *Parvicapsula* (Protozoa: myxosporea), which causes kidney disease in pen-reared coho salmon (Johnstone 1984). A significant risk exists for transfer of pathogens from captive to wild fish if the captive fish are infected by exotic pathogens. Thus, the state and federal regulations now in place are essential for the protection of fishery resources.

However, diseases have apparently been transmitted to wild fish from hatchery fish. The diseases were passed either following stocking of hatchery fish into natural waters, or to wild fish downstream from a freshwater hatchery containing diseased fish when the diseased condition of the stocked fish was not determined or recognized. Parasites can also be transferred by movement of an exotic species into a non-indigenous area. In fresh water, infections of an external parasite, *Gyrodactylus salaris*, occurred in wild and farmed Atlantic salmon in certain Norwegian streams following introduction of salmon parr from infected public hatcheries in Sweden (Johnson and Jensen 1988). The parasite, *Nitsztchia sturionis*, was introduced to the Aral Sea with sturgeon larvae transported from the Caspian Sea, and the parasite decimated the native sturgeon following its introduction (Dogiel and Lutta 1937; Dogiel 1954).

In Washington State, trout in two lakes became infected with the bass tapeworm (*Proteocephalus ambloplitis*) following the introduction of largemouth bass (Becker and Brunson 1968). The role of the tapeworm in disease was not determined and Becker and Brunson (1968) reported that "whether infections influence the survival of young rainbow trout is conjectural in the absence of controlled experiments." Yoder (1972) observed the parasite, *Myxobolus cerebralis* (which causes whirling disease), in wild brook and brown trout, downstream from a hatchery with infected rainbow trout. From this observation, he concluded that the source of the infection was the hatchery.

Transfer of Disease to Shellfish. Although at least one author has speculated that shellfish can be reservoirs for fish pathogens such as viruses, no definitive research has been conducted on this point (Meyers 1984). Meyers (1984) speculated that bivalve molluscs could serve as reservoirs for fish viruses such as infectious hematopoietic necrosis virus (IHNV), which occurs in wild stocks of sockeye salmon and other salmonids. In addition, Meyers (1979) demonstrated that viruses pathogenic for freshwater fish can be isolated from oysters from Long Island Sound, New York. Although shellfish are known to concentrate certain chemicals and viruses, there is no evidence this ability has any significance for disease transmission to wild stocks of fish and shellfish.

Many reports indicate that vibriosis is a significant disease of both shellfish and fish in intensive husbandry (Elston 1984; Egidius 1987). Vibriosis can be an important problem in fish farming when proper husbandry and, in some cases, vaccination, is not performed. In bivalve mollusc hatcheries, vibriosis is considered a husbandry disease controlled by proper hygienic practices (Elston 1984). One report (Tubiash et al. 1973) cites "cardiac vibriosis" as a disease of adult American oysters, *Crassostrea virginica*. The disease, which occurred in about 0.04% of oysters in a sample in from Chesapeake Bay, caused enlargement of the pericardium, but the oysters were otherwise normal. Although these authors suggested that the disease could be due to *Vibrio anguillarum*, a fish pathogen, they were not able to substantiate this claim with experimental research. Other reports (Brown 1981a,b and other authors; see Elston 1984 for review) indicate that *V. anguillarum* can cause disease in bivalve mollusc larvae in intensive shellfish culture. In practice, this bacterium has not been important in mollusc husbandry in the Pacific Northwest. A relatively newly designated species, *V. tubiashi* (Hada et al. 1984), is recognized as a bivalve mollusc pathogen at certain locations in Europe and North America. It should be noted that reports of vibriosis in mollusc larvae all refer to conditions and diseases in intensive hatchery culture of these animals. There is no evidence that vibriosis is important in limiting natural populations of bivalve mollusc larvae, but this has not been systematically investigated.

5.8.2 Impacts of Diseases

Introduction of Exotic Pathogens. As discussed above in Section 5.8.1, a primary concern with the growth of the fish farming industry in Washington is the possible increased risk of introduction of exotic diseases. This increased risk is minimal because regulations are in place to restrict importation of serious exotic pathogens of salmon. These regulations are discussed further in Section 5.8.2.1.

Fish eggs are currently being imported into Washington on a limited basis for existing freshwater aquaculture industries, with each case reviewed by the appropriate state agency. Live salmonids cannot be imported. State regulations (WAC 220-77) to control importation of exotic fish pathogens are administered by WDF. In addition, salmonid eggs imported from foreign sources must be individually permitted and inspected by a USFWS agent under Title 50 of the U.S. Code of Federal Regulations.

Transmission of Disease To Wild Fish. Review of the technical literature indicates the risk of transmission of disease from farms to wild fish is possible, but not likely a significant problem. Fish disease control regulations, cited below in Section 5.8.2.1, are in place in Washington to prevent the importation of exotic infectious diseases which could pose a significant risk to native fish. In addition, experience with other domesticated animals indicates that husbanded stocks of animals are usually at a greater risk from the transmission of infectious diseases than wild stocks. Diseases observed in fish farm culture of salmonids in Washington are husbandry diseases resulting from holding the fish in captivity. Such diseases are non-exotic; infectious agents that cause such diseases originate from environmental sources or wild fish.

Cultured salmon and trout have been and will continue to be released throughout Washington by State and federal hatcheries. Though the risk is minimal, the possibility of transmission of pathogens from released hatchery-reared fish to wild fish exists today. This risk is likely greater from the many hatchery fish released into state waters, than from the relatively small numbers of captive fish in farms.

The carcasses of dead fish from fish farms are potential vectors of infectious fish diseases although there is no evidence indicating that this has been a significant mode of disease transmission. In the interests of good animal husbandry practices, dead fish should be removed from the pens regularly, then stored and disposed to prevent the potential spread of infectious disease agents which they may contain.

Transmission of Disease To Shellfish. There is no impact related to infectious diseases on invertebrate populations that can be reasonably predicted as a result of salmon farming practices. Fish pathogens are largely distinct from invertebrate pathogens. Although some technical reports cite *V. anguillarum*, a known fish pathogen, as a mollusc pathogen, the examples cited in these reports are exceptional cases from industrialized locations in Europe and North America. They refer to cases occurring in intensive husbandry of bivalve larvae. Important mollusc pathogens such as *V. tubiashi* are distinct from fish pathogenic vibrios.

5.8.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations and guidelines affect the potential impact of disease:

- Washington State importation laws (WAC 220-77), administered by WDF, and federal statutes protecting fish (Title 50 of the U.S. Code of Federal Regulations, part 16.13), administered by USFWS, require certification that all salmon eggs not contain any virus or other significant fish pathogens before fish can be placed or cultured in state waters. Such certification includes source site inspections, quality control specifications, inspection of arriving shipments, quarantine, and reporting requirements regarding the health of the received eggs by the importer. Thus, introduction of fish or eggs into Washington is limited under existing federal and State regulations. No salmon eggs or fish from Japan are allowed in Washington State.

- *Vibrio salmonicida* is apparently the only known and exclusively marine pathogen of salmon exotic to the Pacific Northwest. This disease is contracted in seawater and only fish in their freshwater phase of development or eggs held in freshwater are transported into Washington. The risk of introduction of this bacterium, therefore, is minimal. A parasite occurring in Europe, *Gyrodactylus salaris,* has not been observed in the Pacific Northwest and salmon from Europe must be free of this parasite before importation. Eggs imported from Europe are disinfected as part of the requirements of the WDF. Thus, the risk of importation of this parasite is minimal. Other species of *Gyrodactylus* occurring naturally in the Pacific Northwest are associated with fishes, but are not considered a serious problem in salmon culture.

- The level of fish farming in Puget Sound will not directly affect the implementation of the regulations designed to prevent the introduction of exotic fish pathogens. Additional staff time may be required from WDF and USFWS if increased requests for importations are made. However, a higher level of Puget Sound farm production has already increased the financial incentive to maintain regional broodstock and egg production. This increased local production of salmon eggs should reduce the number of salmon egg importations and the associated risk of disease introductions.

- DOH is authorized through RCW 43.20.050 to protect the health, safety, and well-being of the public and to prevent the spread of disease. DOH regulates food protection and storage (WAC 248-84). They are also charged with approving shellfish growing areas and assuring that these areas, and the commercially harvested shellfish from these areas, are not contaminated (RCW 69.30, WAC 248-58).

5.8.2.2 Preferred Alternative

Existing regulations still allow a small but manageable potential for adverse impacts. In order to avoid significant adverse impacts, the following measure is recommended:

- Development of enough regional brood stock to support the salmon farming industry. This would eliminate the risk of importing exotic salmon diseases with infected eggs. Thus, while the current regulatory policies allow some controlled risk, any trend in the industry to develop a local brood stock would further reduce that risk.

5.8.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Implementing the recommendation in the Preferred Alternative in conjunction with existing regulations is sufficient to avoid significant adverse impacts. No additional mitigation measures are necessary.

5.9 MARINE MAMMALS AND BIRDS

There are two issues of concern regarding the relationship between wildlife and salmon fish farms. First, is the effect of animal predation on captive fish, and the counteracting effect of anti-predator measures on animal populations. Second, is the impact of farms sited near sensitive wildlife habitats.

5.9.1 Affected Environment

Animal Depredation. The presence of captive fish and a floating habitat usually attracts predatory birds and marine mammals to fish farms. Herons may land on walkways and attempt to capture small fish through the netting. Larger predators, such as harbor seals, California sea lions, and river otter, may attempt to get larger fish through the underwater netting. Attempts by these animals to capture penned fish can damage nets, and if the predators are successful, kill or injure fish. To protect their investments, fish farmers have developed methods to discourage or prevent depredation by birds and marine mammals.

The severity of the problem depends to some extent on the location of the site, and on the species that inhabit the area. Marine mammals are generally regarded as more damaging than birds.

Predators have been successfully controlled in Washington waters with anti-predator nets. There are only isolated instances where intentional killing has occurred. Killing is usually the result of inadequate protection by harassment techniques or anti-predator nets (Forster 1988; Lindbergh 1988). Most available information shows that early preventive actions can reduce predator problems. Once predators establish use patterns around a facility, the problem is difficult to correct (Jefferies 1988; Scordino 1988).

Marine Mammals. Marine mammals live along much of the shoreline and in most of the open waters of Puget Sound. Four species are of concern to fish farms in Washington. These are the harbor seal, California sea lion, northern sea lion, and river otter. Killer whales also occur in Puget Sound. Although there have been no reports of problems associated with fish farms in Washington, killer whales are a predator of fish, seals, and marine birds (Maser et al. 1981).

Seals and sea lions rest or haul out on shorelines and floating objects such as log rafts (Figure 12). Both harbor seals and northern sea lions reside in Washington year round, with harbor seals being the most widely distributed of the two. California sea lions reside in Washington waters during the winter months (October through May) and use haulout sites in southern Puget Sound (near Fox Island), northern Puget Sound (Port Gardner), and in the northern San Juan Islands (Sucia Island) (EPA 1987).

California sea lions do not appear to use potential haulout sites in central Puget Sound. However, during the last several winters they have been consuming steelhead and salmon entering Lake Washington at the Ship Canal, and in the Duwamish River. Sea lions are also commonly observed in southern Puget Sound.

Since implementation of the *Marine Mammal Protection Act*, many seal and sea lion populations in Puget Sound and other Washington bays have increased in size and range. WDW estimates that the harbor seal population in Puget Sound is increasing at the rate of 8% annually. Northern sea lion population in the Pacific Northwest is considered stable (Scordino 1989 personal communication). However, the Alaska populations of northern sea lions are being considered for designation as "depleted" under the *Marine Mammal Protection Act*.

Resident killer whales forage regularly in the waters of Puget Sound. Although they will eat any sea animal, their primary food resource in this area is fish, such as salmon, rockfish, and cod. They are apparently well-adapted to human activity and tend to avoid people who intentionally interfere with them (Angell and Balcomb 1982).

River otters are found primarily in quiet shoreline areas containing freshwater streams (EPA 1987). Otters can be found in appropriate habitats throughout southern Puget Sound, around Vashon Island, in Hood Canal, and on the Kitsap Peninsula. Other areas where they forage offshore and along the shoreline include the Strait of Juan de Fuca, Whidbey and Camano Islands, Padilla and Skagit Bays, and the San Juan Islands.

Predation. Predation by marine mammals occurs at some Washington fish farms. Most workers characterize predation by marine mammals as a minor to moderate problem (Gibson 1988; Lindbergh 1988). At the NMFS facility near Manchester, Kitsap County, fish have escaped through nets damaged by California sea lions (Scordino 1988). Gibson (1989) speculates that marine mammal predation could be a significant problem at the SeaFarm Washington facility in Port Angeles Harbor if predator control methods were not used.

Harbor seals and sea lions may damage and kill fish by biting through the netting of the rearing farm. Occasionally the attacks damage the netting, which in addition to predation, may allow many valuable fish to escape. Observers often do not distinguish between California and northern sea lions, but biologists believe most sightings involve California sea lions (Jeffries 1988; Scordino 1988). While predation by marine mammals occurs throughout the year, reports are most frequent during the winter, when California sea lions are present (Lindbergh 1988). Even though river otters occasionally injure or kill farm fish without damaging the netting, in some areas they are the main predators of farm fish.

Birds. Puget Sound attracts both open-coast bird species and those common to protected marine habitats. Prevalent groups include grebes, alcids, shorebirds, gulls, cormorants, diving ducks, and birds of prey (Figure 13). Species that have been identified as predators on farm fish include great blue herons, belted kingfishers, pigeon guillemots, cormorants, grebes, and mergansers.

Predation by birds is not a significant problem at most fish farms due to the use of anti-predator nets, strings placed in parallel over the farm, and the normal level of human activity associated with farm operation. Birds are only a problem while small fish are available. Once farm fish have grown too large for birds to eat, there is little

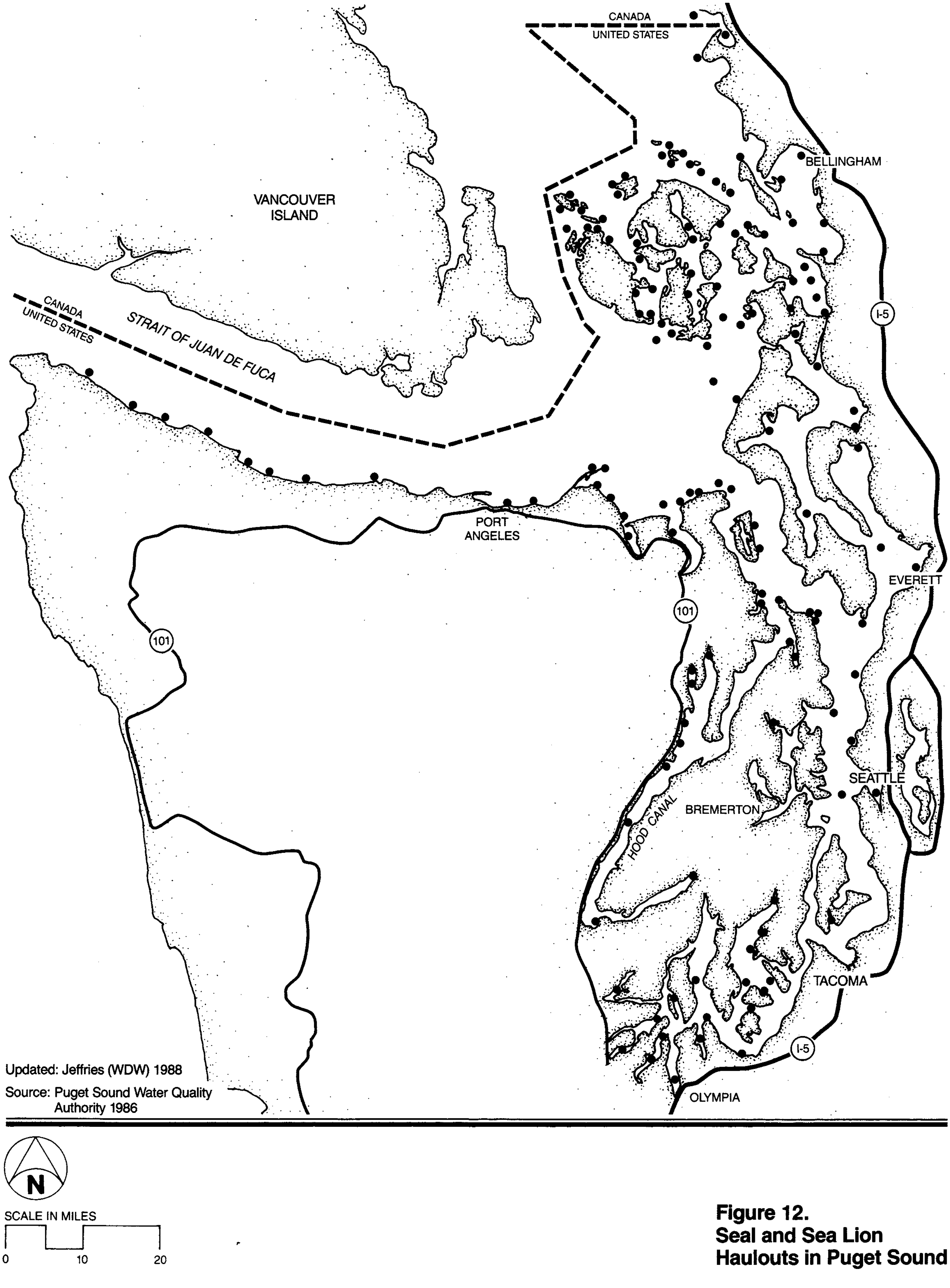
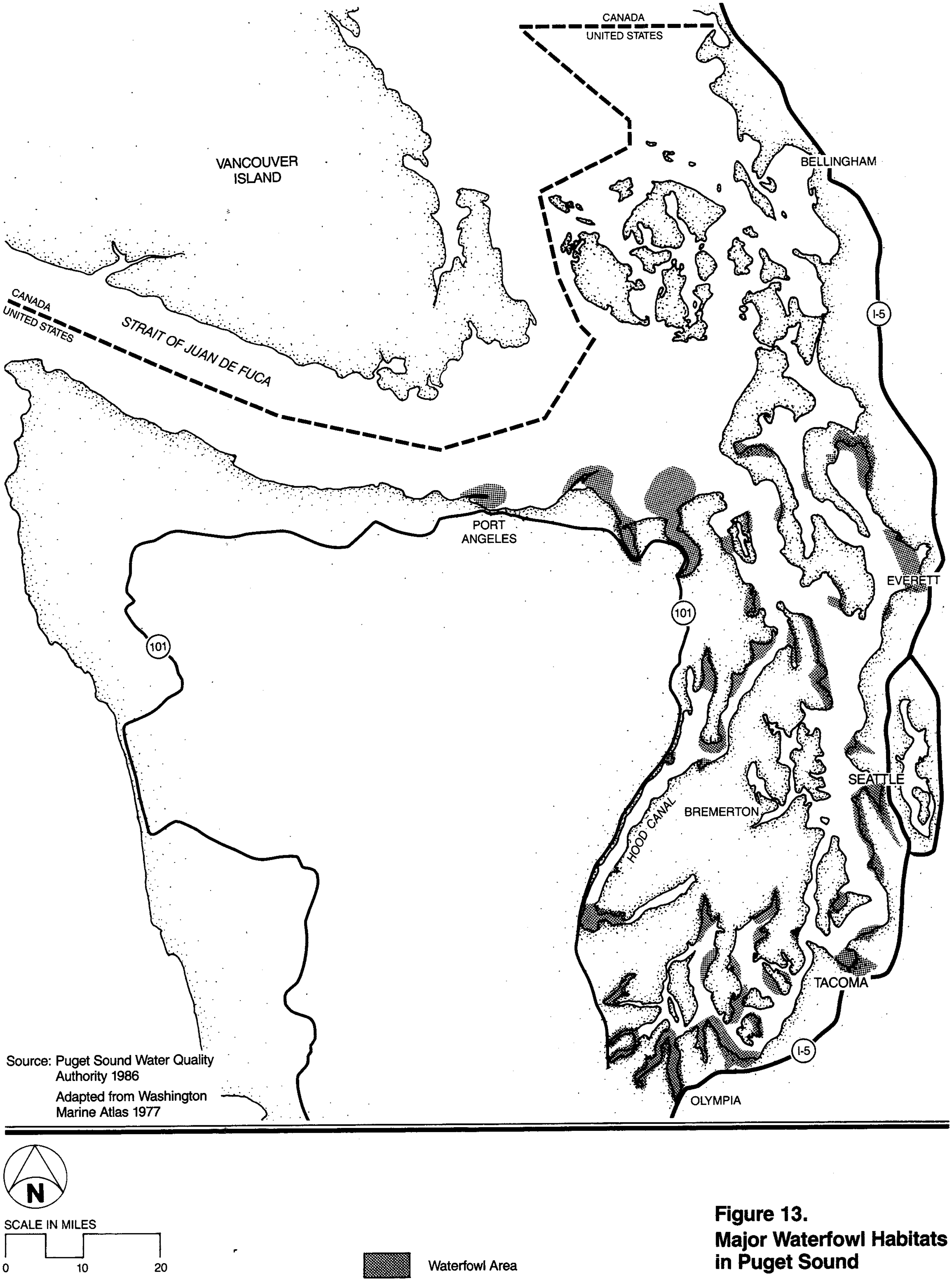


Figure 12.
Seal and Sea Lion Haulouts in Puget Sound



Source: Puget Sound Water Quality Authority 1986

Adapted from Washington Marine Atlas 1977

Figure 13.
Major Waterfowl Habitats in Puget Sound

need for netting over the farm. Some farmers use dogs to chase birds off the farm.

Fish farms may benefit some bird populations by providing food resources (such as algae, invertebrates, and herring, sticklebacks and other small fish attracted to the farm) and feeding and resting habitat. Observations by workers at the Domsea and NMFS fish farm operations near Manchester suggest that bald eagles prey on waterfowl attracted to the farm. No one has observed the eagles taking fish from the farm (Mahnken 1988).

Predator Control Methods. Surrounding farms with protective nets is the primary predator control method at Washington fish farms. These anti-predator nets prevent birds and marine mammals from reaching the interior pen below the water, or gaining access to the pen interior from walkways on the water surface. Anti-predator nets are typically attached to a walkway or outrigger approximately three feet from the inside net. The anti-predator net extends below the growing pen 3 to 9 ft and loops back to the opposite side, enclosing the pen. Weights are attached to the predator net to keep it taut and reduce movement toward the fish-rearing pen.

Anti-predator nets generally provide effective control. With their use, marine mammal predation at Washington fish farms is not a significant problem. Minor problems can occur when strong currents push the pen and anti-predator nets together, allowing seals or sea lions to reach the penned fish more easily than when the nets are not affected by the currents. In addition, marine mammals occasionally charge the fish farm, driving the anti-predator and pen net together and biting through the nets.

Fish farmers also use other non-lethal methods to discourage predation by marine mammals. Acoustic harassment devices (AHDs) have been developed to create loud noises and scare animals away. Near the Ballard Locks in Seattle these AHDs have been used extensively to attempt to control predation by sea lions which threaten the wild steelhead run. Experience in Puget Sound has shown that California sea lions initially respond to AHDs by leaving the area of the noise. However, the animals typically become accustomed to the disturbance and return because there is no negative stimulus to accompany the noise (Jeffries 1988).

A few fish farmers have also used AHDs. Marine mammals sometimes evade the noise by approaching the farm with their heads out of water, or approaching within the acoustic shadow formed by the farm (Boldt 1988). Resource agencies and farm managers report AHDs do not provide effective long-term control of marine mammals (Juelson 1988; Scordino 1988).

Chemical taste aversion using lithium chloride has also been tried in several experiments at the Ballard Locks and by a farmer. It has showed limited success in predator control (Forster 1988; Lindbergh 1988). No Washington fish farm uses lithium chloride for predator control (Gibson 1989).

Sensitive Wildlife Species and Habitats. The USFWS, NMFS, and the WDW maintain databases identifying sensitive wildlife species and habitats. Examples include bald eagle nesting and roosting sites, peregrine falcon nesting and wintering areas, marine bird nesting colonies, and marine mammal haulout areas.

5.9.2 Impacts on Wildlife

Construction and operation of a fish farm would alter habitats for birds and mammals. Some species can tolerate or benefit from the presence of a fish farm facility, while species sensitive to human activity are forced to seek habitat elsewhere. The significance of potential impacts to wildlife will depend on site specific considerations such as types and numbers of species in the area and proximity to sensitive habitat areas.

Fish farms may create disturbances through several types of activities. Noise and human activity would generally be low during operations and would not cause significant impacts on nearby wildlife populations. This assumes the farm is not located near habitats of special significance. Noise and activity would probably be greatest during construction of the facility.

The widespread use of lethal methods to control predators could have an adverse impact on marine mammal and bird populations. However, because non-lethal methods provide effective control, significant impacts on populations are not expected. Anti-predator nets have occasionally drowned marine mammals (Scordino 1988). But properly hung and maintained anti-predator nets should cause little harm to these creatures. Taste aversion and acoustic harassment appear to have no adverse impacts on marine mammal and bird populations.

5.9.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing State, federal, or local regulations and guidelines affect the potential impacts of fish farms on marine mammals and birds:

- In 1972, Congress enacted the *Marine Mammal Protection Act* (MMPA) to prohibit the killing or harassment of any marine mammal, except in situations where life or property are in imminent danger due to the mammals (for example, commercial fishers may kill seals to protect their nets). In 1988, the MMPA was revised to require all persons seeking to harass or kill marine mammals that endanger their property to obtain an exemption from the provisions of the MMPA. This exemption does not allow killing northern fur seals, northern sea lions, or killer whales.

  NMFS has jurisdiction over marine mammal protection with support from WDW. NMFS is presently implementing the provisions of the revised MMPA and may require fish farm operators to maintain written logs of marine mammals activity near farms and farmers interaction with these animals. NMFS has enforcement authority to fine or incarcerate offenders (Scordino 1988).

- USFWS administers a permit system that allows selected killing and trapping of nuisance birds to protect aquaculture facilities (Juelson 1988). *The Migratory Bird Treaty Act* and various state statutes protect birds from unlawful killing or trapping. It is the regional policy of USFWS not to issue these permits to private facilities occurring in public waters.

- Peregrine falcons and bald eagles are protected by the *Endangered Species Act*. Neither of these species is a threat to farm fish, but both may be affected by fish farm siting decisions. USFWS reviews ACOE permits and may recommend conditions to the permit as necessary to protect any endangered species.

  WDW also has protection responsibility for the bald eagle through its newly adopted *Bald Eagle Protection Rules*. The new rules require that individual site management plans be prepared for developments affecting eagle nest and roost sites on public and private lands. These management plans are based on local conditions and may include a zone of separation restricting development activity near eagle nest and roost sites.

- WDW reviews proposed fish farms during the SEPA review process. Using the most current data available, WDW determines if a proposed farm is near a habitat of special significance, such as near a marine mammal haulout area or bald eagle nesting site. If necessary, WDW would recommend measures such as site specific buffers around sensitive habitat areas to ensure that no significant adverse impacts would occur to birds or marine mammals.

- The ACOE permitting process provides a similar review by NMFS and USFWS. Both of these agencies provide comments and recommendations to ACOE before they issue the necessary permit to the farm proponent. This review allows federal agencies with the expertise and responsibility of protecting marine mammals and birds an opportunity to recommend conditions to permits that might influence siting decisions.

- The *Interim Guidelines* recommend that fish farms be located at least 1,500 ft (457 m) from bird and mammal habitats of special significance where the farms are incompatible with these habitats. Depending on the characteristics of the site and the nature of the fish farm proposal, this separation may be increased or reduced as appropriate. Particularly sensitive features may require more than 1,500 ft (457 m) as a buffer, while other features may require less.

- The *Guidelines* also recommend using non-lethal techniques to protect farmed fish from predators. Predator control methods must follow federal and state rules, and fish farm operators must possess all necessary permits. There are no guidelines specifying the size of anti-predator nets.

- WDW and the Wildlife Commission are charged with protecting, preserving and perpetuating wildlife within Washington State (RCW 77.12). Prohibited acts and penalties for wasting, mutilating, taking of protected species, etc. are also defined (RCW 77.16). WDW's policy is to assure no outside intervention results in any net loss of wildlife habitat. Other goals and policies are implemented through the various programs of the agency.

- Some local shoreline programs include specific regulations that prohibit killing or abusive harassment of birds or mammals that may visit a farm. The *San Juan County Shoreline Master Program* states that

  "Predator control shall not involve killing or abusive harassment of birds or mammals. Approved controls include but are not limited to double netting for seals, overhead netting for birds, and three-foot high fencing or netting for otters."

- Some counties in Washington provide rules for the protection of marine mammal and bird habitat. For example, San Juan County requires that aquaculture not be allowed in areas near National Wildlife Refuges or "critical habitats" where the proposed activity will adversely affect the refuge/habitat use or value (*Shoreline Master Program* [San Juan County], Chapter 16.40.503).

5.9.2.2 Preferred Alternative

The existing State and federal review processes allow site specific factors and the most current data to be considered in the process of siting fish farms.

In areas where WDW, NMFS, or USFWS indicate that predators may be present, it is recommended that the use of anti-predator nets be required of fish farmers through adoption of this requirement into the appropriate WACs. In these areas, the anti-predator net should be installed before fish are placed in the pens.

In areas where WDW, NMFS, or USFWS require anti-predator nets, it is recommended that the following guidelines for net size and placement be used by agency personnel when permitting fish farm proposals:

- The anti-predator net should be separated from the fish net by at least 3 ft (0.9 m), either by suspending it from the outside cage walkway or from an outrigger structure.

- The anti-predator net should extend 3 to 9 ft (0.9 to 2.7 m) below the bottom of the fish net, loop back up to create a bag-type structure and be weighted sufficiently to remain taut.

- The anti-predator net mesh size should be less than 5 inches (12.7 cm) to avoid accidental entrapment of animals.

- Perimeter fencing should be installed to prevent resting and haulout of seals and sea lions on the pens.

- A 7-inch (17.8 cm) stretch mesh net, or parallel strings over the top of the fish pen to stop birds from entering from above should be installed.

5.9.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

The existing State and federal review processes provide an opportunity for all agencies with expertise to assess the potential impacts of fish farms on marine mammals and birds. A case-by-case evaluation of proposals allows these agencies to use the most current information to assess a proposal at a specific site.

The use of existing State and federal regulations with the anti-predator net requirement recommended in the Preferred Alternative will avoid significant adverse impacts to marine mammals and birds. No additional mitigation measures are necessary.

6. THE BUILT ENVIRONMENT

6.1 VISUAL QUALITY

The issue of visual impact involves how different people perceive the same structure, how structure design and location can be altered to reduce potential visual impacts, and what types of controls can be implemented to address cumulative impacts.

Fish farms are commonly placed in open water where no manmade structures exist. The above-water portion of these farms alters views from adjacent vessels or boats and may alter views from nearby land areas. Many people perceive any structure placed in open water as creating an adverse visual impact.

6.1.1 Affected Environment

Puget Sound and adjacent waters, where fish farms would be located, provide views that are of interest to nearly all residents and visitors. These waters, which include the Strait of Juan de Fuca on the west, the Strait of Georgia on the north, Puget Sound on the south, and the waterways in between, form an intricate landscape of bays, channels, and islands. This inland embayment is the drowned portion of a broad hilly lowland flanked on the west by the Olympic Mountains and on the east by the Cascade Mountains. The Olympic Mountains rise above Hood Canal on the west side of Puget Sound and closely above the southern shore of the Strait of Juan de Fuca. The Cascade Mountains stand further back from the east shore of Puget Sound and the Strait of Georgia, except in the north where foothills extend to saltwater south of Bellingham. From most vantage points, these two ranges form a jagged skyline that appears as rows of green-sloped mountains with craggy and snow-covered peaks.

Views from these shorelines and from the water vary considerably. Along the Straits of Juan de Fuca and Georgia, the opposite shoreline typically lies at a considerable distance from the observer so that views are dominated by the sky and a broad, flat expanse of water. Depending upon the weather and sun position, the water surface may appear monotonal and static on cloudy, calm days, or dynamic and highlighted on windy, sunny days.

In other locations, where the waterbody is not as broad, the shoreline and nearby land areas are more evident and form the dominant visual element. In these areas, the landscape appears more complex and intimate to the viewer. Tree-covered slopes, rocky headlands, or steep bluffs rise from the water in many areas and create a visually varied landscape.

Human activity affects views along the inland marine waters of western Washington. It varies from the intense and diverse activities associated with the metropolitan areas in central Puget Sound to the near absence of activity in sparsely inhabited areas. In no portion of these inland waters are views of human activity completely absent. Docks, boats, houses, or other signs of human presence are almost always within view of shoreline residents and visitors. In some areas of the Puget Sound region, overwater structures, such as log rafts, docks, boats, or marinas, dominate the marine view.

Despite the rather uniform views provided by the inland marine waters of western Washington, particular areas are visually unusual or distinctive. An example of an aesthetically unusual location is Dungeness Spit. In size and form, Dungeness Spit is a landform unique to the study area, and the view from the south across the spit and the

Strait of Juan de Fuca beyond is therefore visually unique.

Other locations may be visually distinctive within the study area, but they are not unique because they share certain attributes with other portions of Puget Sound and adjacent waters. An example of such a distinctive area would be the west end of Fidalgo Island and the adjoining San Juan Island archipelago.

This EIS does not attempt to identify unique or visually distinctive views; these must be identified by shoreline regulators. This analysis discusses potential impacts on these views from farms, and possible subsequent mitigation measures.

6.1.2 Impacts on Visual Quality

Visual quality impacts are subjective and difficult to quantify. Attitudes and perceptions vary considerably, so that two observers often perceive their views to be differently impacted by the same facility. This section describes the features of fish farms that may affect views, how these features may be perceived, and how alternatives may affect views.

Background. Impacts to visual quality from fish farms depend on several variables. These include: the location, size, and design of the facility, the number and location of observers and their attitudes about the facility, and the nature of the surroundings.

Fish farms have floats and railings that typically extend about 1.5 m (60 inches) above the water. They also commonly include a small building extending about 3 m (10 ft) above the water (see Section 2, Background, and Figure 3).

Like many human-made objects, the form of a fish farm is dominated by straight lines and a regular pattern. These characteristics, together with the immobility of a fish farm structure, contrast with the water surface and tend to draw the attention of observers.

Fish farm structures become less evident as the observer/facility distance increases. Typical farm facilities at distances greater than 458-610 m (1,500-2,000 ft) appear as a thin line on the horizon for observers at about the same elevation as the water surface (EDAW and CH2M Hill 1986). For two observers at the same distance from a fish farm, the facility would be more evident to the observer who is higher above the water surface. For two observers at the same height above the water surface, farms would be more evident to the less distant observer (see Figures 14 and 15).

Structure color also affects visual distinctness. Brightly colored structures are generally more evident than somber-toned structures; and grays, blues, and greens are generally less evident than reds, yellows, or oranges. Structures composed of reflective materials are more evident to an observer than structures composed of materials with matte surfaces. Lights, particularly blinking or rotating ones, greatly increase the visual distinctness of a structure at night. The visual impact of structures varies with sun orientation, wave action, and cloud cover, factors that are not constant at any particular site.

Attitudes toward fish farms vary significantly for different observers. Some observers consider a farm to be a visual intrusion, while others consider the same facility to be a neutral or interesting part of the visual environment. Some observers find fish farms interesting and attractive in a manner similar to a fish hatchery.

Observer attitudes will be affected by the overall visual environment near a farm site. Observers in an area with few human-made structures would probably perceive a farm as visually intrusive. A farm facility in a complex landscape dominated by man-made objects, such as an urban area, may be visually unobtrusive.

Description of Impacts. The visual impact of fish farms depends on the distance between the observer and the farm, on the altitude of the observer, and on the surrounding views. In general, only viewers within about 2,000 ft

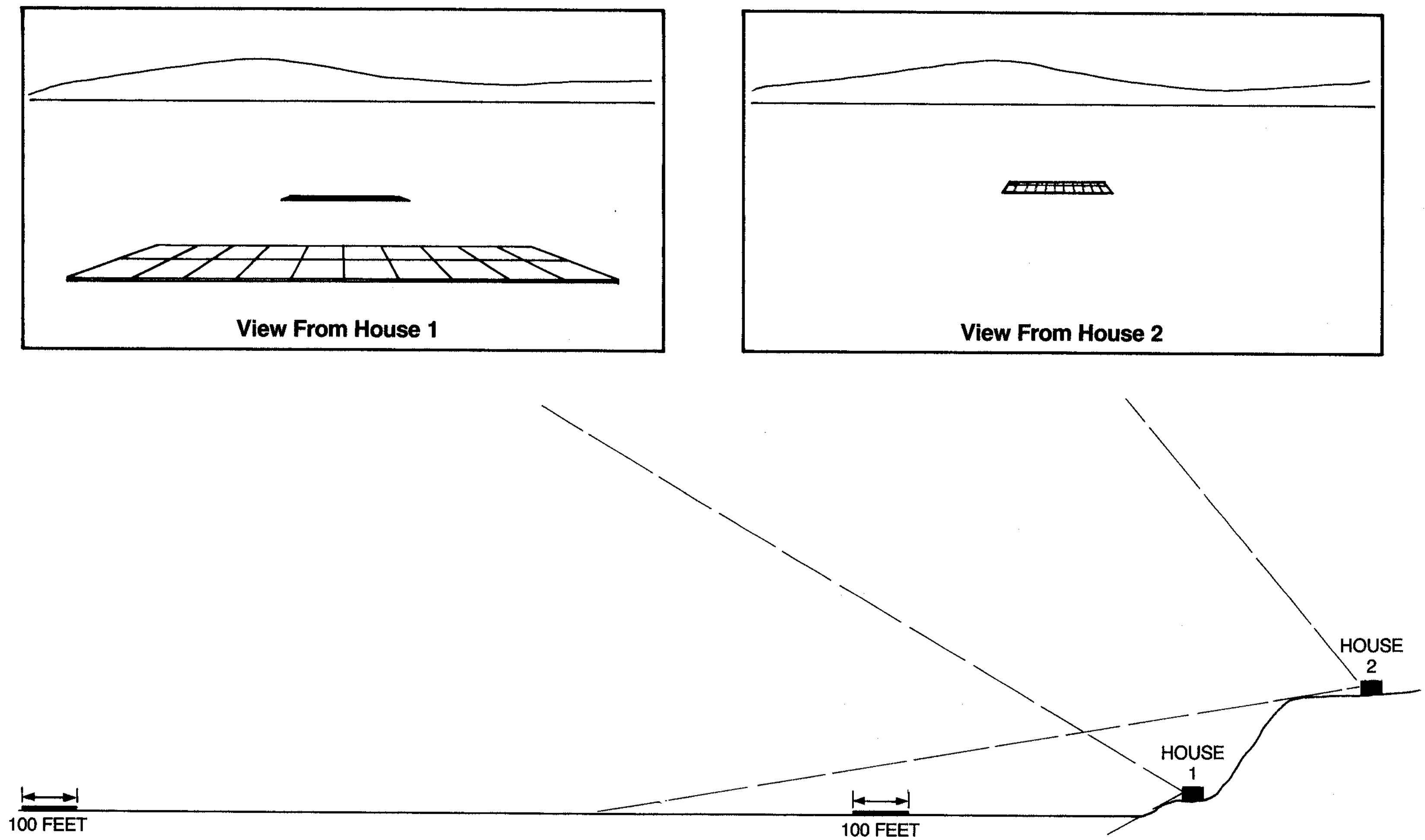


Figure 14.
Topography of the Shoreline and Views of Fish Farm Facilities

(610 m) are likely to see a fish farm as anything more than a thin line on the horizon (EDAW and CH2M Hill 1986). Viewers in the immediate vicinity of the farm could have their view substantially altered by the presence of the farm.

The relationship between the location of the observer and the distance of the farm from shore affects visual impacts. Views from residences on the shoreline are primarily oriented toward the water and often toward landmarks on the far shore. A schematic representation of the impacts associated with the placement of a farm relative to the shoreline can be seen in Figure 16. In this example, the predominant viewscape is assumed to be oriented directly out over the water. Situation A of Figure 16 places the farm 300 ft from shore. While the facility will be visible along the shoreline, it will not be a major visual impact to the observer in the example. However, when the farm is moved 1,000 ft (305 m) from the shoreline, as in situation B, it falls within the predominant viewscape of the observer.

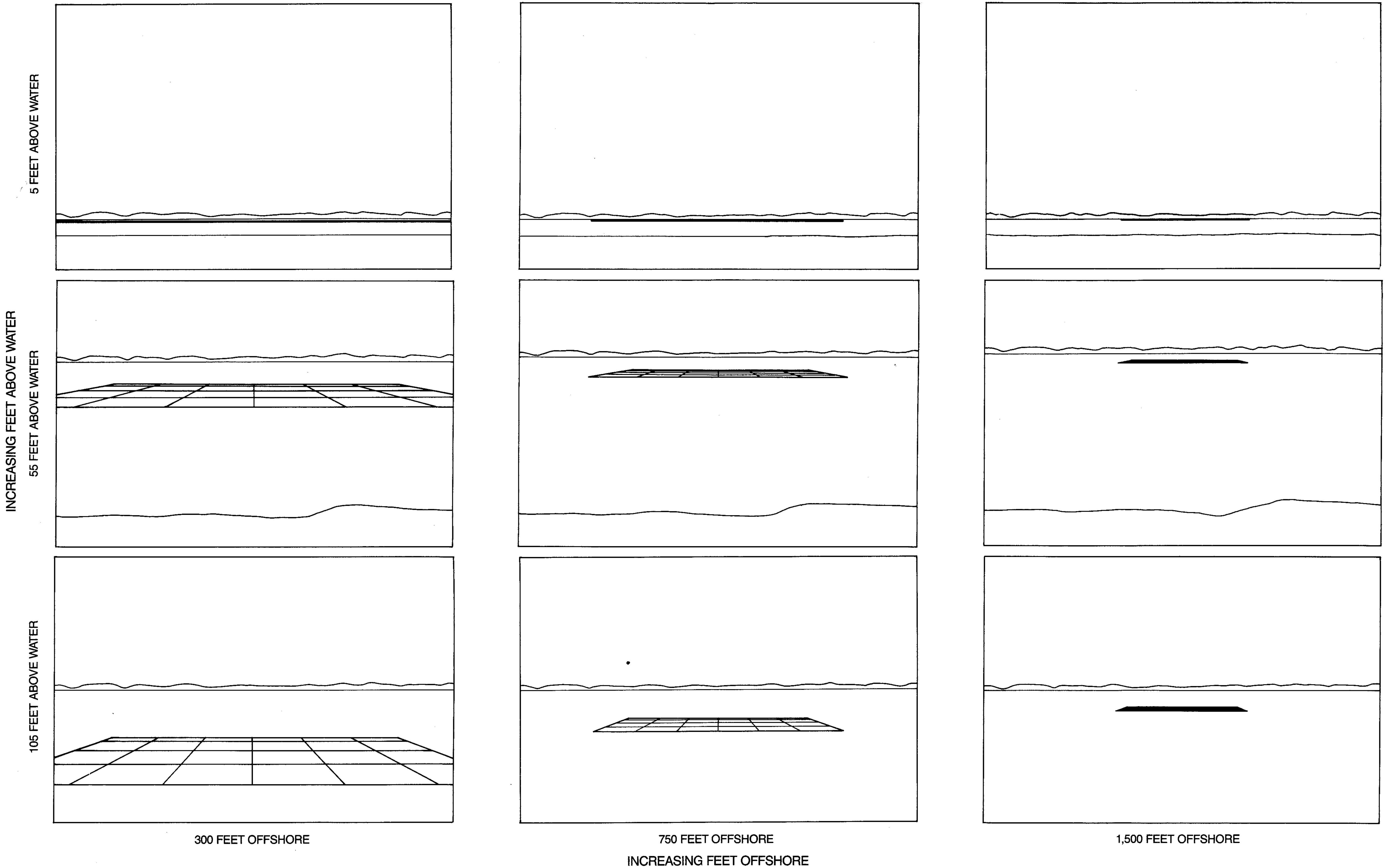
Yet, now, the facility in situation B is visible from only 3,944 ft (1,202 m) of the shoreline. This hypothetical example is included to indicate that placing a farm as far from shore as possible is not always the most effective way to minimize visual impacts. Because the orientation and location of views will vary from case to case, each fish farm proposal should be evaluated separately to determine the effect of distance and orientation on views.

The horizontal angle of view occupied by a farm depends on its orientation and the position of the observer as illustrated in Figure 17. There are a variety of farm configurations; however, a farm facility (100 ft by 1,000 ft [30 m by 305 m]) at a distance of 1,000 ft (305 m) from shore is used as an example. For observers on the shore immediately in front of the farm, an orientation with the long dimension parallel to the shore results in a substantially greater impact than an orientation with the long dimension perpendicular to shore. As an observer moves along the shore in either direction, the farm orientation with the long dimension perpendicular to shore has greater visual impact at distances greater than 600 ft (185 m) off to the side. However, at these distances, the visual impact in either case would probably not be substantial. Although the farm would occupy a definite horizontal angle in the field of view of an observer at water level, at distances approaching or exceeding 2,000 ft (610 m), the farm would tend to merge with the water line and be nearly indiscernible to the observer.

Some residents and visitors will be visually affected by the presence of a fish farm. Whether or not it substantially alters their view, these people will be affected because they consider any structure and its operation, such as a fish farm, an undesirable intrusion into what they perceive as an unaltered natural environment.

Placement of several farms in proximity to each other can result in cumulative visual impacts. A greater number of farms would probably increase the number of observers whose views would be impacted. For a particular observer, an increase in the number of farms in an area may or may not result in greater potential impacts. Additional farms placed at greater distances from an observer than an existing farm would probably not result in substantially greater visual impacts. The nearer, existing farm or farms would have the primary effect on views. Conversely, additional farms placed closer than or at similar distances from an observer may substantially increase visual impacts.

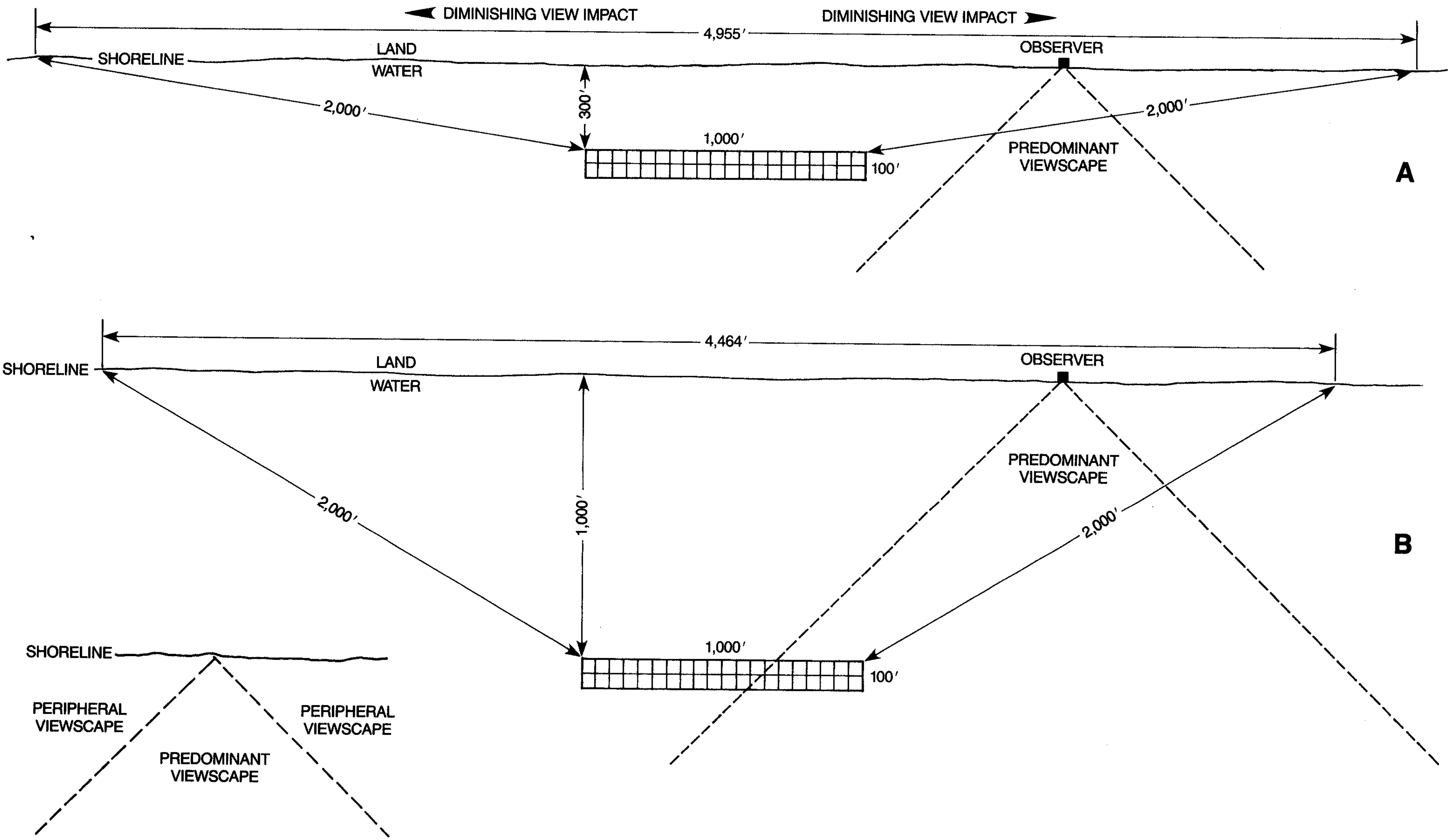
The overall cumulative impact resulting from five farms in an embayment, for example, would vary considerably depending on whether there were other human-made structures in the area and on observer attitudes. Placement of several farms in an embayment that had few other human-made structures might be perceived by some observers as altering a natural environment to an urbanized environment. Other observers may not perceive any significant visual change due to an increase in the number of farms because they do not perceive fish farms as a visual intrusion, or they perceive *any* fish farm to be a visual intrusion.



Source: EDAW, 1986

Note: 60° angle of view, facility covers 5 acres and consists of a 100 foot spaced grid.

Figure 15.
Visual Effect of Distance and Observer Position



Note: Refer to text for discussion of this figure.

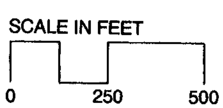
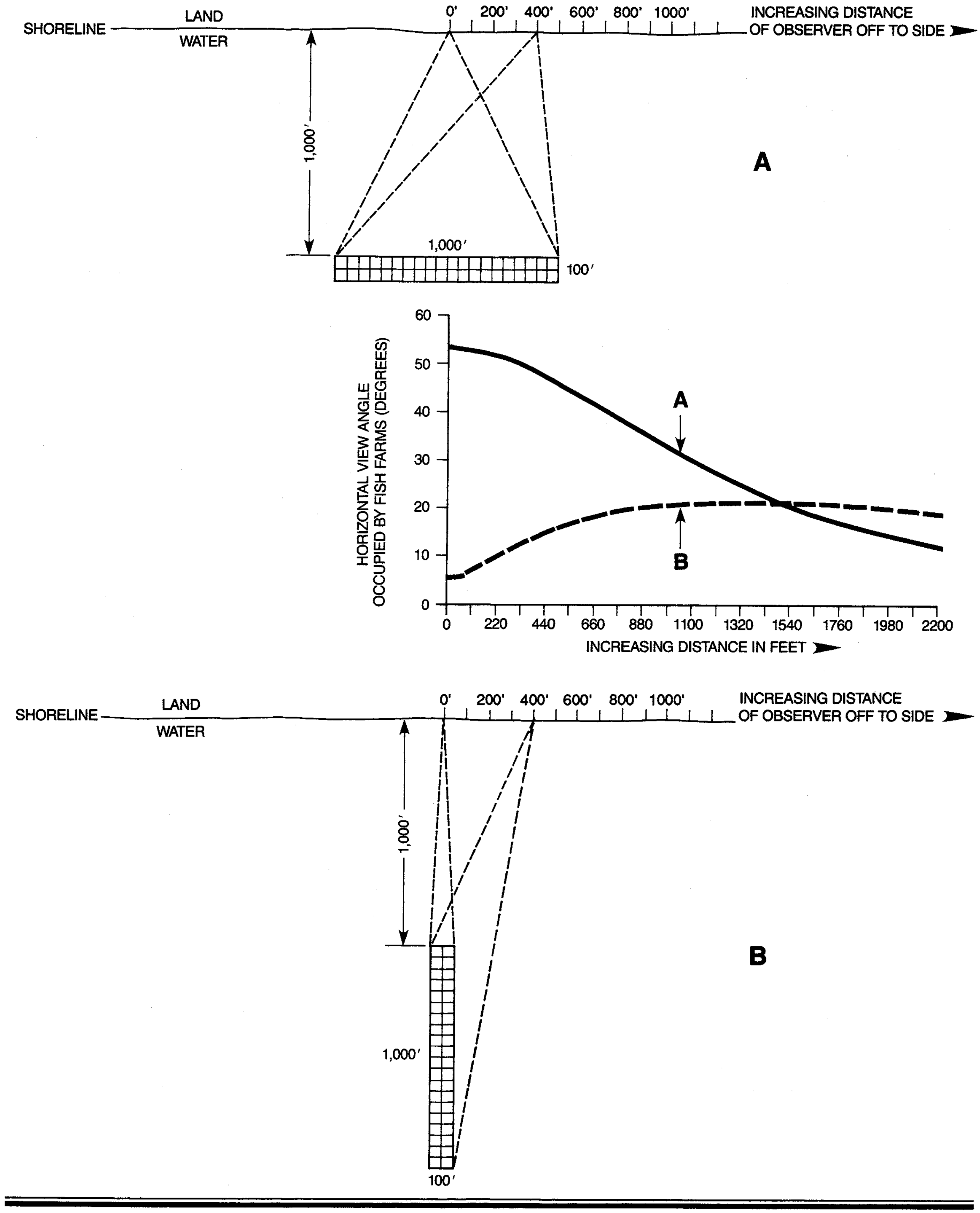


Figure 16.
Schematic Example of View Impacts Related to Distance and Orientation of Fish Farms



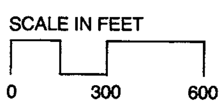


Figure 17.
Effect of Fish Farm Orientation and Observer Distance on Visual Impact

A hypothetical placement of five farms in a typical Puget Sound embayment using the upper end of Carr Inlet as an example is illustrated in Figure 18. A 2,000-foot (610-meter) radius is drawn around each farm to illustrate the probable maximum extent of visual impact. This figure illustrates that at a density of more than five farms per embayment, the farms could be spaced so that no shore observer is within 2,000 ft (610 m) of more than one farm at any time. This indicates that with adequate spacing of farms, the cumulative impact of several farms in an embayment could be minimal. In other situations where there are few visually sensitive observers, it may be appropriate to more closely space farms to avoid placing farms in areas having more observers.

The cumulative visual impact of many farms sited closely together would be greater than the visual impact of one farm. Methods of spacing farms to reduce this cumulative effect are illustrated in Figures 19, 20, and 21. Combined with controls on the distance from shoreline, these three methods would achieve similar results. Regulations incorporating these types of controls could be adopted into local shoreline master programs.

6.1.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect potential visual quality impacts:

- State regulatory language for consideration of visual impact values is based on the *Shoreline Management Act* (RCW 90.58), and is found in varying degrees in different local shoreline master programs. The *Shoreline Management Act* requires local governments, when appropriate, to include a conservation element in their shoreline programs that addresses the preservation of natural resources, including scenic vistas and visual impacts (RCW 90.58.100 [2][f]). Most local programs include general language regarding visual impacts. For example, in Kitsap County's *Shoreline Management Master Program*, preference is given to uses which "actively promote aesthetic considerations" (Part 7).

- The regulations for developing local shoreline master programs contain guidance for local governments on specific uses such as aquaculture (WAC 173-16-060 [2]). The language involving visual impacts includes:

  - "Recognition should be given to the possible detrimental impact aquacultural development might have on the visual access of upland owners and on the general aesthetic quality of the shoreline area.

  - As aquaculture technology expands with increasing knowledge and experience, emphasis should be placed on structures which do not significantly interfere with navigation or impair the aesthetic quality of Washington shorelines."

  In response to these guidelines, counties have included policies and regulations on aquaculture in their shoreline programs. Specific regulations vary from program to program, but most local programs include language addressing visual impact values. For example, the following broad language is used in the Kitsap County program:

  > "Aquacultural development shall be designed and constructed to harmonize insofar as possible with the local environment, and shall be maintained in a neat and orderly manner."

- There are no specific regulations in place that define the maximum number of fish farms that can be placed in a given area.

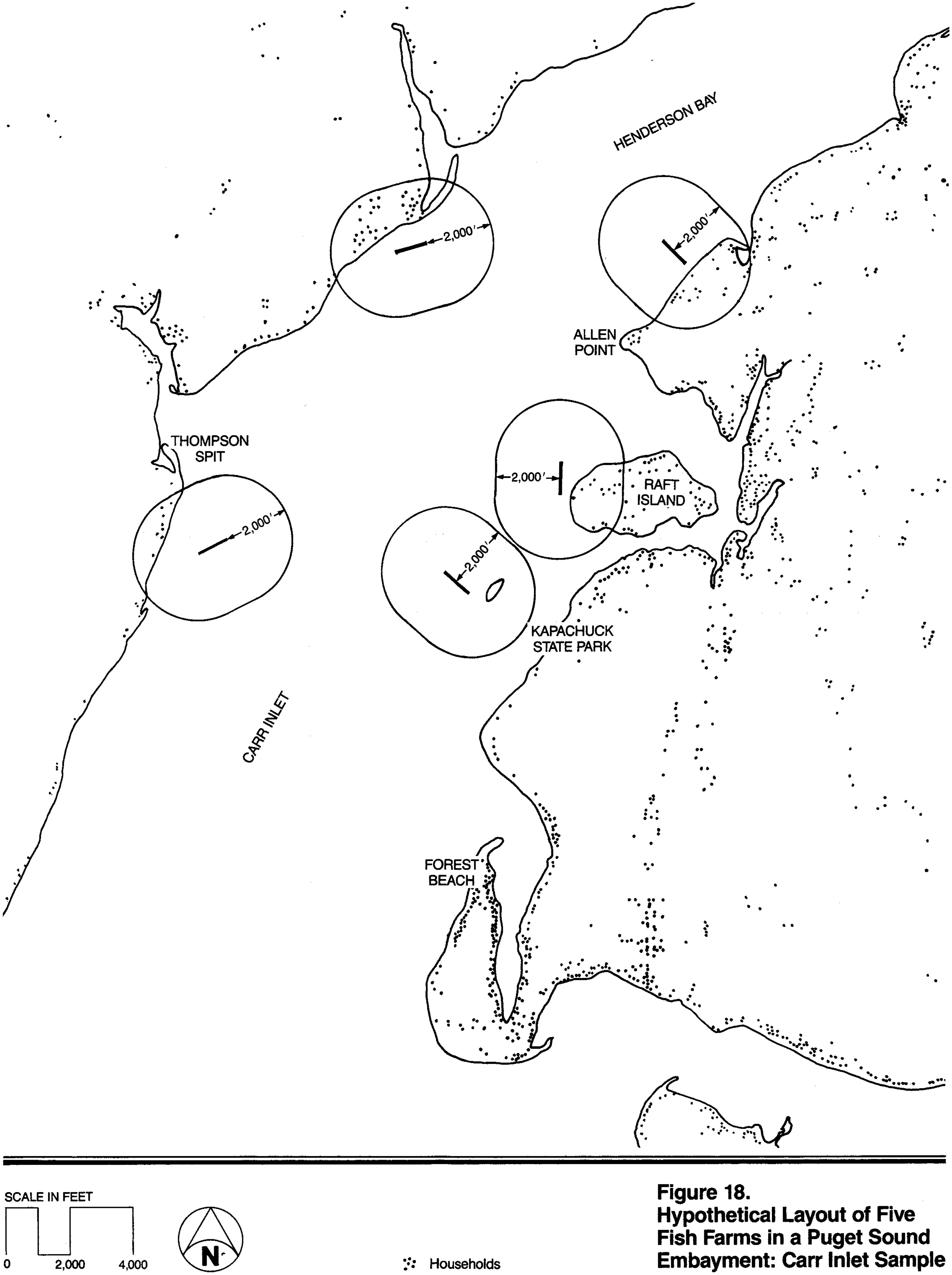


Figure 18. Hypothetical Layout of Five Fish Farms in a Puget Sound Embayment: Carr Inlet Sample

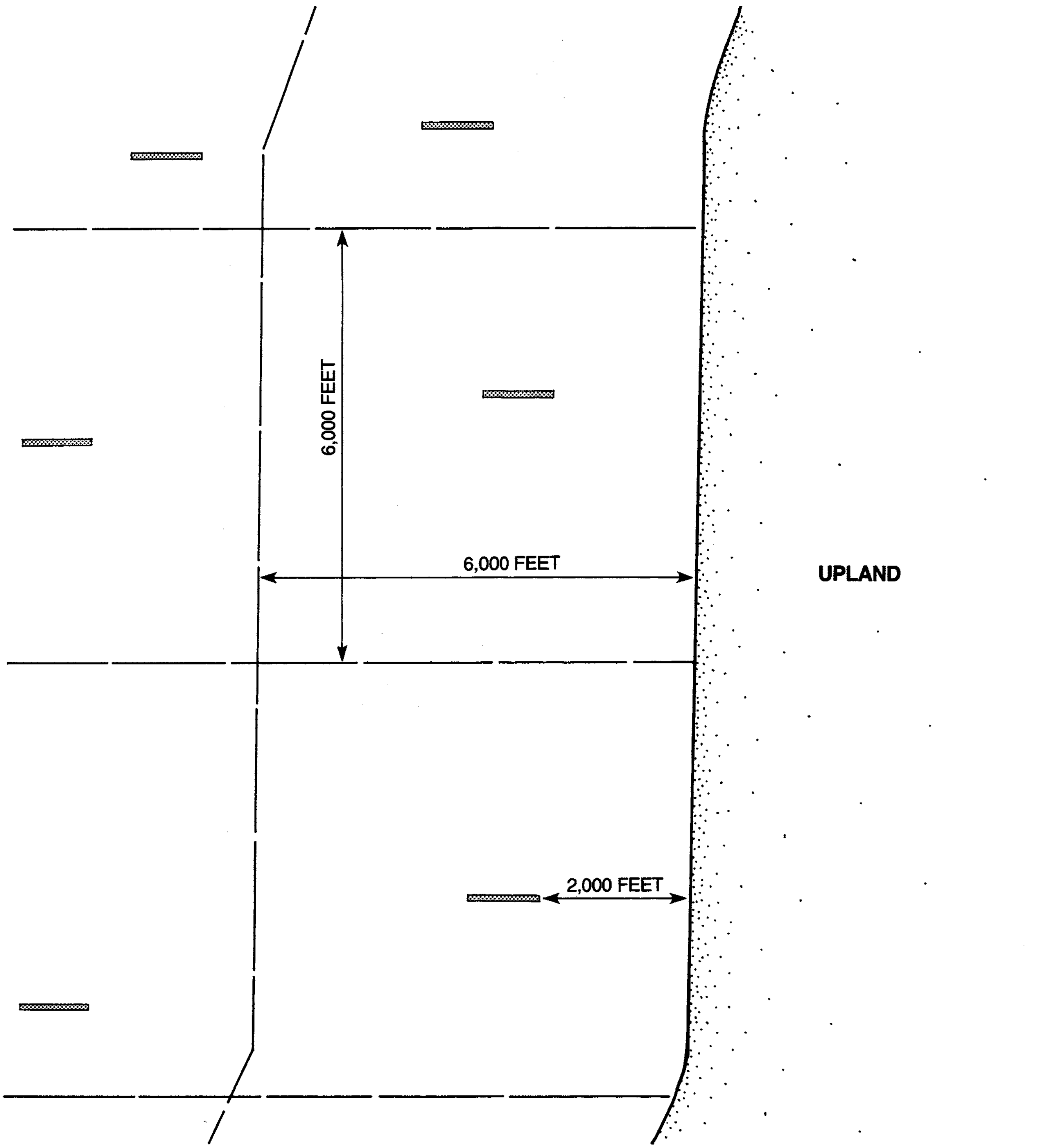
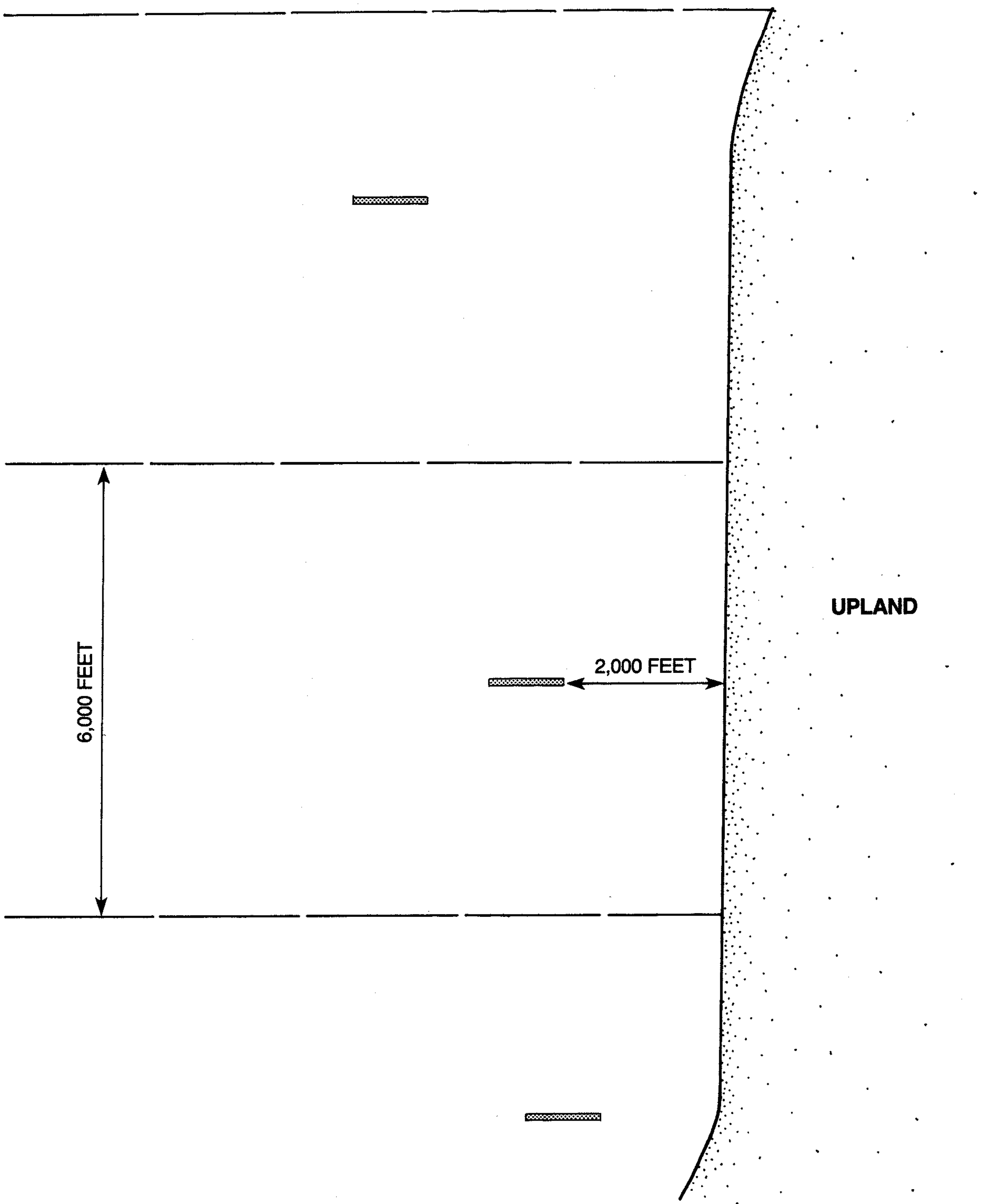
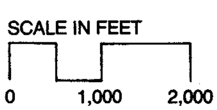


Figure 19.
Potential Method of Fish Farm Density Control, Area by Square Footage





100′ × 1,000′ Fish Farm

Figure 20.
Potential Method of Fish Farm Density Control, Area by Shoreline Footage

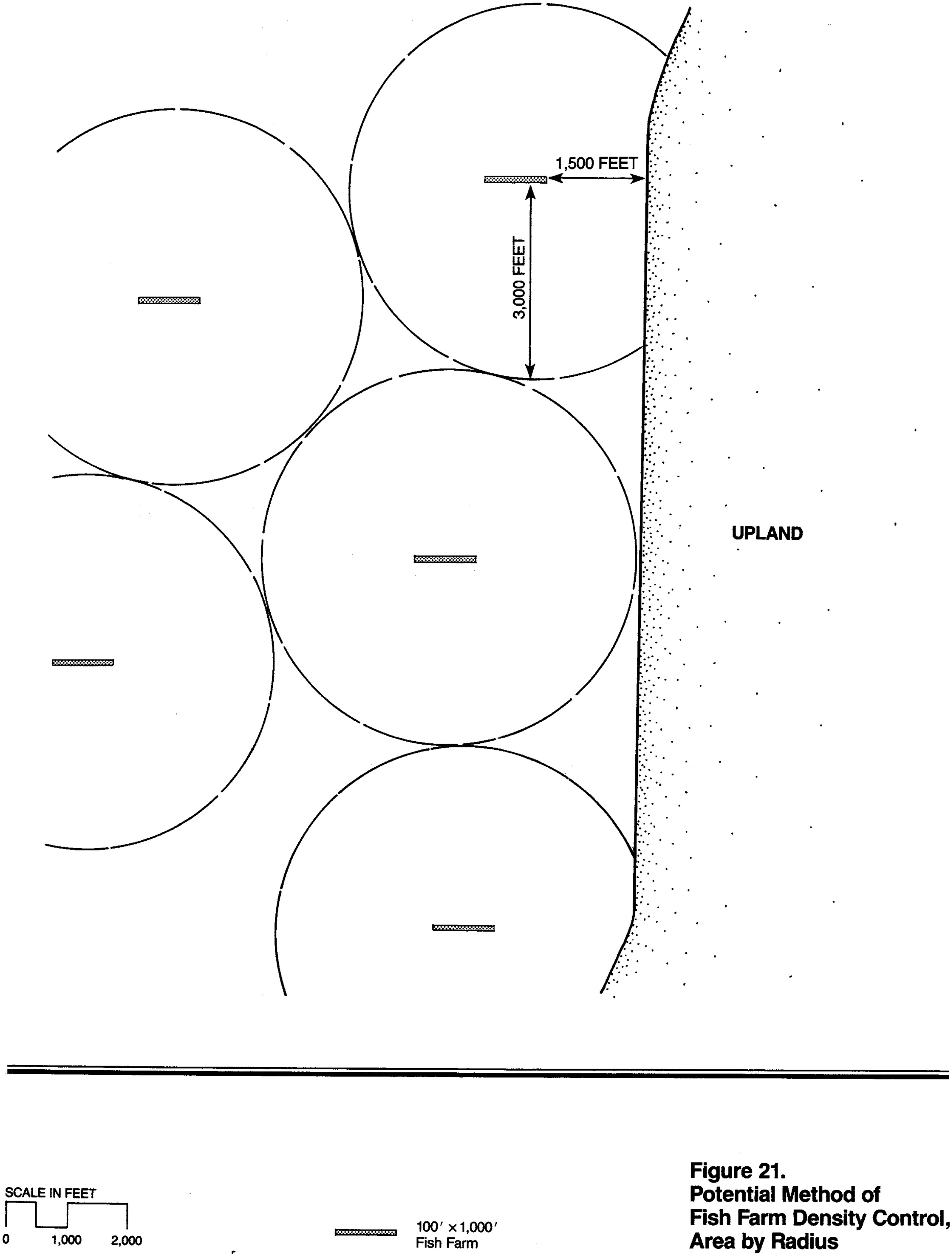


Figure 21.
Potential Method of Fish Farm Density Control, Area by Radius

However, DNR presently uses a distance guidelines of one mile to separate farms.

- Guidelines for minimizing potential visual impacts from aquaculture operations are included in the *Aquaculture Siting Study* (EDAW and CH2M Hill 1986). This study divides the guidelines into two areas, alternate site selection, and modification of siting and design. The following is the language used in the guidelines:

  "When feasible, aquaculture facilities should be located in waters offshore:

  - Culturally modified landscapes, preferably those with existing commercial/industrial maritime activity
  - Rural or uninhabited shorelines
  - Low bank shorelines
  - Open shorelines.

  When feasible, aquaculture facilities should be sited or designed to be:

  - At least 1,500 to 2,000 ft offshore
  - Horizontal in profile
  - Incorporated as part of, or designed to appear as, docks or marinas
  - Limited in overall size and surface coverage so as not to cover more than 10% of normal cone of vision (dependent on the degree of foreshortening created by distance offshore to the facility and the height of the observer above sea level)
  - Of a color which complements the dominant blue/green colors of Puget Sound
  - Ordered and of limited variations in material and color."

- One method of visual analysis is set forth in the *Aquaculture Siting Study* (EDAW and CH2M Hill 1986). This method consists of a series of formalized rating sheets which provide an inventory of existing conditions (including scenic quality, sensitivity level, and visibility) and an assessment of visual impact. Visual impact can be rated by considering the various elements of the existing conditions inventory. Thus, a facility with high visibility in an area of high scenic quality with viewers or uses with high sensitivity was rated as having a high visual impact. This method has the advantage of providing a structure and consistency to visual impact analyses. On the other hand, this method tends to be rigid, and may be insufficiently detailed to adequately distinguish the range of situations occurring in the Puget Sound area.

  The EDAW study also includes a brief listing of factors which contribute to potential for cumulative visual impacts such as the size of project, size of the embayment, distance offshore, and viewing height, but does not offer any specific guidelines.

6.1.2.2 Preferred Alternative

Visual quality impacts from fish farms are site specific. The various factors influencing the potential for impacts (for example, topography, number, location, attitudes of observers, and existing visual and development character) vary within Puget Sound and adjacent waters. Given this variability, uniform, specific visual quality guidelines that would apply throughout the region are not appropriate.

Although specific guidelines regarding visual quality are inappropriate, more general guidelines could be applied throughout the region. These are:

- In areas of high residential use or sensitive uses such as shoreline parks, or natural visual character, fish farm facilities should be designed and located to reduce their visual obtrusiveness as much as possible
- In areas of high residential or sensitive use, fish farms should be sufficiently separated to minimize the cumulative visual impact on these uses
- Potential visual quality impacts should be assessed on a case-by-case basis to determine appropriate mitigation measures.

Specific guidelines are best determined by local jurisdictions, and expressed as policies and regulations in individual shoreline master programs. It is recommended that local governments adopt measures that use design or location guidelines to address local concerns regarding visual impacts.

Design. The design of farm structures may serve either to increase their visibility or to visually submerge them in their surroundings. For example, increasing visibility could serve as an architectural statement and be appropriate in some urbanized areas. In many areas, however, fish farm structures should be designed to be visually unobtrusive.

The following measures describe some design features that would help visually submerge a farm structure:

- Limit the distance structures that would project above the water surface to that distance necessary for the safe and efficient operation of the facility.
- Where it would not significantly affect existing navigation patterns, design farms as small sets of pens grouped together instead of a large pen complex, thus avoiding extensive visual elements.
- Design materials used in farm structures to be non-reflective, somber-hued, and gray, green, or blue in color.
- Design lighting provided on the structure to be the minimum necessary for safe operation and navigation, and directed away from land areas, if possible.
- Plan storage on land for the equipment used in the farm operation that is not a functional part of the farm structure.
- Maintain the minimum number and size of buildings on the floats necessary for the safe, efficient operation of the facility.

Location. Farms sited 1,500 to 2,000 ft offshore will prevent significant adverse visual quality impacts to shoreline areas. However, increasing the distance between farms and adjacent shorelines may increase conflicts with navigational use and commercial fishing. It is recommended that local governments allow flexibility in their policies to accommodate site specific conditions that may warrant different separation distances. Where low-level shorelines are nearby, the farms can be sited 600 m (2,000 ft) or more from shore to minimize visual detection of the farms. In areas of high shoreline bluffs and adequate nearshore water depth and currents, the visual impacts may be minimized by placing the farms close to the shoreline where they can only be seen from the edge of the bluff.

Implementation. Design and location measures described in this section could be implemented through the shoreline permitting process. As an alternative to the analytical framework outlined in the *Aquaculture Siting Study*, fish farm proposals could include a visual quality analysis describing the proposal's compliance with design and location guidelines. Without prescribing the nature of the visual impact analysis, this requirement would not be particularly rigid, and it could be adapted to the needs of each local jurisdiction.

6.1.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

If guidelines in the Preferred Alternative are tailored to address local concerns and adopted by local governments through their shoreline master programs, significant adverse visual impacts will be avoided and no further mitigation measures would be necessary.

6.2 NAVIGATION

Concerns have been raised that fish farms will impair normal navigation routes and present a hazard to commercial and recreational vessel traffic. An additional issue is the potential impact of numerous aquaculture facilities in an area restricting access to popular cruising, fishing, and moorage areas.

6.2.1 Affected Environment

The waters of Puget Sound comprise roughly 6,500 km^2 (2,500 square miles) of surface area. Vessels using Puget Sound vary from large ocean-going bulk cargo and container ships, to ferries, towboats, commercial fishing boats, recreational boats, and other assorted water craft.

Nautical charts showing depths, obstructions, and aids to navigation are available for all of Puget Sound. In addition, boaters can receive the *Notice to Mariners* publication. This publication identifies changes in navigation aids and new obstructions in the water since the latest chart was issued.

Most large ocean-going ships travel within the established shipping lanes clearly marked on nautical charts. Vessels in the state ferry system have established routes in Skagit, San Juan, Island, Snohomish, King, Kitsap, and Pierce counties. In addition, some counties such as Skagit and Whatcom provide their own small ferry service.

Other commercial shipping does not have established routes identified on nautical charts. For example, the towboat industry hauls barges and logs all over Puget Sound. Towboats use the main shipping lanes, but will also hug shorelines if they offer protection from wind, strong currents, or wave conditions that would jeopardize the cargo or delay delivery.

Puget Sound is also the location of some of the finest recreational boating opportunities anywhere in the nation. Data are not available on the densities of recreational boaters at specific locations and the routes used by boaters to get from their point of origin to their destination. However, destinations usually have some amenity such as access to a state marine park, public beach, recreational fishing "hole," marina, or retail goods like restaurants and stores. In addition, many commercial and recreational boats will use protected bays for shelter during storms (see Section 6.5, Recreation).

6.2.2 Impacts on Navigation

A fish farm, like an island or dock, is a fixed object in the water. Fish farms can impact navigation if sited in established navigation lanes, narrow channels, or where boats would be unable to navigate safely around them. In addition, if fish farms break loose from their anchors during severe weather conditions they could become a hazard to vessel traffic. If fish farms are inadequately lighted or made visually unobtrusive, they pose a greater risk to navigating vessels and may be a significant safety hazard, especially at night or during inclement weather.

Placement of one or more fish farms in an embayment may affect safe anchorages. During inclement weather, recreational boaters and towboats may seek sheltered bays for protection from storms. If floating structures restrict the use of a sheltered bay for anchorage by blocking channels or limiting maneuverability, towboats and other boaters may have to travel to the next available safe anchorage. Depending on the weather conditions, this could create a hazard for the boat, passengers, or commercial cargo.

Fish farms located near shore would affect navigation in a manner similar to a long dock, a marina, or a series of anchored boats. Most commercial traffic will tend to stay in deeper water, thus avoiding such areas. However, some commercial traffic such as towboats towing barges or log rafts may hug the shoreline. The further offshore the farm is located, the greater the navigational risk because structures are not expected, reference points are not nearby, traffic is more intense, and vessels are usually travelling faster.

Fish farms may also have a beneficial impact on navigation. In more remote areas, typical of recently permitted farm sites, fish farms can provide a point of assistance/ refuge for boaters. The farm sites usually have some form of sea-to-land communication.

6.2.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect potential navigation impacts:

- Presently, siting decisions for fish farm proposals are made on a case-by-case basis. Any structure that may interfere with navigation must receive an ACOE Section 10 permit. The U.S. Coast Guard (USCG) has the responsibility for reviewing all proposed structures in Puget Sound for potential navigation hazards through the ACOE permitting process. The USCG review ensures that all proposals, including fish farms, will not be sited in established navigation areas.

- The USCG is also responsible for establishing and maintaining a series of public buoys and lights to aid navigation through Puget Sound and may require structures such as fish farms to install private aids to navigation to reduce the potential for collision. The USCG has established a minimum brightness standard that requires navigational lights to be visible on a clear night for at least one mile (1.6 km). In addition, the USCG standardized a 6-second flash rate (0.5 seconds on and 5.5 seconds off) for lights associated with fish farms. The number and placement of any required private aids to navigation is at the discretion of the USCG District Commander (Title 33 CFR Part 66). Also, structures in the water that receive the appropriate permits will be included in the *Notice to Mariners* and will be placed on charts when updated.

- DNR requires a bond from fish farmers to ensure cleanup of any debris caused by accidental destruction of the farm. This bond would ensure that impacts to navigation caused by the breakup of a farm during a storm would be temporary.

- The Washington State Parks and Recreation Commission (WSPRC) reviews applications for proposed fish farms under SEPA. This review specifically evaluates the potential navigation hazard to recreational boaters visiting Washington marine parks.

- The impacts of a fish farm on navigation are also considered by local government as part of the permitting process under the *Shoreline Management Act*. For example, Kitsap County's *Shoreline Management Master Program* provides rules for fish farm establishment with respect to navigation. The Program states that "aquacultural structures [fish farms] shall be placed, when practicable, so as to minimize interference with surface navigation" (Part 7, Chapter II). The Program also states that fish farms that are hazards to navigation should be suitably marked for day and night visibility.

6.2.2.2 Preferred Alternative

It is recommended that local governments implement the following measures through their SEPA and shoreline permitting processes to reduce impacts to navigation:

- Provide major recreational and commercial boating organizations with SEPA and shoreline permit notices to help identify areas of special importance to boaters.

- Provide notification to recreational and commercial boating organizations and all marinas and ports near the farm of the precise location of farms and their aids to navigation.

There may be site specific conditions that warrant additional siting considerations to further reduce the potential impact on navigation. These siting considerations include:

- In areas suitable for raising fish and with high-bank shorelines, low boating use, and adequate currents and depth to avoid biological impacts; it is recommended that local governments encourage siting farms near the shoreline. Thus, in areas where the site does not exacerbate other problems, impacts to navigation would be reduced.

- In areas suitable for raising fish and where adequate depth and currents exist to avoid biological impacts, it is recommended that local governments encourage siting farms adjacent to existing structures such as docks and marinas to reduce impacts to navigation.

6.2.3 <u>Mitigation Measures and Unavoidable Significant Adverse Impacts</u>

The SEPA review and ACOE Section 10 permitting processes allow an opportunity to evaluate fish farm proposals on a case-by-case basis. These mechanisms provide the assessment of navigation impacts to be determined using the most current information for a specific site. Local implementation of the two notification measures recommended in the Preferred Alternative and the use of existing regulations are adequate to avoid significant adverse navigation impacts. No additional mitigation measures are necessary.

6.3 COMMERCIAL FISHING

Since fish farms occupy space in the water, there is the potential for commercial fishing boats to run into or have their nets become entangled with the farms. The resulting displacement of fishers from accustomed fishing areas is therefore the larger issue. This displacement could reduce the overall catch to a fishery, or affect the attainment of court-ordered allocations between tribal and non-tribal fishers. The reduction in catch and damage to fishing gear represents a loss of income to individual fishers.

6.3.1 <u>Affected Environment</u>

<u>General</u>. The State of Washington has an active commercial fishing industry. Ward and Hoines (1986) estimate the total catch value of all Washington sea products (salmon, halibut, shellfish, bottomfish, and other marine fish) caught by the industry in 1986 was worth roughly 132 million dollars. Many boats in the fleet will pursue more than one species of fish during the year. While there are many different fish species caught by the commercial fishing industry, the dominant species sought in Puget Sound are salmon: chinook, coho, chum, pink, and sockeye. Gillnetters are the dominant salmon fishery in

Puget Sound with almost 1,200 licensed boats in 1986 that harvested 19 million pounds. The number of licenses issued to various segments of the Puget Sound commercial fishing industry in 1986 is listed in Table 6.

maintain the court-ordered balance of allocation between treaty and non-treaty fishers.

A primary consideration in the Puget Sound harvest management process is the determination of the harvestable amount of each salmon run returning to Puget Sound. The process begins with estimates of expected populations of returning runs for each species on each river. The optimum number of fish needed for hatchery and natural spawning is then determined. This escapement goal is subtracted from the total run forecast to achieve a harvestable number of fish. In a lengthy series of court decisions culminating in a 1979 U.S. Supreme Court opinion, the tribal right to harvest fish – a right first established by the District Court in *U.S. v. Washington* in

Table 6. Number of Puget Sound salmon, bottomfish, and shellfish commercial fishing licenses by gear type, 1986.

Gear Type	Number
Salmon	
Gill Net	1188
Purse Seine	343
Reef Net	50
Troll	707
Bottomfish	
Bottomfish Pot	9
Dip Bag Net	84
Drag Seine	66
Handline/Jigger	595
Lampara/Round Haul	19
Otter Trawl	108
Purse Seine	2
Set Line	278
Set Net	55
Troll	232
Shellfish	
Beam Trawl	26
Geoduck Clam	13
Ring Net	178
Shellfish Pot (Crab)	247
Shellfish Pot (Non-crab)	173

Source: Ward and Hoines 1986.

Management of fishery resources in Washington is complex. In an effort to effectively manage fishery resources to achieve a sustainable yield, the State and treaty tribes regulate where, when, and for how long the commercial fishing industry can fish for specific species. Although WDF and the tribes administer many management programs for commercial finfish and shellfish harvesting, the most complex is the salmon program. That program is designed to meet the specific spawning requirements for each salmon stock, and

1974–was found to be guaranteed by the treaties between the United States and Indian tribes in Washington.

In order to ensure the proper implementation of this treaty right without court intervention, the salmon and steelhead originating from Puget Sound are cooperatively managed by the tribes and the State. Harvest management, artificial and natural production, and other issues affecting the survival and abundance of the fisheries resource are cooperatively addressed by state and tribal fisheries managers. Tribal review of, and comment on, issues affecting the marine habitat are based in part in their role as a manager of the fisheries resource.

Each year, a management plan is established between the tribes and WDF for each salmon species. This management plan includes harvestable amounts for each species, the time periods during which fish will be harvested, and specific harvest plans and conservation measures.

Treaty tribes fish in "usual and accustomed" marine and freshwater fishing areas throughout the fresh and salt waters of the Puget Sound Basin. Non-Indian fishers harvest in these same areas. In order to facilitate management, the marine areas of Puget Sound and the Strait of Juan de Fuca have been divided into numerous management areas to create discrete geographical areas within which distinct populations of fish can be managed. The Puget Sound salmon management and catch reporting areas are shown in Figures 22 and 23. Within these areas, fishery managers can reasonably predict the origin of a particular stock of fish, or the mix of stocks.

Management periods define the time "window" during which fishery managers will regulate the harvest of each fish stock. The basic management periods for each species and management area are provided in Table 7. Management periods are based on the central 80% of the run, and considering "early arrivals" and "stragglers," fish runs extend over a lengthy time period. These management periods are individually established by WDF and the tribes for specific runs of fish in specific management areas.

The active use of Puget Sound waters for commercial fishing varies in intensity. Some areas experience extreme congestion during a commercial opening while other areas are not used at all. The State establishes which management areas will be open for commercial fishing at a particular time during the season and for how long a specific gear type can fish during the opening. The number of salmon caught in 1986 by various gear types for the various management areas is shown in Table 8.

The number of areas in Puget Sound open simultaneously for commercial salmon fishing ranges from one to nine (Clocksin 1988). When only a few areas are open at one time, commercial boats from all over the Sound will congregate in these areas, creating a lot of congestion. This congestion is exacerbated at some management area boundary lines, where fishers line up to get "first crack" at fish entering the management area open for fishing.

The Hood Canal bridge is the northern boundary line of management area 12 and is a prime example of this congestion. At times when area 12 is open for commercial salmon fishing, as many as 100 boats will congregate at the bridge to catch fish bound for streams that drain into Hood Canal.

Puget Sound Commercial Fishing Techniques. The Puget Sound commercial fishing fleet uses a variety of techniques to catch fish. These techniques can be categorized into three groups (stationary, powered, and drifting) according to how they move through the water.

Stationary techniques include reef nets, set gillnets, and crabbing. The technique of fishing with reef nets involves creating a false reef using stationary nets near the shoreline that intercept fish in their migration routes. Fish swim between two nets hung vertically in the water forming a "V" that leads into a third net. This net forms an artificial reef which can be lifted to entrap the

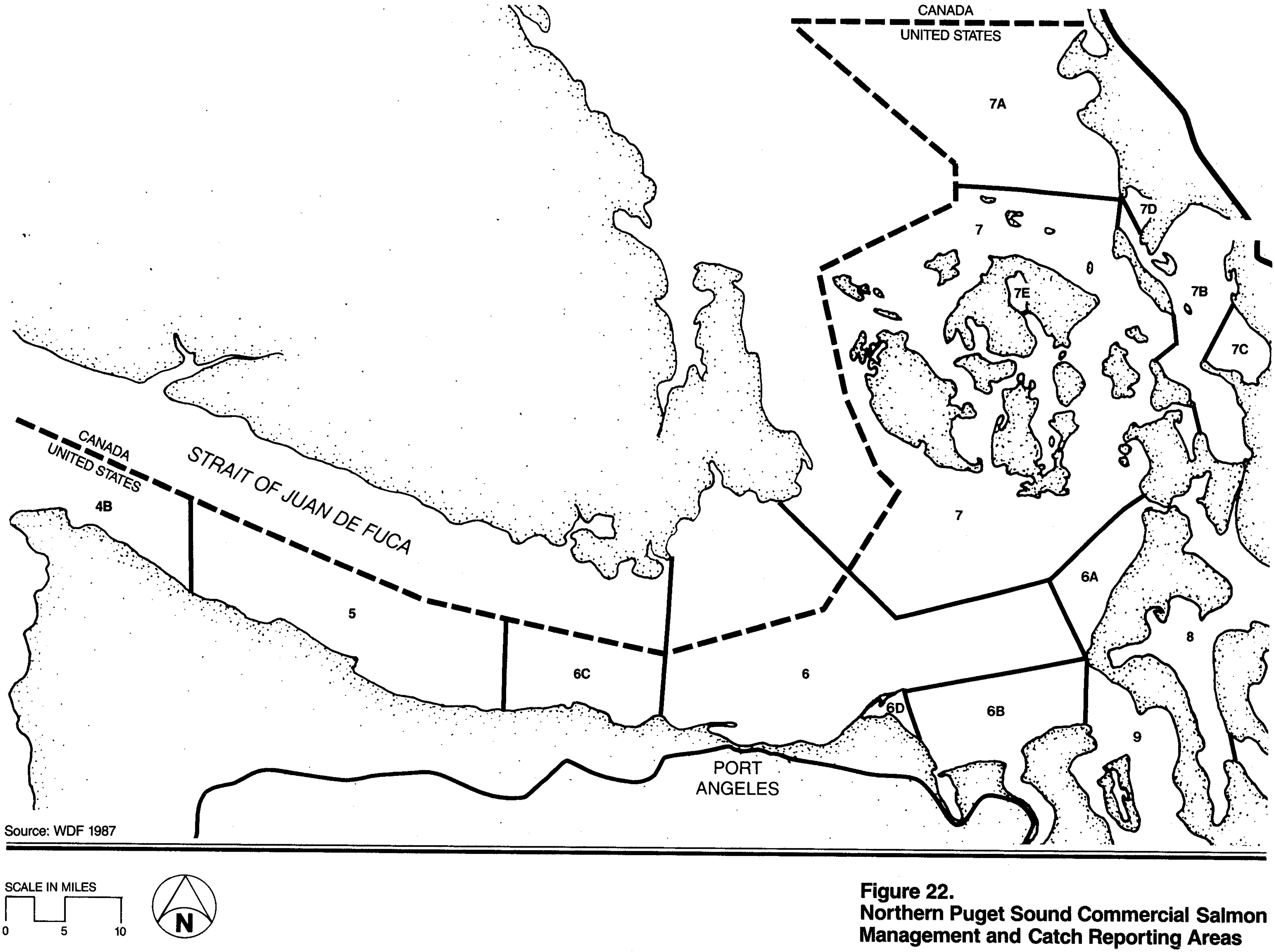
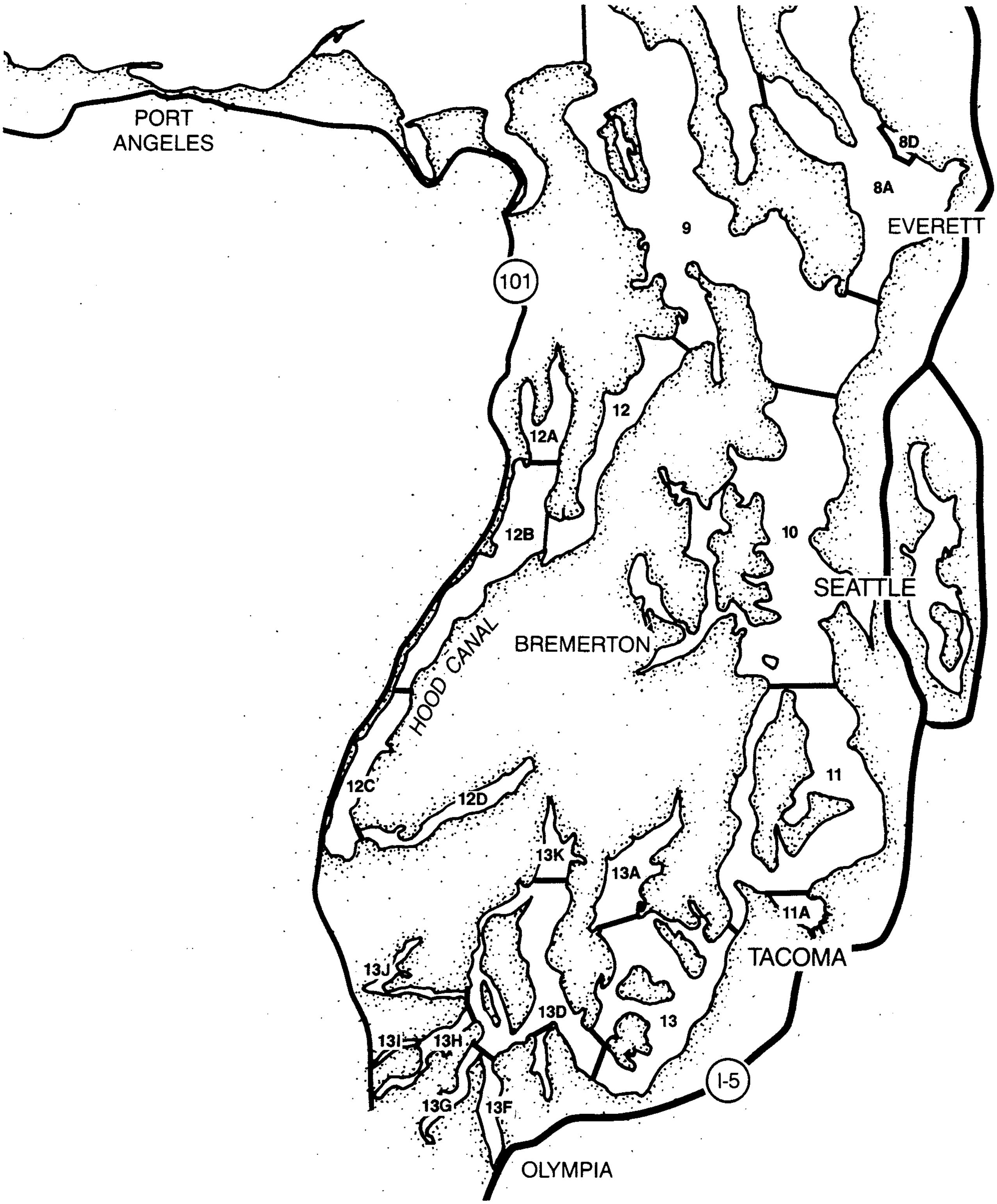


Figure 22.
Northern Puget Sound Commercial Salmon Management and Catch Reporting Areas



Source: WDF 1987

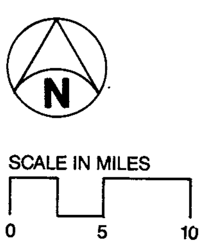


Figure 23.
Southern
Puget Sound Commercial
Salmon Management and
Catch Reporting Areas

Table 7. Generalized salmon management periods by management area[1].

Area	SP Chin	S/F Chin	Pink	Coho	Chum	E. Stuart and Puget Sound Sock.	Mid-Late Fraser R. Sock
4B	4/15-6/15	6/26-8/16	8/14-9/9	8/13-10/5	10/5-12/14	6/1-7/28	6/20-10/1
5	4/15-6/15	6/26-8/16	8/14-9/9	8/13-10/5	10/5-12/14	6/1-7/28	6/20-10/1
6	4/15-6/15	7/1-8/29	8/14-9/11	8/21-10/13	10/3-12/17	6/3-8/4	6/20-10/1
6A	4/15-6/15	6/16-9/6	8/4-9/13	8/29-10/21	10/3-12/17	6/3-8/4	6/20-10/1
6B	4/15-6/15	7/7-9/4	6/30-9/11	8/24-10/15	8/7-12/19	6/3-8/2	SNP
6C	4/15-6-15	7/1-8/21	8/14-9/9	8/13-10/5	10/5-12/14	6/1-7/28	6/20-10/1
6D	4/15-6/29	7/21-9/21	6/30-9/21	9/20-10/28	10/27-12/7	SNP	SNP
7	4/15-6/15	6/16-9/6	8/22-9/13	9/1-10/12	10/1-12/17	6/5-7/28	6/20-10/1
7A	4/15-6/15	6/16-9/13	8/25-9/14	8/22-10/18	10/3-12/17	6/5-7/28	6/20-10/1
7B	4/15-[2]	-9/7[2]	6/30-8/17	9/8-10/26	10/27-12/14	***	SNP
7C	4/15-	-MID OCT	SNP	10/15-10/26	10/27-12/7	SNP	SNP
7D	SNP	-9/7	SNP	9/8-10/26	10/27-12/14	SNP	SNP
8	4/15-[2]	-8/13	8/22-9/15	9/2-10/27	10/25-11/28	6/24-7/13	SNP
8A	***	7/21-9/9	8/9-9/9	9/10-10/12	10/22-11/30	***	SNP
8D	SNP	7/21-9/21	SNP	9/22-11/12	11/11-12/17	SNP	SNP
9	4/15-6/15	7/12-9/4	7/11-9/5	8/24-10/15	8/12-12/25	6/3-8/4	SNP
10	4/15-6/29	7/1-9/7	8/18-9/19	9/8-10/12	9/8-1/1	6/10-8/4	SNP
10A	SNP	7/1-9/14	SNP	9/15-11/2	11/3-11/30	6/10-8/4	SNP
10C	SNP	7/1-9/28	SNP	9/28-11/30	SNP	6/10-12/31	SNP
10D	SNP	7/15-10/5	SNP	10/6-12/14	SNP	6/10-12/31	SNP
10E	SNP	7/1-9/13	SNP	9/14-10/11	9/28-12/31	SNP	SNP
10F	SNP	7/1-9/14	SNP	9/15-11/30	SNP	6/10-8/4	SNP
10G	SNP	7/1-9/28	SNP	9/29-11/30	SNP	6/10-12/31	SNP
11	4/15-6/29	7/1-9/10	8/18-9/10	9/11-10/21	9/10-1/8	***	SNP
12	4/15-6/29	7/17-9/6	7/16-8/24	9/7-10/18	8/16-12/7	SNP	SNP
12A	4/15-6/29	***	***	9/6-10/7	8/26-12/21	SNP	SNP
12B	4/15-6/29	7/17-9/6	7/16-8/24	9/7-10/18	8/16-12/14	SNP	SNP
12C	4/15-6/29	7/24-9/6	7/23-8/31	9/11-10/25	8/26-12/21	SNP	SNP
12D	4/15-6/29	7/24-9/6	SNP	9/11-10/25	8/26-11/27	SNP	SNP
13	4/15-6/29	7/1-9/24	8/10-9/25	9/25-11/6	9/17-1/15	SNP	SNP
13A	4/15-6/29	8/8-9/16	8/16-9/17	9/17-11/9	10/23-12/31	***	SNP
13C	SNP	7/15-10/13	SNP	10/14-11/30	10/12-1/16	SNP	SNP
13D	SNP	7/1-9/21	SNP	9/22-10/12	9/17-12/31	SNP	SNP
13E	SNP	7/1-9/21	SNP	9/22-10/12	10/12-12/31	SNP	SNP
13F	SNP	7/1-9/21	SNP	9/22-11/6	11/7-12/12	SNP	SNP
13G	SNP	7/1-9/21	SNP	9/22-11/6	11/7-12/12	SNP	SNP
13H	SNP	7/1-9/21	SNP	9/22-10/12	10/12-12/31	SNP	SNP
13I	SNP	7/1-9/21	SNP	9/22-10/12	10/12-12/31	SNP	SNP
13J	SNP	7/1-9/21	SNP	9/22-10/12	9/22-12/31	SNP	SNP
13K	SNP	7/1-9/21	SNP	9/22-11/6	9/22-12/31	SNP	SNP

[1]Management periods adjusted annually for administration of fisheries.
[2]Management period currently under technical dispute; subject to change according to long range management planning.
***Stock present but no management period established.
SNP - Stock not present.

Table 8. Total commercial net catch of Pacific salmon in Puget Sound by management area, 1988 (in numbers of fish).

Area	Non-Indian		Indian		Other		Total
	GN[a]	PS[b]	GN[a]	SN[c]	PS[b]	Gear Types[d]	
4B	82	---	8,675	3,921	---	16	12,694
5	5,930	---	250,442	3,568	---	---	259,940
6	36,927	---	9,093	---	---	61	46,081
6C	135	---	1,667	1,984	---	16	3,802
6D	6,787	3	---	1,820	---	---	8,610
7	314,386	720,604	431,330	5,850	730,374	89,665[e]	2,292,209
7A	202,526	563,013	259,858	15,194	181,086	70	1,221,747
7B	98,471	31,915	90,259	26,800	16,643	---	263,088
7C	3,538	---	316	---	212	---	4,066
7D	7,449	---	501	---	---	---	7,950
7E	45,723	1,461	---	---	---	---	47,184
8	28,921	4,568	12,173	755	580	7,879	54,876
8A	32,434	138,020	170,745	2,973	83	5,684	349,939
8D	4,420	6,351	632	28,664	---	3,399	43,466
9	43,234	---	250	8,618	---	---	52,102
9A	---	---	---	5,998	---	---	5,998
10	112,363	180,574	79,702	2,750	57,286	---	432,675
10A	---	---	41,744	2,456	---	---	44,200
10E	---	---	13,052	21,917	379	6	35,354
10F	---	---	3,587	34,618	---	---	38,205
11	28,406	117,268	18,452	90	---	18	164,234
11A	---	---	41,254	854	---	---	42,108
12	59,635	328,001	206,652	3,326	866	---	598,480
12A	1,202	777	8,501	23,951	---	1,847	36,278
12B	3,295	10,592	22,421	5,539	---	25	41,872
12C	1,938	15,887	43,877	60,379	---	4,732	126,813
13	---	---	910	802	---	1,712	3,424
13A	2,782	1,739	30,914	18,442	---	4,944	58,821
13C	---	---	---	---	---	4,930	4,930
13D	---	---	19,994	93,282	---	2,213	115,489
13F	---	---	---	302	---	---	302
Totals	1,039,584	2,120,773	1,767,001	374,853	987,509	127,217	6,416,937

Source: WDF 1988.
[a] Gillnet
[b] Purse Seine
[c] Set Net
[d] Both Indian and non-Indian. Includes reef nets, beach seines, and other gear types.
[e] All fish caught by reef nets.

fish. Reef netting zones, established by statute, are primarily located in the San Juan Islands.

Set gillnets are vertically hung nets anchored in migration routes. Fish will swim into the mesh of the net and become entangled. To help keep the net vertical in the water, it is supported at the surface by a series of floats and weighted at the bottom. Set gillnets can be attached to shore, dock, or other shoreline feature, and are usually anchored to the bottom at the net's other end.

The crabbing industry uses round traps (1-meter-diameter pots) that rest on the bottom. Each crab boat has many baited crab pots, which are attached to a line with a float, and then dropped overboard. The pots sit on the bottom until they are retrieved for harvesting. The smaller commercial shrimp fishing industry uses similar gear.

Commercial fishing techniques that use motor power to fish include purse seining, trolling, and trawling. Purse seine fishing involves encircling a school of fish with a net and then gathering the bottom of the net, forming a purse that traps fish inside. While setting the net, usually about 550 m (1,800 ft) long, a small power skiff is used to hold the end of the net in place while they drift with the current. When the school is completely surrounded by the net, the bottom is closed off, and the fish become trapped. The seine boat then retrieves the net from the water and harvests the fish.

Trolling involves a boat slowly moving through the water, trailing lines with baited hooks in the water. Fish are retrieved from the lines after they take the bait, and the hooks are baited again and set back into the water.

Another technique for catching fish using motor power is the trawl. Various types of trawls (for example, otter and beam) are used to catch several species of bottomfish and shrimp. This method consists of dragging a large bag-shaped net at various depths, most commonly along the bottom. Fish are caught in the net as the boat drags the net through the water.

Gillnetting is the primary commercial fishing technique that involves drifting with the current. As with set gill nets, the intent of the fisher is to block the path of the fish so they swim into the vertically hung net and become entangled. Most gillnet boats will use a net 550 m (1,800 ft) long by 9 to 30 m (30 to 100 ft) deep. The net is supported at the surface by floats, and kept relatively vertical in the water by a weighted line on the bottom of the net.

Gillnetters set their nets perpendicular to the prevailing current to block the migration route of the fish. They then drift with the current, and when the skipper determines that sufficient time has passed, the net is pulled back on the boat by a power-operated drum, and the fish are removed from the net. The amount of time necessary to "pick" the net will vary from about 20 minutes to an hour depending on the amount of fish and debris in the net. During the process of retrieving the net and harvesting the fish, the boat continues to drift.

6.3.2 Impacts on Commercial Fishing

Fish farms are a physical obstruction in the water which, along with the area encompassed by their anchor lines, pose a threat to commercial fishing like that described in Section 6.2, Navigation. This potential problem is complicated by the complex nature of fisheries management, especially for managing the various salmon species.

The direct impact of floating fish farms on commercial fishing is the potential for collision or entanglement of the fishing nets with the farms, resulting in a loss of available fishing area and a financial loss because of damaged or destroyed gear. The probability of such an occurrence depends upon the location of the farm, and the type and intensity of fishing in the area. Results of this impact can be displacement of fishers from a productive and accustomed fishing area, lost harvest potential, and reduced opportunity of the fishers to catch their allotment of salmon.

Gillnetters are the group potentially most affected by the placement of fish farms because the number of boats using this technique is greater than all other techniques, they have limited maneuverability, and they fish at night when visibility is limited. Placing a fixed object in the middle of a drift forces gillnetters to avoid the immediate area, or attempt to pull their nets near the farm and risk entanglement. Drift netters must also avoid natural and manmade obstacles as part of their fishing effort. These include islands, points of land, rocks, docks, buoys, and bridge supports.

Because drift netters rely on currents to carry their nets while fishing, the potential conflict is increased. Similar current areas are also desirable for fish farms which need moderate currents to flush the pens and to minimize sediment accumulations. However, the areas of greatest conflict are not only determined by current or other factors, but also by the location of WDF management area boundaries along which most fishing is concentrated.

The size of the area from which drift netters would be prevented from fishing depends on many factors, especially the distance of the farm from shore. The further offshore the farm extends, the greater the area affected. Moving pens offshore 610 m (2,000 ft), as previously suggested to minimize visual quality impacts (Section 6.1, Visual Quality), increases the impacted area by extending the farm further into fishing channels, while also excluding the standard 550 m (1,800 ft) net inshore of the farm. In addition, some fishing boats use tapered nets that allow them to fish close to shore in areas where the bottom is free of objects that could entangle their nets. In intensely fished areas, such as the waters near the Hood Canal Bridge, the presence of a fish farm could result in intense conflicts with fishers, and significant risk of collision and entanglement during the fishing season. In other areas where fishing is much less congested, a fish farm would have proportionately less impact.

While the fishing area for gillnetters affected by fish farms is relatively large due to the size of the nets used and the limited maneuverability of the boats, other types of gear would be less affected. Purse seiners have greater control over the location of their sets and could fish close to the farm, especially on the down current side. Trawlers could fish close to the farm site, excluded only from the area occupied by the farm and anchor lines. Crab and shrimp fishers could set pots within the perimeter of the anchors. For those gear types able to fish close to the farm, there may actually be benefits to the fishers because of the attraction of commercially desireable fish and shellfish to the area of the floating fish farm, especially crab. Migratory fish may also be concentrated as they navigate around the pens.

The displacement of fishers from an established fishing area may have an effect on the commercial fishing industry, but the significance of the potential impact depends on site specific conditions. If non-tribal fishers have the opportunity to catch the same fish in another area opened for fishing, displacement of fishers from a particular site may not exclude those non-tribal fishers from catching fish. This may be the case in situations where a relatively large area exists between the farm site and the management area boundary.

The potential displacement of tribal fishers could also occur. Tribal fishing efforts are restricted to their "usual and accustomed" fishing areas. Each of the treaty tribes included in *U.S. v. Washington* (Boldt decision) have specific areas of Puget Sound that are designated as their "usual and accustomed" fishing areas. If a farm prevents a particular tribe from fishing in these areas, the tribe would have nowhere else to fish, and a significant impact could result.

In some cases, fish may not be available to the same fishing group. If opportunities for harvest are reduced in established non-tribal fishing areas, and the fish migrate into areas open only to tribal fishing (generally closer to the mouths of spawning rivers), the non-tribal fishers may lose part of their salmon allocation. The current salmon management plans would be disrupted, and adjustments would be required.

A third potential impact would be that the fishing opportunity is lost to all fishers, and fish return to their native streams. Because salmon are already managed to assure that adequate numbers of fish return to the streams to maintain viable runs, these additional fish would be surplus. Any surplus to the needed number of spawners that eludes tribal and non-tribal fishers would represent an unnecessary loss to the fishing industry.

6.3.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations and guidelines affect the potential impacts of fish farms on commercial fishing. Regulations related to potential navigation impacts are discussed under Section 6.2, Navigation.

- WDF is required to promote orderly fisheries, and enhance and improve recreational and commercial fishing in Washington (RCW 75.08.012). WDF has the authority to ensure that a fish farm does not interfere with an orderly fishery.

- WDF reviews fish farming proposals for potential impacts to commercial fishing through the SEPA process. This process allows WDF to identify whether a proposal is near an important commercial fishing area and provide their expertise to the SEPA lead agency when determining a proper farm location.

- WDF also reviews projects under its HPA permit process (RCW 75.20). This mechanism allows WDF an opportunity to modify a fish farm proposal to ensure that the commercial fishing industry is not significantly affected.

- The ACOE Section 10 permit process also provides an opportunity to identify important commercial fishing areas. WDF provides their input to Ecology for inclusion in the State response to ACOE.

- The *U.S. v. Washington* case (Boldt decision) determined that treaty tribes in Puget Sound shall be allowed to fish in their "usual and accustomed" fishing areas.

6.3.2.2 Preferred Alternative

The existing requirement that WDF promote orderly fisheries (RCW 75.08) is adequate to protect commercial fishing from significant adverse impacts related to the siting of fish farms. The review of proposals under SEPA and the ACOE Section 10 permit provide ample opportunities to identify important commercial fishing areas and supply decisionmakers with appropriate information regarding siting of fish farms.

It is recommended that the following measures be implemented by local governments through their SEPA and shoreline permitting processes to further reduce impacts to tribal and commercial fishing activities:

- Provide commercial fishing organizations and tribes with SEPA notices related to fish farm proposals. This will help identify areas of special importance to tribes and commercial fishing groups.

- Provide notification to the tribes and commercial fishing organizations of the precise location of farms and the layout of their anchor lines.

As with navigation issues, there may be site specific conditions that warrant additional siting considerations to further reduce the impacts on fishing activities. These include:

- In a suitable fish farming area with low visual impact potential (for example, high-bank shorelines), adequate currents and depth to avoid biological impacts, and significant fishing activity occurring more than 2,500 ft offshore; it is recommended that local governments encourage siting farms close to shore, and aligning them parallel to the shoreline.

- In areas suitable for raising fish where adequate depth and currents exist to avoid biological impacts, it is recommended that local governments encourage siting farms adjacent to existing structures such as docks and bridge supports to reduce potential impacts to tribal or commercial fishing activities.

6.3.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

The SEPA review and ACOE Section 10 permitting processes allow a case-by-case evaluation of proposals using current commercial fishing conditions. Local implementation of the two notification measures identified in the Preferred Alternative and use of existing regulations are adequate to avoid significant adverse impacts to the commercial fishing industry. No additional mitigation measures are necessary.

6.4 HUMAN HEALTH

Human health concerns have centered around the possible bacterial contamination of shellfish by fish farming practices. This issue is discussed below in addition to the risks of parasitic diseases that might be contracted from farm-reared fish.

6.4.1 Affected Environment

The primary concern with bacterial contamination in the marine environment affected by fish farming practices has centered around members of the bacterial genus *Vibrio*. Vibrios are among the most commonly occurring bacteria in the marine environment and include a diversity of species that may be non-pathogenic, human pathogenic, or animal pathogenic. Many environmental isolates of this common group do not appear to fit into presently described species. The animal pathogenic species are known primarily for their effects on intensively cultured animals. Thus, vibriosis of fish and shellfish is regarded as a disease of animal husbandry.

Vibrio anguillarum is the best known and most widely distributed of the fish pathogenic vibrios. There are four other species of fish pathogens: *V. ordalii*, *V. damsela*, *V. carchariae* and *V. salmonicida* (Egidius 1987). Other authors (Colwell and Grimes 1984) have cited vibrios known to be human pathogens as fish pathogens. These pathogens include *V. alginolyticus*, although this is not generally regarded as a fish pathogen, and *V. parahaemolyticus*, which the authors describe as rather obscure in fish. As cited by Egidius (1987), an isolate of *V. cholerae* has been associated with fish disease in Japan by Muroga et al. (1979) and Yamanoi et al. (1980), and *V. vulnificus*, biogroup 2 (Tison et al. 1982), is reported to cause disease in eels. However, as also noted by Egidius (1987), the literature on these four species of *Vibrio* as fish pathogens is "restricted and somewhat contradictory," and they have only been reported from warm water aquaculture sites. Thus, there is no literature citation from the large knowledge base on vibriosis which demonstrates that the vibrio pathogens of salmon are human disease-causing organisms.

The documented fish pathogenic species which affect salmonids in intensive husbandry (*V. anguillarum*, *V. ordalii*, and *V. salmonicida*) are distinct from the known human pathogenic vibrios potentially causing gastroenteritis. The vibrios that cause gastroenteritis include *V. cholerae* and the closely related *V. mimicus* and *V. parahaemolyticus*. Other species such as *V. alginolyticus* and *V. vulnificus* may be pathogenic through the infection of wounds or other means (Blake 1984). However, *V. alginolyticus* is one of the most commonly occurring species in marine coastal environments and is not generally regarded as pathogenic for humans.

Vibrio parahaemolyticus can cause gastroenteritis following consumption of contaminated fisheries products. The number of cases of *V. parahaemolyticus* gastroenteritis is small in the United States and the disease is not considered "reportable" by the Centers for Disease Control. In the Puget Sound area, only three cases were reported between 1982 and 1986 (Weston 1986). Environmental isolates of *V. parahaemolyticus* are common and more than 99 percent are considered non-pathogenic (Sakazaki et al. 1968; Thompson and Vanderzant 1976). The pathogenicity of isolates of *V. parahaemolyticus* is practically determined by the presence of a thermostable hemolysin (Miyamota et al. 1969) in an assay known as the Kanagawa test. This species of *Vibrio* increases in abundance in the summer and fall (Bartley and Slanetz 1971). Thus, both the known human pathogenic species, if not the actual pathogenic strains of *Vibrio*, as well as non-pathogenic species are indigenous, if not common, in the marine environment at certain times of the year. The probability of encountering Kanagawa-positive strains of *V. parahaemolyticus* increases during warm months and in embayments susceptible to warming as the overall concentration of *V. parahaemolyticus* increases. In Puget Sound, the highest concentrations of this species of bacteria occur in summer months in warm shallow embayments such as Oakland and Rocky Bays (Kaysner and Weagant 1982).

Watkins and Cabelli (1985) investigated the relationship of sewage enrichment in Narragansett Bay to the concentration of *V. parahaemolyticus*. They reported that nutrient enrichment did not produce an effect on *V. parahaemolyticus* levels but hypothesized an indirect effect. The bacteria did increase in conjunction with some types of particulate matter. The concentrations of this vibrio decreased sharply with depth and distance from the sewage source. There are no reports of a change in the prevalence of *V. parahaemolyticus* gastroenteritis in association with fish farming (Weston 1986).

Blake (1984) notes that "*Vibrio parahaemolyticus*, the most common cause of disease among these *Vibrio* species, in this country is almost invariably associated with eating cooked seafood which has been mishandled after cooking, allowing the organism to multiply." *Vibrio parahaemolyticus* gastroenteritis can result from eating raw shellfish contaminated with the bacteria although the number of such cases is small. Blake (1984) also notes the importance of water temperature, season and adequate cooking for reducing the risks due to this disease. Greenberg et al. (1984) reported preliminary data which suggested that the risk of parahaemolytic food poisoning is no greater from eating clams from a polluted area than that of eating clams from a relatively clean area. Thus, while vibrios are commonly found in the marine environment, the problems of seafood contamination and subsequent gastroenteritis with this species are most often linked with poor food handling processes.

Wekell and associates (1989) conducted a preliminary study between December 1987, and August 1988, comparing the bacteriological characteristics of shellfish held near three salmon farms in Puget Sound to those of shellfish from three comparable sites not near fish farms. In this study, the researchers examined the shellfish for the presence of a variety of human pathogens (indicators) including *Vibrio cholerae*, *V. parahaemolyticus*, *Yersinia*, *Listeria*, *Campylobacter*, *Salmonella*, and *Clostridium perfringens*, and fecal coliforms as well as other non-pathogenic species including aeromonas and *V. alginolyticus*. Sediment samples were also taken from beneath the pens and at nearby control sites. The preliminary study found no differences in the bacteriological character of the shellfish from the fish farm sites compared to the other sites. No *Vibrio cholerae*, *Yersinia*, *Listeria*, or *Campylobacter* were found in any samples. *V. parahaemolyticus* was found in a few samples.

These authors also performed bacteriological test on several lots of fish feed and isolated *Salmonella cubana* from one sample of moist feed as well as other bacteria. No *Salmonella* was found in oyster, sediment, or water samples from the farm sites or other sites.

Three parasites of salmon have been reported to infect humans in the Pacific Northwest: *Nanophyetus salmincola* (Digenea, a trematode worm) (Eastburn et al. 1987), *Diphyllobothrium* sp., a tapeworm, (Margolis et al. 1973; Ruttenber et al. 1984), and anisakine nematode worms (Deardorff et al. 1986, 1987). Salmon are infected with *Nanophyetus* and *Diphyllobothrium* during their freshwater phase of development. *Nanophyetus* infects fish by direct penetration of the cercarial stage of the worm, whereas fish become infected with *Diphyllobothrium* by ingesting infected copepods. Fish are infected with anisakine worms by ingesting infected arthropods or fishes in seawater.

These parasites are prevalent in wild salmon throughout the Pacific Northwest (Margolis 1982), and all reported human infections from salmon have been associated with wild caught fish. Deardorff and Throm (1988) found a mean of 46 anisakine worms per fish in wild salmon examined from fish markets in Seattle. Wild salmon from drainages in Washington, where the snail intermediate host is present, show a high prevalence and intensity of infection of *Nanophyetus* (Milleman and Knapp 1970), and *Diphyllobothrium* spp. occur frequently in wild Pacific salmon (Margolis 1982). In contrast, a survey of salmon from two fish farms in Washington revealed none of these parasites in 236 market-size fish (Deardorff and Kent 1989). Absence of anisakine worms was attributed to the fish feeding almost exclusively on pelleted feed through their grow-out phase in seawater. *Nanophyetus* and *Diphyllobothrium* infections were apparently prevented at the freshwater hatcheries before introduction to fish farms.

6.4.2 Impacts on Human Health

Because the bacteria associated with salmonid and other cold water fish farming are distinct from human pathogens, there is no foreseeable way fish farming activities will contribute bacterial human pathogens to the environment. In addition, it is clear that the occurrence of *V. parahaemolyticus* gastroenteritis is relatively rare and is most commonly associated with poor food handling processes. Fish farming appears unlikely to have an effect on cases of parahaemolytic gastroenteritis associated with eating contaminated raw shellfish.

The single isolation of *Salmonella* from fish feed (Wekell 1989) indicates that care must be exercised in the production and storage of fish feeds.

The vibrios of fish are distinct from the human pathogens. While highly contaminated areas of Puget Sound may contain shellfish, such areas are not suitable for fish farming. Furthermore, there is no direct correlation between human sewage enrichment and concentrations of *V. parahaemolyticus* (Watkins and Cabelli 1985). Fish farming may help prevent shoreline activities that contribute bacterial contamination to embayments around the Sound because such contaminated activities would degrade water quality, making the areas less suitable for fish farming.

Sale of salmon for raw consumption is a relatively small portion of the salmon market today. However, raw salmon is eaten as sushi and sashimi. It seems likely that parasitic human diseases from the consumption of raw salmon would decrease as a result of fish farming activities if farmed salmon products have an absence of parasites as research indicates. While examining fish from only two fish farms, the studies by Deardorff and Kent (1989) indicated that the farm-reared fish had no worms infectious to humans. This absence of parasites, the study concluded, occurs because farm-reared salmon live in a controlled environment during their freshwater development and are fed commercially prepared diets during seawater growth. However, further studies over a broader geographic range will be necessary to determine whether these findings have general applicability.

6.4.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations affect potential impacts on human health:

- The U.S. Food and Drug Administration is charged with regulating the safety of food fish. The FDA has an active research and regulation program aimed toward determining and implementing food safety requirements. Procedures involving efficacy, toxicity, and chemical residues are required for the licensing of antibiotics for use on food animals.

- DOH is authorized through RCW 43.20.050 to protect the health, safety, and will-being of the public and to prevent the spread of disease. DOH regulates food protection and storage (WAC 248-84). They are also charged with approving shellfish growing areas and assuring that these areas, and the commercially harvested shellfish from these areas, are not contaminated (RCW 69.30, WAC 248-58).

- WSDA, through the Washington Food Drug and Cosmetic Act (RCW 69.04), prohibits sale of adulterated or misbranded food. This relates to the fish farm industry in that it would prohibit sale of fish which are decomposed or contain antibiotic residues because they would be considered adulterated under RCW 69.04.210.

6.4.2.2 Preferred Alternative

While human health risks appear to be minimal, it is recommended that the following measures be implemented to further reduce any potential impacts on human health:

- Fish farms should be sited in areas that provide water quality compatible with good husbandry practices and productivity to ensure that farms are not placed in the warm, rich embayments of Puget Sound susceptible to seasonal increased levels of *V. parahaemolyticus*.

- Further research to determine bacteriological characteristics of fish food is desirable, since typical levels or significance of bacteria in fish food are not known. Although there is no information to indicate the presence of a significant human health risk, the preliminary findings of Wekell and associates (1989) indicate that further studies may be warranted.

- Further research to validate the geographic distribution of lowered parasite loads in farmed fish is desirable, because fish farming activities may increase the safety of eating raw salmon.

- Provide advisory notices to fish farmers on proper storage conditions for fish food.

6.4.3 Mitigation and Unavoidable Significant Adverse Impacts

Implementing the recommended measures identified in the Preferred Alternative in conjunction with the existing federal health regulations will avoid significant adverse impacts to human health. No further mitigation measures are necessary.

6.5 RECREATION

This section discusses the potential impact of fish farms on both aquatic and shoreline recreation.

6.5.1 Affected Environment

Puget Sound offers some of the finest opportunities in the country for recreation in a marine environment. The area is popular both with boaters and with persons using its beaches. Although recreation occurs in a variety of settings, areas with public access are generally more heavily used than are other areas. For example, recreational boaters will typically seek a destination that provides an amenity, such as a state marine park, public beach, or access to retail goods such as shops or restaurants. If a destination does include an onshore amenity, boaters will try to anchor close to shore to reduce the distance necessary to row to shore in a dinghy.

The depth of water in an embayment is also a factor in deciding where to anchor a boat. Because the average length of anchor line on recreational boats is 200 ft, most boats will anchor in water less than 15 m deep (Boyce 1988). Boaters also use embayments for temporary or overnight protected moorage during inclement weather. In addition, wind direction, wave conditions, water depth, and currents are factors boaters will consider when deciding which bays to pull into to wait out storms.

Other recreational users of the state's beaches usually seek a destination with good road access and intrinsic natural values. Many people use the public shorelands around Puget Sound for sunbathing, picnicking, birdwatching, beach combing, and general relaxation. In addition, persons with waterfront property use their own private beaches for recreational pursuits.

Recreational fishing can occur throughout Puget Sound, but tends to concentrate in specific areas at certain times of year. The areas used intensively for recreational fishing depend upon the species of fish being sought and the accessibility of the area.

In addition to boating, fishing, and recreational use of the shoreline, other recreational pursuits in Puget Sound include activities such as SCUBA diving, water skiing, swimming, kayaking, and windsurfing. Swimming and SCUBA diving generally take place in waters less than 30 m (100 ft) deep; the other activities can occur anywhere in Puget Sound.

Several agencies have authority over public recreational lands in and near Puget Sound. These agencies include the Washington State Parks and Recreation Commission, DNR, WDW, WDF, USFWS, and the National Park Service. There are also a variety of county and local parks located on the Sound.

6.5.2 Impacts on Recreation

Fish farms have the potential to impact recreational activities by obstructing access to shore or water areas traditionally used for recreation, or disrupting the intrinsic and visual quality of the area (see Section 6.1, Visual Quality). Fish farms may positively affect recreation by causing local increases in the numbers of crab and finfish near the farm site.

If farms are located in areas used for recreational boating or fishing, they could reduce the use of these areas, or require recreational boaters to travel around the facility (see Section 6.2, Navigation). Recreational anglers could entangle their fishing lines on farm anchor lines. Generally, fish farm anchors are placed at a distance away from the farms equal to about four times the water depth. Thus, trollers may risk entanglement within about 100 yards (91 m) of a fish farm. Other fishers who are mooching, jigging, or trolling near the surface could fish closer to the farm, or in between the anchor cables. Shoreline use could also be reduced by boat docks or other land-based installations associated with the farm. Odors and noise resulting from fish farms may also adversely impact recreational users (see Sections 6.6 and 6.7, Noise and Odors). Fish farms could also adversely affect the visual quality of an area (see Section 6.1, Visual Quality) which may reduce the value of an area for recreational use.

Floating fish farms can also have positive impacts on recreational activities. Personnel from farms could provide assistance during boating emergencies, and the farm structure itself could be used for temporary moorage during an emergency.

6.5.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations and guidelines affect the potential impact of fish farms on recreation:

- The SEPA review process allows the potential impacts of fish farms on recreational activities to be examined on a case-by-case basis. In all proposals for sites near State marine parks, the lead agency under SEPA seeks input regarding potential impacts from the Washington State Parks and Recreation Commission (WSPRC). Federal agencies such as the USFWS, National Park Service, and the U.S. Forest Service can also participate in the SEPA review process for proposals near lands under their jurisdiction.

Potential impacts of fish farms on recreational activities can also be addressed in local shoreline permitting processes. Both the SEPA and local shoreline permitting processes allow all agencies and groups concerned with potential impacts to recreation to provide input to the decisionmaking process.

- WDF is required to promote orderly fisheries, and enhance and improve recreational and commercial fishing in Washington (RCW 75.08). WDF has the authority to ensure that a fish farm does not interfere with an orderly recreational fishery.

  WDF reviews fish farming proposals for potential impacts to recreational fishing through the SEPA process. This process allows WDF to identify whether a proposal is near an important recreational fishing area and provides WDF with an opportunity to contribute their expertise to the SEPA lead agency when determining a proper farm location.

- WDF also reviews projects under its HPA permit process (RCW 75.20). This mechanism allows WDF an opportunity to modify a fish farm proposal to ensure that recreational fisheries are not significantly affected.

- The ACOE Section 10 permit process also provides an opportunity to identify important recreational fishing areas. WDF provides their input on fishing areas and potential impacts to Ecology for inclusion in the State response to ACOE.

- As stated in Section 6.5.2, fish farms could disrupt the visual quality of recreation areas. The *Aquaculture Siting Study* recommends that aquaculture facilities be sited 1,500 to 2,000 ft offshore. This guideline could effectively prevent any significant adverse impacts to the visual quality of state, local, or federal shoreline recreation areas.

6.5.2.2 Preferred Alternative

The SEPA review and Section 10 permitting processes provide a case-by-case evaluation of fish farm proposals. These mechanisms allow the most current information about the recreational activities at a specific site to be considered during the siting process. No additional measures are recommended.

6.5.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

The use of existing regulations is sufficient to avoid any significant adverse impacts to recreation and no additional mitigation measures are necessary.

6.6 NOISE

Sources of noise from aquaculture facilities include boats to service fish farms, pumps and generators necessary for operation, and communication between workers. Concerns have been raised about the potential impact to nearby residences.

6.6.1 Affected Environment

Existing noise levels on and along the shore of Puget Sound vary due to differing land uses and overwater activities. Daytime noise levels (measured L_{eq}, see below) are about 45 dBA to 50 dBA in areas adjoining rural residential land uses and having little overwater activity. Daytime noise levels can be 70 dBA or higher in areas adjoining urban land uses and having considerable overwater activity (EPA 1974). The unit dBA indicates decibels, which are units of sound measurement weighted to approximate the response of the human ear to sounds of different pitches. Noise levels in some sheltered bays during calm weather have been measured to be less than 30 dBA (Hurlburt, personal communication 1988). The designation L_{eq} indicates an equivalent constant sound level, and is used to compare noise sources whose levels vary over time.

6.6.2 Impacts of Noise

Potential noise impacts would primarily occur during daytime hours when farm operations take place. Sources of noise from fish farms would include boats servicing the farms, motors, compressors for aeration, and incidental noise from personnel working on the facility. Actual noise levels would vary depending on the equipment being used and the activities taking place. Pumps and compressors are only used during unusual conditions. Usually, they are used during certain summertime periods when algal blooms or low oxygen conditions necessitate aeration to circulate the water. Because of the usual absence of obstructions above the water surface, any noise produced by farm operations will tend to carry further than would be expected for a similar noise source located on land. Some noise would also result from truck traffic servicing the land-based portion of the facility.

In rural areas, the relatively low existing noise levels would make additional noise noticeable, even though resulting noise levels may be allowable under state regulations. Hurlburt (1988) observed that under unusually quiet conditions (background noise <30 dBA), the sound of a small engine-driven pump (74 dBA at 4 ft [1.2 m]) was still detectable to the human ear at 158 m (520 ft), although the measured level was less than 5 dBA above existing levels. Noise from 5-8 cm (2-3 inch) waves produced similar noise levels at the receiving property during the same study. In non-rural areas, noise generated by a fish farm may not be noticeable because of higher levels of surrounding activity.

An acoustical evaluation prepared for a proposed salmon farm in south Puget Sound predicted noise levels that would be generated by that facility (Towne et al. 1988). This study estimated an ambient peak hour L_{eq} of about 43 dBA at a distance of 488 m (1,600 ft), with levels up to 48 dBA occurring under certain weather conditions. Results of the study predict that under the observed conditions, the increase in noise levels due to the fish farm would be less than 3 dBA. Depending on facility-receiver separations and the nature of equipment used in the farm operation, noise levels could vary from those just described. Noise-producing equipment such as generators, pumps, and boats are usually only in operation intermittently.

6.6.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations and guidelines affect the potential impacts of noise from fish farms:

- Noise is regulated by Ecology which has established noise standards for various environments and activities (see Table 9). Local government may adopt stricter noise standards. In fact, some local shoreline programs include language regulating noise related specifically to aquaculture (fish farming) activities. For example, the *San Juan County Shoreline Master Program* states that:

  - Aquaculture activities shall comply with all applicable noise standards.

  - All projects shall be operated and maintained to minimize noise.

  - Aquaculture activities shall be restricted to reasonable hours and/or days of operation when necessary to minimize significant adverse impacts from noise.

  Also, Kitsap County requires that "aquaculture development shall make reasonable provisions to control nuisance factors such as noise. . . (*Shoreline Management Master Program*, Part 7, Chapter II). However, most jurisdictions have not adopted such standards and noise is regulated by the State standards.

- Noise sources other than recreational watercraft are subject to the *Maximum Environmental Noise Levels* (WAC 173-60). Maximum environmental noise levels are defined by this regulation and depend on the type of activity, source, and receiving property. The highest noise levels are allowed where both the source and receiving properties are used for economic or industrial activity (including agriculture). The lowest noise levels allowed occur where both properties are used for residential or similar uses. The maximum allowable one-hour noise levels are shown in Table 9. Depending upon the categorization of fish farm activity as a commercial or industrial use, the maximum allowable daytime one-hour noise level at a residential receiving property is 57 dBA or 60 dBA.

- The State also regulates noise created by waterborne activities. The *Watercraft Noise Performance Standards* (WAC 173-62) sets noise standards for recreational watercraft, but exempts commercial watercraft from its specific regulation. Recreational boats may not exceed 64 dBA between sunset and sunrise or 74 dBA during the day when measured at a residential property.

- EPA Region Ten (Washington and other northwest states) has set forth guidelines for evaluating the impact of increased noise levels on residential or other sensitive receptors. These guidelines state that an increase of less than 5 dBA would have a slight impact, an increase between 5 and 10 dBA would have a significant impact, and an increase greater than 10 dBA would have a very serious impact (EPA 1980). The Federal Interagency Committee on Urban Noise (FICUN) has established guidelines for maximum noise levels considered allowable for residential environments. The maximum 24 hour L_{dn} or daytime L_{eq} level is 65 dBA (FICUN 1980).

- In addition to the regulations listed above, the SEPA review process allows any concerns about significant noise impacts to be considered in the decisionmaking process.

6.6.2.2 Preferred Alternative

It is recommended that the following measures be implemented by local governments through their shoreline permitting process to reduce any potentially adverse noise impacts:

- Require installation and regular maintenance of mufflers on all motorized equipment.

- Require enclosures on all motorized equipment.

- In areas with access to shoreline electrical power (for example, adjacent to a dock), require farms to use electric motors to operate pumps and compressors.

6.6.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Use of the existing State noise standards and implementation of the measures in the Preferred Alternative are adequate to avoid significant adverse impacts to shoreline residents or other shoreline users. No additional mitigation measures are necessary.

6.7 ODORS

Concerns have been raised about the potential smell of fish farms. There is concern that odors will occur near the farm from rotting dead fish, drying nets, and fish feed left out in the sun.

6.7.1 Affected Environment

Existing odors along the shore of the Puget Sound are mostly the result of natural processes. The predominant source of natural odor along a shoreline is from the decay of organic material such as algae and zooplankton on the beaches. On muddy beaches at low tide, especially during warm summer weather, the predominant odor can be from hydrogen sulphide ("rotten egg" smell) release from the anaerobic decay of organic material in the sediments. Additional odors are produced by vegetation, animals and decay of

Table 9. Maximum allowable one-hour environmental noise levels. (These levels are 10 dB lower during nighttime hours.)

Activity at Source Property	Activity at Receiving Property Residential	Commercial	Industrial
Residential	55 dBA	57 dBA	60 dBA
Commercial	57	60	65
Industrial	60	65	70

Source: WAC 173-60.

organic material from these sources. In residential and rural areas, additional odors result from a number of sources: fireplaces, furnaces, burning yard debris, automobile exhaust, fertilizer applications, or domestic animals. In commercial and industrial areas, a wide variety of odors may result from these activities.

The nature and extent of these odors will depend upon the type of odor and its source, the location of the receiver (people) relative to the source, the sensitivity of the receiver, the direction and velocity of the wind that carries and dilutes the odors, and other factors such as temperature and humidity. The environment, and the appropriateness of the odor to that environment (for example, the natural aroma of a marine beach would be very noticeable in a forest environment), can also affect how odors are perceived.

6.7.2 Impacts of Odors

Because a large amount of organic matter is associated with marine facilities and fish farming, farms have the potential to be a concentrated source of additional odors. Most of these odors are similar to those occurring naturally on beaches (for example, decay of organic matter in a saline environment). The major potential sources of odors are spilled or improperly stored fish food, air drying of nets fouled with attached marine life, and dead fish. In addition, decaying organic matter from all of these sources can accumulate on the farm walkways.

Finally, boats servicing the facility, and internal-combustion motors used to power pumps and aeration equipment, would contribute minor amounts of exhaust fumes to the immediate area of the facility. In many cases, attributing particular odors to a fish farm may be difficult, because other activities in the area, manmade or natural, may produce similar odors.

All odor impacts would be occasional and intermittent. The impact of odors on people in the area of the farms would depend on the factors presented above, such as odors from other sources, the distance between the facility and the receiver, and weather. If good management practices are not followed, there is a potential for strong, unpleasant odors near the farm. These practices include removal of dead fish, cleanup of spilled feed, and general maintenance of the facility.

The placement of several farms in a localized area could result in cumulative odor impacts. With an increased number of farms in an area, odor impacts would probably be more frequent, although still intermittent due to weather. The extent of odors at some locations could increase depending on facility locations.

6.7.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations and guidelines affect the potential impacts of odors from fish farms:

- There are general laws in the State of Washington that prevent nuisance to individuals. Relief from a nuisance such as excessive odors would be sought through the judicial system.

- Most shoreline master programs mention odor in their aquaculture regulations in a general way. For example, Kitsap County's aquaculture regulations state, "aquaculture [fish farm] development shall make reasonable provisions to control nuisance factors such as noise or odor" (*Kitsap County Shoreline Management Master Program*, Part 7, Chapter II). The *San Juan County Master Program* also requires that all aquaculture projects be operated and maintained to minimize odor.

- Master programs also typically contain language requiring proper disposal of wastes. Regulation of waste disposal would reduce the potential for odors. Two examples from the City of Anacortes and San Juan County master programs include:

    - "Aquaculture operations shall not generate nuisance or dispose of wastes which would degrade the shoreline or reduce water quality" (*City of Anacortes Shoreline Master Program*, page 16)

    - "Aquacultural wastes shall be disposed of in a manner that will ensure compliance with all applicable governmental waste disposal standards. No garbage, wastes, or debris shall be allowed to accumulate at the site of any aquaculture operation" (*San Juan County Shoreline Master Program*, page 30).

6.7.2.2 Preferred Alternative

It is recommended that best management practices (BMPs) be developed for the fish farming industry. These BMPs would address issues such as odor and would include measures such as:

- Daily removal and disposal of dead fish and cleanup of spilled food.

- Regular cleaning of nets.

- Storage of food in closed containers.

- Use of walkways that are designed to allow spilled food to readily fall into the water.

Local governments may want to implement additional siting considerations to further reduce the potential impacts of odors on nearby residents. These factors could include:

- Encouraging sites that increase the distance between the farm and residences. These sites would have to be in areas without intensive navigation use to avoid increasing potential navigation conflicts.

- Encouraging sites downwind of residences (especially during prevailing summer winds).

6.7.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Use of existing regulations and the development of BMPs would avoid significant adverse odor impacts. No additional mitigation measures are necessary.

6.8 UPLAND AND SHORELINE USE

The issue in this section involves the potential displacement of existing uses and also potential shoreline and upland uses near a fish farm.

6.8.1 Affected Environment

Over 2,000 miles of shoreline border the inland marine waters of Washington state. Twelve counties with a combined population of 2.9 million people share this shoreline. This amounts to 65% of the state's population residing in only one-quarter of the state's land area. The spatial distribution of the population is shown in Figure 24. The greatest concentration of people occur on the eastern coastal plains of Puget Sound, particularly in King, Pierce, and Snohomish counties. General land use patterns in the Puget Sound area are shown in Figure 25.

Since 1940, when the growth rate in the 12 county region intensified, the population has been increasing at a rate of nearly half a million people every 10 years (approximately 50% of the statewide growth). In the next several decades, population in the Puget Sound region is expected to grow moderately, between 1.6 and 2.0%. The most rapid percentage growth has been in the more rural counties outside incorporated areas, such as San Juan, Island, and Thurston counties.

This increasing population will have several impacts, including a growing demand for residential property, especially along the water front. This growth will continue to displace forest and agricultural uses of the uplands adjacent to the water. This increasing development will bring growing water pollution problems from point sources (sewer and industrial discharges), and non-point runoff from uplands. In addition, the growing population will expect recreational facilities and activities associated with the water, such as marinas, parks, and fishing opportunities. At the same time, existing commercial users, such as fishing and towboat industries, and public ports will demand maintenance of their existing activities. Thus, population growth will only increase the existing conflicts between these diverse users of the state's shorelines and aquatic areas.

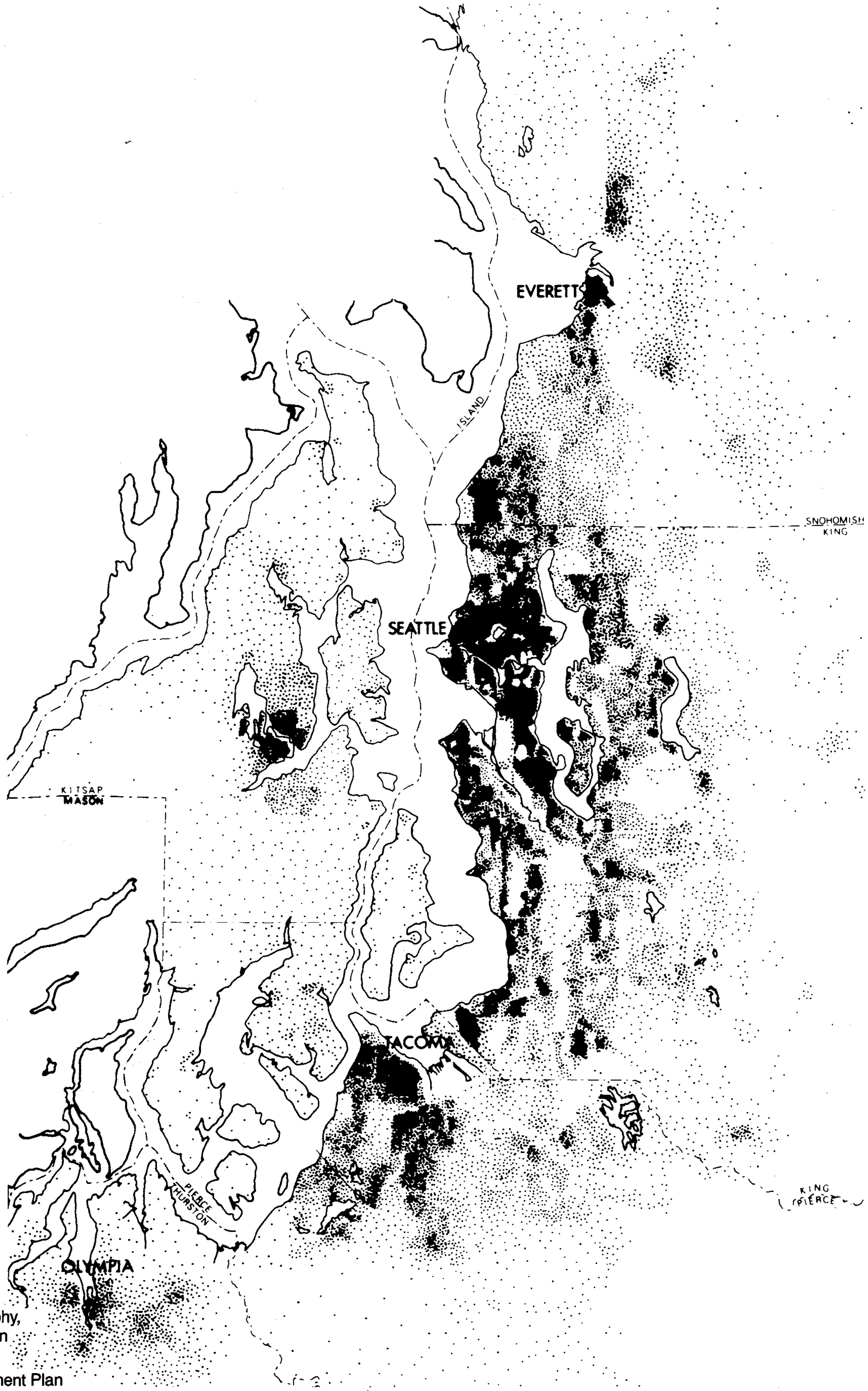
6.8.2 Impacts on Upland and Shoreline Use

An impact to land and shoreline use that has not already been discussed in other sections of this EIS is the potential for fish farms to influence future development patterns in an area.

Fish held in pens are particularly sensitive to degradation of water quality. Salmon have been held in small cages near industrial and municipal outfalls to monitor compliance with discharge standards (if the fish die, the discharge is not meeting state and federal standards). The presence of commercial fish farms will serve a similar function to monitor water quality.

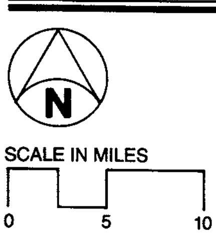
Fish growers will obviously avoid areas of potential poor water quality, such as near industrial and municipal sewage outfalls, and large storm water outfalls. A grower may also want to avoid sites near marinas, shoreline facilities that handle petroleum products, and areas dredged or used for dredge disposal which could potentially introduce pollutants into an area.

Once a fish farm is installed, it will highlight water quality concerns in the area. Therefore, greater attention may be brought to bear on activities that are not presently meeting water quality standards, or proposed activities which could adversely affect water quality. This increased concern about water quality may result in local and state agencies placing additional restrictions on upland projects to prevent water quality degradation. Upland users may also be subject to liability if their actions, in violation of pollution laws, were to damage the fish in the pens.



Source: Mary Stewart,
Department of Geography,
University of Washington

1987 Puget Sound
Water Quality Management Plan



Each Dot
Represents 100 Persons

Figure 24.
Population Distribution
in the Central Puget Sound Region

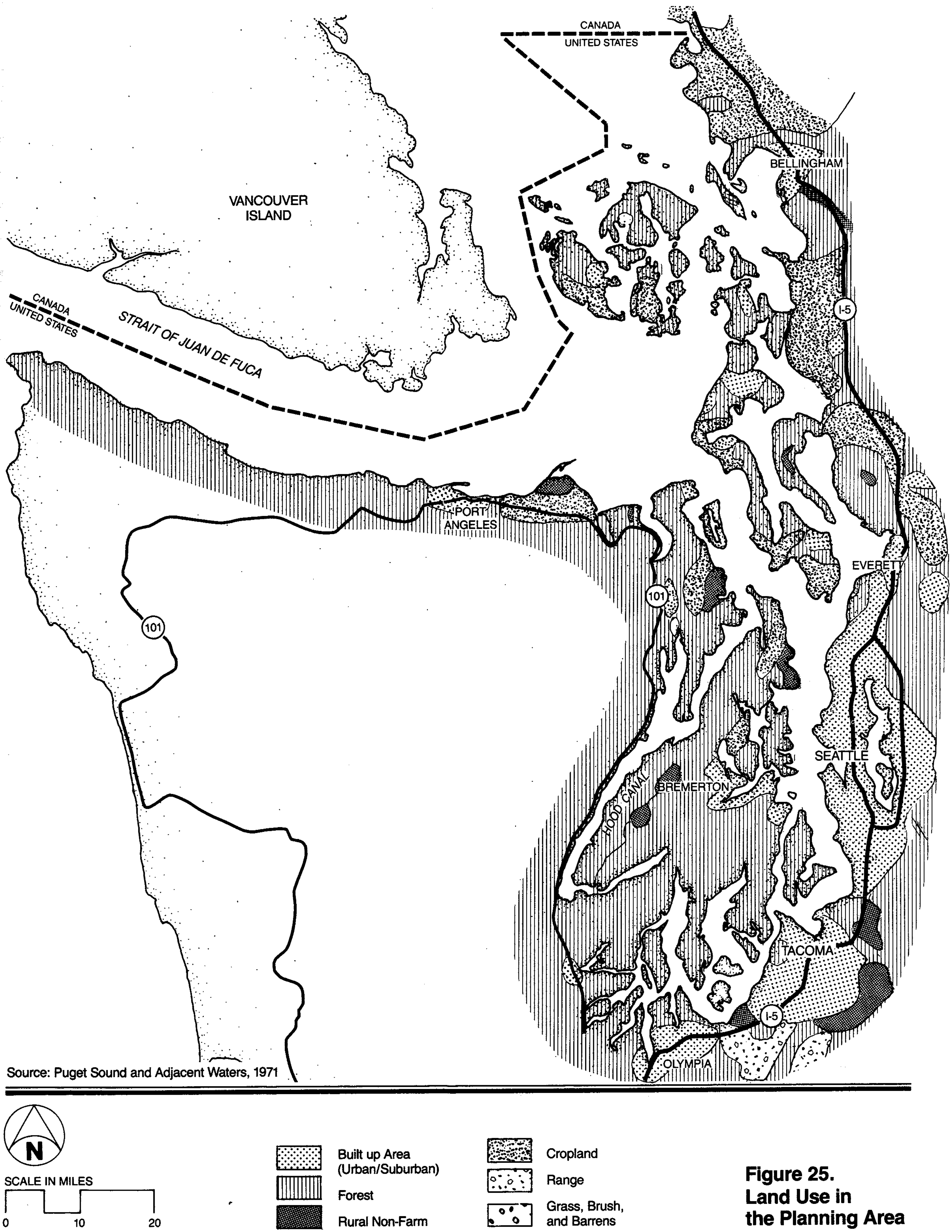


Figure 25. Land Use in the Planning Area

6.8.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following existing regulations and guidelines affect the impacts of fish farms on upland and shoreline use:

- Some counties in Washington provide regulations for fish farming with respect to the surrounding uplands and shorelines. For example, Kitsap County requires that "aquaculture [fish farm] wastes shall be disposed of in a manner that will prevent degradation of associated upland, inland, [and] away from the shoreline proper, when practicable" (*Shoreline Management Master Program* [Kitsap County], Page 7, Chapter II).

  Also, the *San Juan County Shoreline Master Program* states that, "Legally established aquacultural enterprises, including authorized experimental projects, shall be protected from incompatible uses which may seek to locate nearby. Demonstration of a high probability that such an adjacent use would result in damage to, or destruction of such an aquacultural enterprise shall be grounds for the denial of that use."

6.8.2.2 Preferred Alternative

Existing regulations are adequate to avoid significant adverse impacts to upland and shoreline uses and no additional recommendations are being made.

6.8.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Highlighting activities that may degrade water quality and subjecting them to greater regulatory control is not considered an adverse impact. All activities along the shoreline should minimize or prevent water quality degradation. If a fish farm serves to increase awareness of water quality needs, or results in changes to upland activities that are degrading water quality, it is considered a beneficial impact. Existing regulations are adequate to avoid significant adverse impacts to upland and shoreline uses and no additional mitigation measures are necessary.

6.9 LOCAL SERVICES

The issue here is whether the presence of fish farms will impair the ability of governments and utilities to provide their services.

6.9.1 Affected Environment

Most local services in the Puget Sound area are provided by local agencies or utilities. Fire and emergency services are usually provided by either a district within the local county or by a municipal jurisdiction. Solid waste disposal services are provided by local government or private businesses. Police services are provided by county or municipal jurisdiction. Sewer and water services, where available, are usually provided by purveyor districts in rural areas and by municipalities in more urbanized areas. Electrical power is supplied by state regulated utilities throughout the Puget Sound area.

6.9.2 Impacts on Local Services

The operation of fish farms does not require large amounts of fresh water or electricity. If the project is located close to shore, a waterline could be installed to provide fresh water for drinking, spraying down nets, and rinsing walkways. In addition, an electric cable can power electrically-powered pumps, feeding mechanisms, and lights.

When a farm is located a considerable distance offshore, bottled water would be used for drinking, and a portable pump installed to wash down nets and walkways. Sites located offshore would use portable generators. In remote areas without available water or electricity, wells and electrical lines may have to be installed in the upland area.

Fish farms must dispose of solid waste generated at their farm site. The major component of this waste is fish that die and are not harvestable for commercial sale. There are three ways that existing farms in the Puget Sound region dispose of dead fish: (1) dispose of the fish at landfill sites, (2) reprocess the dead fish into fish feed, and (3) incorporate the fish into local agricultural activities. These means of disposal have been adequate to handle the volume of dead fish produced by the fish farming industry.

Fish farms would not have an impact on other local services. Portable toilet units are used on the farms. Fish farms are not expected to have significant demands for police or emergency services. Use of existing boat ramps during farm operations may impact ramp facilities, but the impact would not be significant because farm operations involve only a few boat trips per day.

Increasing the number of farms in a localized area such as an embayment would probably result in a cumulative impact on local services, because any particular service would likely be provided by a single purveyor. Because any one farm results in an insignificant demand on local services, the size of the cumulative impact of several pens would be minor.

6.9.2.1 No-Action Alternative - Existing Regulations and Guidelines

The following regulations affect the impacts of fish farms on local services:

- There are numerous State regulations that deal with local services such as fire, police, landfills, and sewer and water services. None of these regulations specifically identify fish farms as a use that requires special concern.

- Local shoreline master programs do not contain guidelines or regulations that discuss potential impacts on local services from fish farms. These potential impacts have generally been found insignificant and therefore have not been an issue for regulation.

6.9.2.2 Preferred Alternative

It is recommended that local governments require fish farm applicants to provide information regarding solid waste disposal as part of their shoreline permit application. This information should include:

- A high and low estimation of the volume of waste that may be produced by the proposal including potential catastrophic losses.

- The process by which the farm will dispose of its waste.

6.9.3 Mitigation Measures and Unavoidable Significant Adverse Impacts

Costs incurred by service purveyors would be reimbursed through utility fees paid by the farmer. Use of existing regulations and the implementation of the recommendation in the Preferred Alternative is adequate to avoid significant adverse impacts to local services. No additional mitigation measures are necessary.

7. CUMULATIVE IMPACTS ON PUGET SOUND

The potential cumulative impacts from fish farm development in Puget Sound would be minimized by the evaluation process resulting in the proper siting of individual farms. Theoretically, siting five farms in a small embayment on an individual basis, without consideration of other farms in the area, could have a cumulative impact on one or more elements of the environment discussed in this EIS. However, siting five farms in an embayment, or a number of farms throughout Puget Sound, would not have a cumulative impact on those identified elements of the environment if the locations of other nearby farms were considered in the permitting process. Individual farms would receive their own site-specific SEPA review and undergo scrutiny for compliance with the regulations discussed throughout this EIS, including consideration of nearby fish farm development.

The process of analyzing cumulative impacts of fish farms must be sequential. Decisions made on individual farm proposals and the adequacy of a specific site will be made with knowledge of other nearby farms and those that are proposed for a particular area. All fish farm proposals will include cumulative impact analysis, an analysis that will occur in the time between the submission of an application for a fish farm and the issuance of the SEPA and shoreline final permitting decisions.

The following discussion focuses on the potential cumulative impact on Puget Sound water quality from a range of fish farm development, because the analysis can be done without site specific information.

Analysis of the impact of various levels of fish farm development on the entire Puget Sound is an exercise to determine if there is an upper limit on the capacity of Puget Sound for farms within projected levels of fish farm development. This upper limit is the point beyond which additional farms will reduce water quality in the Sound as a whole. The intent of such analysis is to show if projected levels of fish farm development will adversely affect Puget Sound by exceeding the assimilative capacity of the Sound. This analysis assumes that the farms are dispersed throughout the Sound. It is not intended to supplant the need for a thorough and detailed analysis of localized environmental effects around a fish farm.

In addition, basin-wide analysis serves to put the inflow of nutrients and organics from farms in perspective by comparing them to other sources of nutrients and organics, both man-made and natural. If the amount of nutrients from the farms is extremely small compared to the amount from naturally occurring inflows, then it is reasonable to argue that the Sound can sustain that level of impact without excessive degradation.

For purposes of analysis, four hypothetical production levels were selected for the typical farm described in Section 2, Background:

1. 13 farms, 4,400 metric tons (10 million pounds) production
2. 25 farms, 8,600 metric tons (19 million pounds) production
3. 50 farms, 16,400 metric tons (38 million pounds) production
4. 100 farms, 34,100 metric tons (75 million pounds) production

The first production level of 4,400 metric tons is approximately equal to the estimated production from the 13 existing farms in Puget Sound. Production levels 2 through 4 represent an approximately two-, four-, and eight-fold increase over current production. The 100-farm production level is considered by some to be in excess of the maximum number of farms that could be permitted, considering the number of competing uses for potentially suitable sites.

A summary of loading rates for various water quality indicators is given in Table 10. The values in the table were computed from loading analyses for the Discovery Bay fish farm (Kieffer and Atkinson 1988; Parametrix 1988) assuming loading rates of 0.59 kg BOD/kg fish produced, 0.55 kg feed+feces/kg fish, and 0.074 kg N/kg fish.

While farm effluents cannot be directly compared with sewage, components like BOD (biochemical oxygen demand) and dissolved nitrogen loads were compared to various other sources of loading to Puget Sound. The BOD was compared to wastewater treatment effluents from two Metro treatment plants and to one industrial source (Figure 26). In this comparison, 25 and 50 farm capacities are similar to a large wastewater treatment plant, while 100 farms is considerably larger than any single treatment plant on the Sound. However, the farms represent a more diffuse source of BOD loading than a treatment plant.

For nitrogen loading, the fish farm production levels were compared to two wastewater treatment plants and to the inflow of nitrogen to the main basin of Puget Sound from the surrounding land (Figure 27). The nitrogen inflow to Puget Sound is dominated by the natural movement of nitrogen with the tides and with fresh water inflow. Compared to the tidal inflow, all other nitrogen sources are insignificant, and even the 100-farm production level does not represent a large input of nitrogen. It should be noted that not all of the nitrogen sources shown in Figure 27 are for the same nitrogen compound; tidal fluxes are only for nitrate, the treatment plant loadings are only for ammonia, and the farm loadings are for nitrate plus ammonia. A comparison of nitrate and ammonia for all sources would increase the inflow of nitrogen from tides and treatment plants, but farm sources would remain unchanged.

The impact of fish farms on Puget Sound can also be evaluated by presenting the loading from farms as an overall change in nitrogen concentration throughout the Sound. This analysis treats the entire Sound as a well-mixed water body. A more conservative approach is to assume that the loading only affects the surface mixed layer, such as the case of a dissolved substance released near the surface. Assuming a mixed layer from mean low water to approximately 20 meters (66 ft), the total loading from the farm would mix with 36 km^3 of water (McLellan 1954). The mass loading of 1.8 MT/day of dissolved nitrogen would result in an increased nitrogen concentration of 0.05 ug/l/day. Similarly, loading from 50 and 100 farms would increase dissolved nitrogen concentrations by 0.09 and 0.19 ug/l/day. These concentrations are one hundred to one thousand times lower than levels that could have an impact on Puget Sound. Given the strong tidal exchange and the high nutrient outflow rate, the small daily increase in nitrogen would not accumulate to problem levels.

In summary, the impact of 25, 50, or 100 farms on the overall water quality of Puget Sound would be minimal and largely negligible. Consequently, the farms production in Puget Sound will be limited by the availability of sites that can be developed without significant local impact to water quality and degradation of benthic communities. Furthermore, conflicting uses of the water (navigation, fishing, aesthetics, etc.) may limit the number of farms to production levels well below the maximum production level considered here.

Table 10. **Loading of BOD, particulates (feed+feces), and dissolved nitrogen from different levels of fish production in fish farms.**

Number of farms	Production (MT/yr)	Total BOD (MT/yr)	Feed+feces (MT/yr)	Dissolved Nitrogen (MT/day)
13	4,400	7.3	6.8	0.9
25	8,600	14	13	1.8
50	16,400	27	25	3.3
100	34,100	55	52	6.8

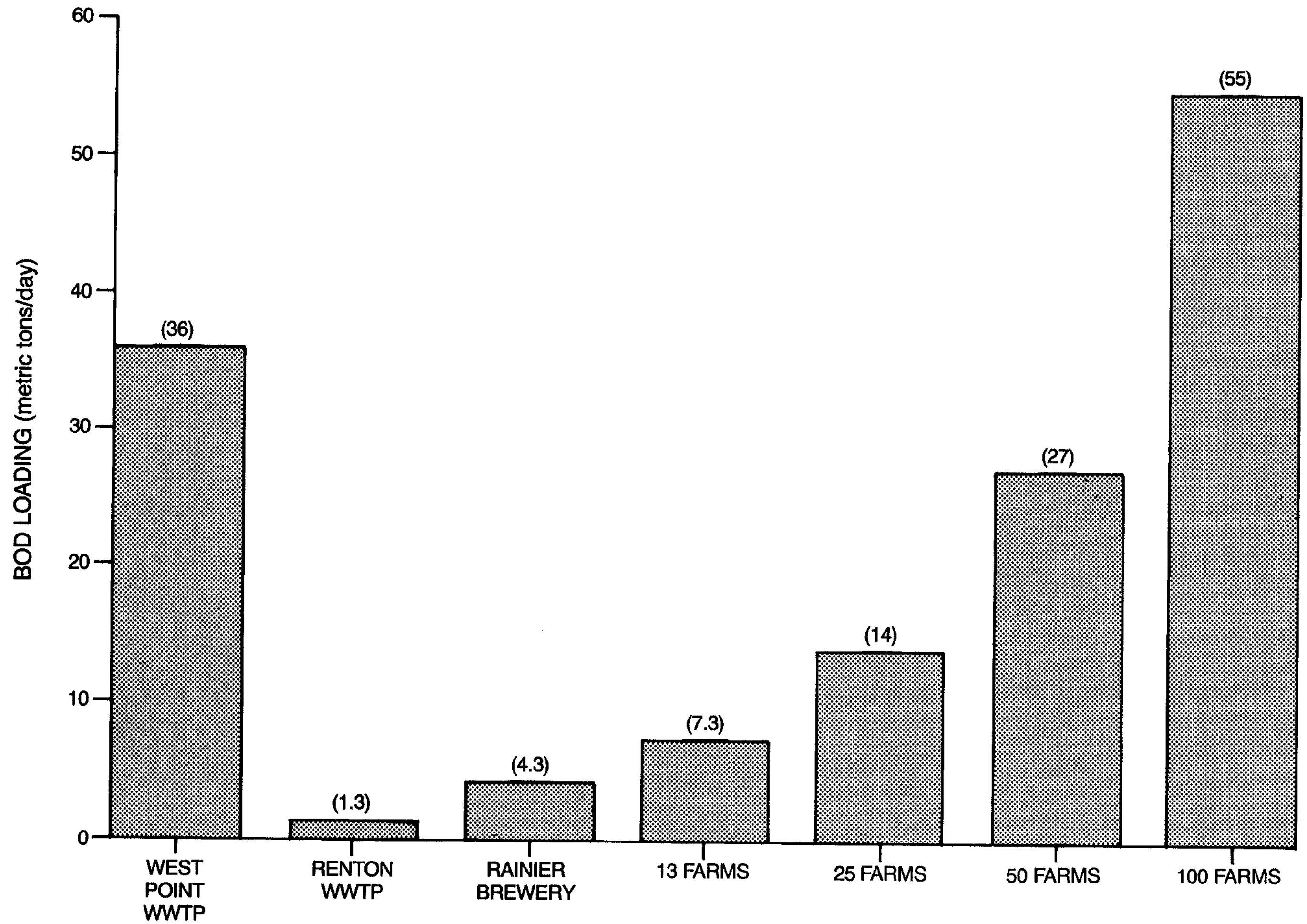


Figure 26.
BOD Loading From West Point and Renton Wastewater Treatment Plants, Rainier Brewery, and Different Levels of Fish Farm Development

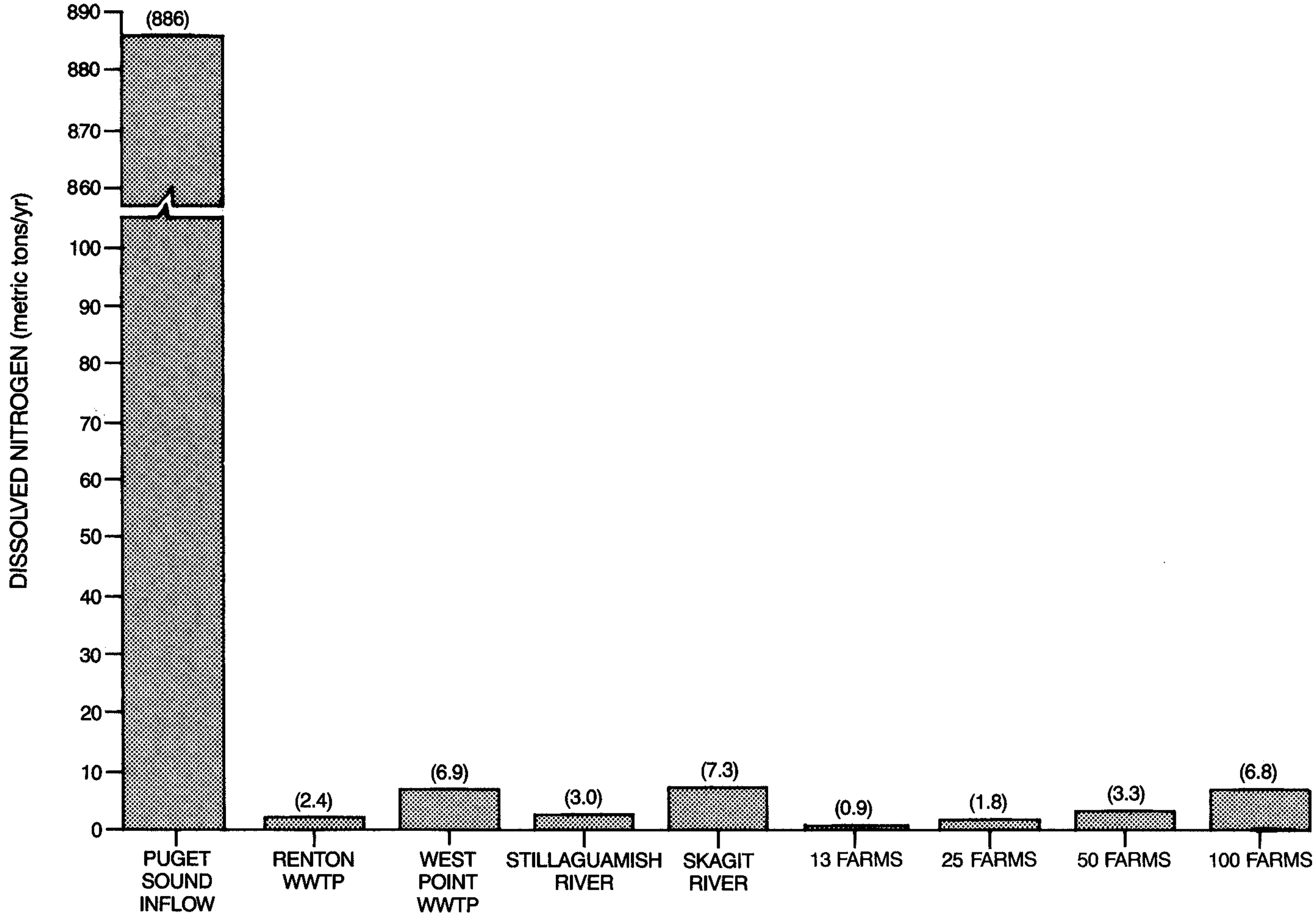


Figure 27.
Nitrogen Loading From Tidal and Freshwater Inflow, Renton and West Point Wastewater Treatment Plants, Stillaguamish and Skagit River, and Various Levels of Fish Farm Development

8. RELATIONSHIP TO LAND USE PLANS AND REGULATIONS

The geographical focus of this EIS is Puget Sound and its adjacent marine waters. This area includes counties, incorporated cities and towns, and large tracts of land under State or federal jurisdiction.

8.1 LOCAL JURISDICTIONS

Local jurisdictions have a variety of land use policies and regulations that affect the construction and operation of fish farms. The land use policies are generally expressed in comprehensive plans and shoreline management master programs. Land use regulations are embodied in zoning codes, the use requirements of shoreline management master programs, and performance regulations (for example, noise ordinances).

Comprehensive Plans. The comprehensive plans of local jurisdictions generally contain goal statements and policies that seek to protect the environment and avoid incompatibilities with surrounding uses. To this end, agricultural and commercial development is usually considered appropriate in designated areas. However, approval of a proposed activity usually hinges on a demonstration that the project will not adversely impact adjacent uses, and can be operated to prevent environmental degradation.

An aquaculture operation can have both agricultural and commercial elements. The Legislature of the State of Washington has determined that aquaculture, including the raising of fish, is an agricultural enterprise (RCW 15.85). This legislation states in part: "The legislature finds that aquaculture should be considered a branch of the agricultural industry of the state for purposes of any laws that apply to or provide for the advancement, benefit, or protection of the agriculture industry within the state." However, processing, wholesale transactions, and other activities, which may be associated with a fish-growing operation, can be considered commercial uses.

Consistency with the goals and policies of a comprehensive plan is addressed as part of permit review. The permits required by a local jurisdiction will depend on the project and the site. A shoreline permit is required for a substantial development within shoreline jurisdiction. A use permit may be required if upland portions of the project are not permitted outright in the zoning ordinance.

Shoreline Master Program. Shoreline master programs contain both policies and regulations affecting substantial development within shoreline jurisdiction. "Shorelines" are defined as all waters of the State, including reservoirs and their associated wetlands. The exceptions are stream segments on rivers having a mean annual flow of less than 20 ft^3/sec and segments on lakes less than 20 acres. "Associated wetlands" include areas within 200 ft of these shorelines, together with marshes, bogs, swamps, floodways and floodplains that influence or are influenced by these waterbodies (RCW 90.58.030).

The policies contained in local shoreline master programs reflect the priorities and guidelines of the *State Shoreline Management Act* (90.58 RCW) and regulations for implementing it (WAC 173-14 through 173-22). Although local governments are given wide latitude in tailoring shoreline master programs to meet local needs, the policies and regulations must be consistent with these state laws. To this end, all master programs must be reviewed and approved by Ecology.

Of specific importance to the development of local policy on aquaculture is the state policy on "shorelines of statewide significance." The *Shoreline Management Act* states that in the case of shorelines of statewide significance, local master programs shall give prioritized preference to uses which:

- recognize and protect the state-wide interest over local interest
- preserve the natural character of the shoreline
- result in long-term over short-term benefit
- protect the resources and ecology of the shoreline
- increase public access to publicly-owned areas of the shoreline
- increase recreational opportunities for the public in the shoreline
- provide for any other element as defined in RCW 90.58.100 deemed appropriate or necessary.

A shoreline of state-wide significance includes all subtidal lands, as well as specifically designated intertidal areas, lakes, and rivers. Therefore, local government must give priority in these areas to developments meeting the criteria listed above. It is the policy of the State to encourage the development and expansion of aquaculture (RCW 15.85). In addition, the State guidelines for shoreline master program development indicate that aquaculture is a water dependent use that, if properly sited and managed to avoid environmental degradation, is a preferred use of the water area (WAC 173-16-060 (2)).

It is in this context that floating fish farms are evaluated in local shoreline master programs. Local shoreline administrations have attempted to account for statewide interests, while taking into consideration local land and shoreline use issues. The adoption of aquaculture policy and regulation at the local level has been a difficult task, and shoreline master programs vary widely on the approach used to achieve a balance.

Fish farms must receive a shoreline substantial development permit in order to operate. Shoreline substantial development permits are approved if the proposed development is consistent with the local shoreline master program. Shoreline permit decisions are reviewed by Ecology, and both permit approvals and denials can be appealed by this agency to the Washington State Shorelines Hearings Board. If a shoreline conditional use permit or variance is involved, Ecology has the authority to deny a permit that has been approved at the local level.

In many local jurisdictions, the shoreline master program is adopted as an element of the comprehensive plan. When this is the case, approval of a shoreline substantial development permit is contingent upon a finding that the proposal is consistent with the comprehensive plan.

Zoning and Other Regulations. Local jurisdictions would also regulate upland portions of a floating fish farm operation or tank farm through zoning regulations. Zoning regulations normally include limitations on the bulk of structures, and also some site design requirements, such as setbacks from property lines. Whether the facility is permitted or requires conditional approval, it would have to meet the requirements of the underlying zone. Zoning ordinances are the implementing arm of the local comprehensive plan. Therefore, approval of a zoning permit requires a finding that all portions of the proposal are consistent with the policies of the comprehensive plan.

Regulations on other aspects of land uses, such as noise and air pollution, may be included in zoning regulations or separate legislation. These regulations are discussed in appropriate sections of this document.

8.2 STATE AND FEDERAL JURISDICTIONS

Locating a fish farm in the marine waters of Puget Sound would require leases and permit approvals from several Washington State agencies. In addition, the federal government has specific authorities over navigable waters and wetlands of the State. A list of the permits which may be required for a floating fish farm development is shown in Appendix F and discussed in Section 4.1, Permits and Approvals. As stated earlier, this list covers both salt and freshwater, floating or land-based aquaculture operations. Some of these permits may not be applicable to all proposed projects.

8.3 PUBLIC TRUST DOCTRINE

The public trust doctrine is a common law principle which recognizes the right and responsibility of each state to protect certain inalienable public rights in coastal resources. The State has a responsibility to manage its aquatic lands for the benefit of all citizens and to make resource allocations in a conservative and responsible manner. The public trust doctrine considers aquatic lands to include both private rights which can be sold and public rights which cannot be sold. Thus, even when selling tidelands, the public maintains a kind of easement which requires that the State continue to protect the public's rights in navigation, fishing, commerce, and recreation.

8.3.1 Historical Basis

The historical origins of the public trust doctrine are found in ancient Roman and English common law. The concept of the public trust in navigable water was adopted early in the United States. In 1821, an American court (*Arnold v. Mundy*) declared the law of public trust as it is known today. The court found that rights in the beds of navigable waters had been held by the Crown in trust for the common use of the people, the states succeeded to this trust, and a grant divesting the citizens of these common rights was void. It thereby became incumbent upon state governments to hold certain natural resources in trust for the people. In addition, the government could not relinquish its responsibility through a transfer of property. Lands to which the doctrine applies carry the burden of the public trust to the private land owners. In fact, American courts have occasionally expressed the view that waters by their nature are incapable of private ownership (Stevens 1980).

8.3.2 Public Trust Doctrine in Washington

Early court cases in Washington recognized the State's public trust responsibilities. These cases related to the sale of tidelands and shorelands and affirmed ownership rights of the state and the absence of riparian rights in Washington. The courts also recognized, in theory, that the state held the rights of navigation and fishing in trust for all the people of the State. By 1970, the legislature and courts expressly began to recognize that private property ownership of aquatic lands must be reconciled with the public trust easement or rights retained by the public.

That the state has asserted its ownership of aquatic resources is evidenced by the thousands of aquatic land leases, easements, and rights-of-way granted over the years. Most recently, legislative direction for managing aquatic lands came in the 1984 Aquatic Lands Act. Consistent with the tenants of the public trust doctrine, the legislature directed these lands to be managed "to provide a balance of public benefits for all citizens of the state. The public benefits provided by aquatic lands are varied and include: (1) encouraging direct public use and access; (2) fostering water-dependent uses; (3) ensuring environmental protection; and (4) utilizing renewable resources. Generating revenue in a manner consistent with subsections (1) through (4) of this section is a public benefit." (RCW 79.90.455).
The public trust doctrine has been substantiated in the *Shoreline Management Act* (SMA), enacted by the state legislature in 1971. The State supreme court has stated that the requirements that the public trust doctrine impose on the state are "fully met" by the *Shoreline Management Act*

(Bodi 1989). The Act established a regulatory scheme and public involvement process for tideland and shoreland development. Some of the stated policies underlying the Act are "to provide for the management of the shorelines of the state by planning for and fostering all reasonable and appropriate uses, "to ensure the development of these shorelines in a manner which, while allowing for limited reduction of rights of the public in navigable waters, will promote and enhance the public interest, and to "protect against adverse effects to the public health, the land and its vegetation and wildlife, while protecting generally the public rights of navigation and corollary rights incidental thereto."

In 1987 and 1988, the Washington Supreme Court issued two major decisions that strengthened the public trust doctrine in the state. One challenged the State's authorization of development. The other challenged the State's prohibition of development. In *Caminiti v. Boyle*, the court rejected a challenge by public recreation users to a State law authorizing shoreline property owners to install and maintain private docks. In upholding this curtailment of public use, the court elaborated upon the nature of the public trust doctrine in Washington. The court found that the State law authorizing docks did not violate the doctrine because the law allowed the State to relinquish "relatively little control", promoted the interests of members of the public (waterfront property owners), and did not substantially impair public uses (Bodi 1989).

The Washington Supreme Court addressed the public trust doctrine in 1988. *Orion Corp. v. Washington* was the first time the court explicitly addressed the applicability of the public trust doctrine to Washington tidelands. In this case, a private landowner (Orion) challenged the State regulatory action that had prevented dredging and filling thousands of acres of tidelands. Under the *Shoreline Management Act*, the State had classified Orion's tidelands for preservation because they supported unique and fragile resources, including fish and shellfish. The court found support for the State prohibition in the public trust doctrine. The court described the doctrine as "a covenant running with the land (or lake, marsh, or shore) for the benefit of the public and the land's dependent wildlife."

8.3.3 The Public Trust and Fish Farms

The aquatic lands on which fish farms will be developed will remain in State ownership. Therefore, issues of delegation from public trust to private land ownership are not involved. The State's public trust responsibilities are carried out through both the State's aquatic land proprietary management and shoreline management programs. Responsible resource management is the goal of both programs.

The public trust doctrine is not automatically violated by net pens locating in navigable waters because the state retains ownership of the bedlands and leases the land for relatively short terms. Each site is evaluated on a case-by-case basis through both the aquatic land and shoreline management programs.

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Department of Trade and Economic Development
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Thurston Regional Planning Council

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Washington Aquaculture Council
Washington Environmental Council
Washington Fish Growers Association
Interclub Boating Association
National Audubon Society
Washington State Sports Council
Marine Environment Consortium
Washington Trollers Association
American Waterway Operators

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REFERENCES

Ackefors, H. and A. Sodergren. 1985. Swedish experiences of the impact of aquaculture on the environment. International Council for the Exploration of the Sea C. M. 1985/E: 40. 7pp.

Akashi, A. and T. Aoki. 1986. Characterization of transferable R plasmids from Aeromonas hydrophila. Bulletin of the Japanese Society of Scientific Fisheries 52(4):649-655.

Alabaster, J.S. 1982. Survey of fish-farm effluents in some E1FAC countries. In: J. S. Alabaster (ed.), Report of the EIFAC Workshop on Fish-farm Effluents. Silkeborg, Denmark, 26-28 May 1981. pp. 5-20. E1FAC Tech. Pap. 41.

Allendorf, F.W. and S.R. Phelps. 1980. Loss of genetic variation in a hatchery stock of cutthroat trout. Transactions of the American Fisheries Society 109:537-543.

Amend, D.F. and J.W. Wood. 1972. Survey for infectious hematopoietic necrosis virus (IHN) in Washington State. Progressive Fish Culturist 34:143-147.

Anderson, D.M. and B.A. Keafer. 1987. An endogeneous annual clock in the toxic marine dinoflagellate Gonyaulax tamarensis. Nature (London). 325:616-617.

Anderson, J., A. Copping, T. Jagielo, J. Postel, W. Peterson, B. Dumbauld, G. Heron, R. Hood, and M. Strom. 1984. Water Column Ecology, Vol. III, Sec. 4. In: Q. J. Stober and K. K. Chew. Renton Sewage Treatment Plant Project, University of Washington, Seattle.

Angell, T. and K.C. Balcomb. 1982. Marine Birds and Mammals of Puget Sound. Washington Sea Grant Program, University of Washinton. Seattle, Washington.

Aoki, T. 1975. Effects of chemotherapeutics on bacterial ecology in the water of ponds and the intestinal tracts of cultured fish, ayu (Plecoglossus altivelis) 19(1):7-12.

Aoki, T. 1988. Drug-resistant plasmids from fish pathogens. Microbiological Sciences 5(7)219-223.

Aoki, T., A. Akashi and T. Sakaguchi. 1986. Phylogenetic relationships of transferable R plasmids from Edwardsiella tarda. Bulletin of the Japanese Society of Scientific Fisheries 52(7):1173-1179.

Aoki, T. and A. Takahashi. 1986. Tetracycline-resistant gene of a non-transferable R plasmid from fish-pathogenic bacteria Aeromonas salmonicida. Bulletin of the Japanese Society of Scientific Fisheries 52(11):1913-1917.

Aoki, T. and A. Takahashi. 1987. Class D tetracycline resistance determinants of R plasmids from the fish pathogens Aeromonas hydrophila, Edwardsiella tarda, and Pasteurella piscicida. Antimicrobial Agents and Chemotherapy 31(8)1278-1280.

Aoki, T. and T. Kitao. 1981. Drug resistance and transferable R plasmids in Edwardsiellatarda from fish culture ponds. Fish Pathology 15(3/4):277-281.

Aoki, T. and T. Kitao. 1985. Detection of transferable R plasmids in strains of the fish-pathogenic bacterium, Pasteurella piscicida. Journal of Fish Diseases 8:345-350.

Aoki, T., T. Kitao, S. Watanabe and S. Takeshita. 1984. Drug resistance and R plasmids in Vibrio anguillarium isolated in cultured ayu (Plecoglossus altivelis). Microbiology and Immunology 28(1):1-9.

Aoki, T. and Y. Egusa. 1980. Frequent occurrence of drug resistant bacteria in ayu (Plecoglossus altivelis) culture. Fish Pathology. 15(1):1-6.

Aoki, T., S. Egusa and T. Arai. 1974. Detection of R factors in naturally occurring Vibrio anguillarum strains. Antimicrobial Agents and Chemotherapy 6(5):534-538.

Aoki, T., S. Egusa and T. Watanabe. 1973. Detection of R bacteria in cultured marine fish, yellowtails (Seriola quinqueradiata). Japanese Journal of Microbiology 17(1):7-12.

Aoki, T., S. Egusa, C. Yaka and T. Watanabe. 1972. Studies of drug resistance and R factors in bacteria from pond-cultured salmonids. I. Amago (Oncorhynchus rhodurus macrostomus) and Yamame (Oncorhynchus masou ishikawae). Japanese Journal of Microbiology 16(3):233-238.

Aoki, T., S. Egusa, T. Kimura and T. Watanabe. 1971. Detection of R factors in naturally occurring Aeromonas salmonicida strains. Applied Microbiology 22(4):716-717.

Aoki, T., S. Takeshita, and T. Tadatoshi. 1983. Antibacterial action of chemotherapeutic agents against non-hemolytic Streptococcus sp. isolated from cultured marine fish, yellowtail Seriola quinqueradiata. Bulletin of the Japanese Society of Scientific Fisheries 49(11):1673-1677.

Aoki, T., T. Arai and S. Egusa. 1977. Detection of R plasmids in naturally occurring fish-pathogenic bacteria, Edwardsiella tarda. Microbiology and Immunology 21(2)77-83.

Aoki, T., T. Kanazawa and T. Kitao. 1985. Epidemiological surveillance of drug resistance Vibrio anguillarum strains. Fish Pathology 20(2/3):190-208.

Aoki, T., T. Kitao and K. Kawano. 1981. Changes in drug resistance of Vibrio anguillarum in cultured ayu, Plecoglossus altivelis Temminck and Schlegel, in Japan. Journal of Fish Diseases 4:223-230.

Aoki, T., T. Sakaguchi and T. Kitao. 1987. Multiple drug-resistant plasmids from Edwardsiella tarda in eel culture ponds. Nippon Suisan Gakkaishi 53(10):1821-1825.

Aoki, T., T. Satoh and T. Kitao. 1987. New tetracycline resistance determinant on R plasmids from Vibrio anguillarum. Antimicrobial Agents and Chemotherapy 31(9)1446-1449.

Aoki, T., Y. Mitoma and J.H. Crosa. 1986. The characterization of a conjugative R-plasmid isolated from Aeromonas salmonicida. Plasmid 16:213-218.

APHA. 1985. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, D.C.

Arakawa, K.Y. 1973. Yoshoku kaki seisan no suii narabi ni kaisan seibutsu gunshu no seni kara mita [Aspects of eutrophication in Hiroshima Bay viewed from transition of cultured oyster production and succession of marine biotic communities]. Nihon Kaiyo Gakkai-Shi 11(2):43-48. (Translated by the Multilingual Services Div., Dept. of the Sec. of State of Canada.)

Åsgård, T., R. Langåker, K.D. Shearer, E. Austreng, and A. Kittlesen. 1988. Ration Optimization To Reduce Potential Pollutants - Preliminary Results. Fisheries Bioengineering Symposium, Portland, Oregon.

Atkinson, C.A. 1984. OTEC pilot plant effluent plume modeling of plankton ecosystem dynamics. Unpublished report to Oceanic Institute Consultants, Inc. Waimanalo, Hawaii.

Atkinson, C.A., D.A. Kiefer, D.A. Rietzel, J.S. and J.D. Zieman. 1984. Predicted environmental and socioeconomic consequences of constructing and operating the 40 megawatt O.T.E.C. plant at Kahe Point, Oahu. 310 pps.

Aulstad, D., T. Gjerdrem and H. Skjerold. 1972. Genetic and environmental sources of variation in length and weight of rainbow trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 29:237-241.

Austin, B. 1985. Antibiotic pollution from fish farms: effects on aquatic microflora. Microbiological Sciences. 2(4):113-117.

Austin, B. and A.M.J. Al-Zahrani. 1988. The effect of antimicrobial compounds on the gastrointestinal microflora of rainbow trout, Salmo gairdneri Richardson. Journal of Fish Biology. (In press).

Austin, B. and D. Allen-Austin. 1985. Microbial quality of water in intensive fish rearing. Journal of Applied Bacteriology. 59(Suppl.14):207S-226S.

Austin, B. and D.A. Austin. 1987. Bacterial Fish Pathogens: Disease in Farmed and Wild Fish. Ellis Horwood Ltd., Publishers, Chichester.

Ayres, P.A., D.D. Seaton, and P.B. Tett. 1982. Plankton blooms of economic importance to fisheries in UK waters 1968-1982. International Council for the Exploration of the Sea C.M. 1982/L:38. 21 pp.

Bams, R.A. 1976. Survival and propensity for homing as affected by presence or absence of locally adapted paternal genes in two transplanted populations of pink salmon (Oncohynchus gorbuscha). Journal of the Fisheries Research Board of Canada 33:2716-2725.

Banner, C.R., J.J. Long, J.L. Fryer and J.S. Rohovec. 1986. Occurrence of salmonid fish infected with Renibacterium salmoninarum in the Pacific Ocean. Journal of Fish Diseases. 9:273-275.

Banner, C.R., J.S. Rohovec and J.L. Fryer. 1983. Renibacterium salmoninarum as a cause of mortality among chinook salmon in salt water. Journal of the World Mariculture Society 14:236-239.

Bartley, C.H. and L.W. Slanetz. 1971. Occurrence of Vibrio parahaemolyticus in estuarine waters and oysters of New Hampshire. Applied Microbiology. 21:965-966.

Bauer, O.N. and G.L. Hoffman. 1976. Helminth range extension by translocation of fish, Pages 163-172 in Leslie Andrew Page, editor. Wildlife Diseases. Plenum Publishing Corporation, New York, New York.

Becker, C.D. and W.D. Brunson. 1968. The bass tapeworm: a problem in northwest trout management. Contribution No. 266, College of Fisheries, University of Washington. Seattle, WA.

Bell, G.R., W. Griffioen, and O. Kennedy. 1974. Mortalities of pen-reared salmon associated with blooms of marine algae, pp. 58-60. In: Proc. Northwest Fish Culture Conference, 25th Anniversary, December 4-6, 1974, Seattle, WA.

Beveridge, M.C.M. 1974. Cage and pen fish farming. Food and Agriculture Organization of the United Nations Technical Paper No. 255. 131 pp. Rome.

Birkeland, C. 1974. Interactions between a sea pen and seven of its predators. Ecological Monographs. 44:211-232.

Black, E.A. and B.A. Carswell. 1986. Sechelt Inlet, spring 1986 -- the impact of salmon farming on the marine water quality. Unpublished report by the British Columbia Ministry of the Environment, Vancouver, BC.

Blake, P.H. 1984. Prevention of food-borne disease cause by Vibrio species. Pages 579-591 in R.R. Colwell, editor. Vibrios in the environment. John Wiley & Sons, Inc., New York.

Bodi, F.L. 1989. The public trust doctrine in the state of Washington: does it make any difference to the public? Environmental Law 19:645-653.

Boldt, D. 1988. Personal communication of September 28. Sea Farms of Washington, Port Angeles, WA.

Boyce, J. 1988. Use Conflicts and Floating Aquaculture in Puget Sound. Report prepared for the Department of Ecology, Olympia, WA.

Braaten, B., J. Aure, A. Ervik, and E. Boge. 1983. Pollution problems in Norwegian fish farming. International Council for the Exploration of the Sea C. M. 1983/F: 26. 11pp.

Broeker, W.S. and T. Peng. 1982. Tracers in the Sea. 690 pp. Lamont-Doherty Geological Observatory, Columbia Univeristy, New York.

Brooks, N.H. 1960. Diffusion of sewage effluent in an ocean current In pp. 246-267 Proceedings of the International Conference on Waste Disposal in the Marine Environment. Pergamon, Oxford.

Brown, C. 1981a. Bacterial diseases in bivalve larval cultures and their control. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Milford Laboratory, Milford, CT. p. 1-20.

Brown, C. 1981b. A study of two shellfish pathogenic Vibrio strains isolated from a Long Island hatchery during a recent outbreak of disease. Journal of Shellfish Research. 1:83-87.

Brown, J.R., R.J. Gowen, and D.S. McLusky. 1987. The effect of salmon farming on the benthos of a Scottish sea loch. Journal of Experimental Marine Biology. 109: 39-51.

Bullock, G.L., H.M. Stuckey, D. Collis, R.L. Herman and G. Maestrone. 1974. In vitro and in vivo efficacy of a potentiated sulfonamide in control of furunculosis in salmonids. Journal of the Fisheries Research Board of Canada. 31:75-82.

Burrows, R.E. and B.D. Combs. 1968. Controlled environments for salmon propogation. The Progressive Fish Culturist, July 1968.

Burrows, J.E. 1972. Salmon husbandry techniques. pp. 375-402 In J.E. Halver (ed.), Fish Nutrition. Academic Press. New York.

Burton, N.F., M.J. Day and A.T. Bull. 1982. Distribution of bacterial plasmids in clean and polluted sites in a south Wales river. Applied and Environmental Microbiology. 44:1026-1029.

Butz, F. and B. Vens-Cappell. 1982. Organic load from the metabolite products of rainbow trout fed with dry food. In J.S. Alabaster (ed.), Report of the EIFAC Workshop on Fish-Farm Effluents. Silkeborg, Denmark, 26-28 May 1981, pp 73-82. EIFAC Tech. Rep. 41.

Caine, E.A. 1980. Ecology of two littoral species of caprellid amphipods (Crustacea) from Washington, U. S. A. Marine Biology 56: 32-335.

Campbell, S.A., W.K. Peterson and J.R. Postel. 1977. Phytoplankton production and standing stock in the main basin of Puget Sound. University of Washington, Department of Oceanography. Final report to the Municipality of Metropolitan Seattle. 75 pp.

Cardwell, R.D., C.E. Woelke, M.I. Carr, and E.W. Sanborn. 1977. Evaluation of water quality of Puget Sound and Hood Canal in 1976. NOAA Technical Memorandum ERL MESA-21. 36 pp.

Cardwell, R.D., S. Olsen, M.I. Carr, and E.W. Sanborn. 1979. Causes of oyster larvae mortality in southern Puget Sound. NOAA Technical Memorandum ERL MESA-39. 73 pp.

Cannon, G.A. 1983. An overview of circulation in the Puget Sound estuarine system. NOAA Technical Memorandum ERL PMEL-48.

Carlucci, A.F. and D. Pramer. 1960. An evaluation of factors affecting the survival of Escherichia coli in sea water. Applied Microbiology. 8(4):251-254.

Chester, A., D. Damkaer, D. Day, and J. Larrance. 1978. Puget Sound energy related research project plankton studies. Final Report for Research Unit A-3-1. Pacific Marine Environmental Laboratory, NOAA, Seattle, WA. 117 pp.

Chilcote, M.W., S.A. Leider, and J.J. Loch. 1985. Hatchery summer-run ssteelhead natural reproductive success in the Kalama river. Washington Department of Game, Report No. 85-24, Olympia, WA.

Clark, E.R., J.P. Harman and J.R.M. Forster. 1985. Production of metabolic products by intensively farmed rainbow trout, Salmo gairdneri Richardson. Journal of Fisheries Biology. 27:381-393.

Clocksin, T. 1988. Personal communication of November 28. Washington Department of Fisheries.

Collias, E.E. and J.H. Lincoln. 1977. A study of the nutrients in the main basin of Puget Sound. Report by the University of Washington, Department of Oceanography for the Municipality of Metropolitan Seattle. M77-2. Seattle.

Colwell, R.R. and D.J. Grimes. 1984. Vibrio diseases in marine fish populations. Helgolander Meeresunters. 37:265-287.

Cox, D.I., C.M. Morrison, B. Zwicker and G. Shum. 1986. Report on a new Aeromonas species infecting skin lesions of Atlantic salmon (Salmo salar L.) in sea water. Bulletin of the European Association of Fish Pathologists. 6(4):100-102.

Cravedi, J.P., G. Choubert and G. Delous. 1987. Digestibility of chloramphenicol, oxolinic acid and oxytetracycline in rainbow trout and influence of these antibiotics on lipid digestibility. Aquaculture. 60:133-141.

Cross, S.F. 1988. A preliminary study of the deposition and dispersion characteristics of waste materials associated with salmon farming operations in British Columbia. Report to B.C. Min. Environment and Parks. Aquametrix Research Ltd, Sidney, B.C.

Dahlback, B. and L.A.H. Gunnarson. 1981. Sedimentation and sulfate reduction under a mussel culture. Marine Biology. 63:267-275.

Damkaer, D. 1988. Personal communication of October 14. National Marine Fisheries Service, Seattle, WA.

Darley, W.M. 1982. Algal Biology: a Physiological Approach. Blackwell Scientific Publications, Vol. 9. Oxford.

Deardorff, T.L. and M. L. Kent. 1989. Prevalence of larval Anisakis simplex in pen-reared and wild-caught salmon (Salmonidae) from Puget Sound, Washington. Journal of Wildlife Diseases. 25(3):416-419.

Deardorff, T.L. and R. Throm. 1988. Commercial blastfreezing of third-stage Anisakis simplex larvae encapsulated in salmon and rockfish. Journal of Parasitology. 74:600-603.

Deardorff, T.L., J. Altman and C.M. Nolan. 1987. Human anisakiasis: two reports from the state of Washington. Proceedings of the Helminthological Society of Washington. 54(2):274-275.

Deardorff, T.L., T. Fukumura and R.B. Raybourne. 1986. Invasive anisakiasis - a case report from Hawaii. Gastroenterology. 90:1047-1050.

Dixon, I. 1986. Fish Farm Surveys in Shetland; August 1986. Summary of survey reports, Volume 1. A Report to NCC, Shetland Island Council and Shetland Salmon Farmers Assoc. Oil Pollution Research Unit, Field Studies Council, FSC/OPRU/30/86. Orielton Field Center, Pembroke, Dyfed Scotland.

Dogiel, V. and A. Lutta. 1937. Mortality among spiny sturgeon of the Aral Sea in 1936. Rybnoe Khozyaistvo 12:26-27. Translated in Fisheries Research Board of Canada, Ser. No. 528. 1965.

Dogiel, V.A. 1954. Objectives of parasitological investigations in connection with the reconstruction of the fishing industry. Voprosy Ikhtiologii 2:57-58. Translated in Fisheries Research Board of Canada, Ser. No 346. 1961.

Droop, M.R., 1968. Vitamin B12 and marine biology. IV. The kinetics of pure uptake, growth and inhibition in Monochrysis lutheri. J. Mar. Biol. Ass. UK. 48:689-734.

Duxbury, A. 1988. Personal communication of October 31. Private Consultant, Seattle, WA.

Earll, R.C., G. James, C. Lamb, and R. Pagett. 1984. A report on the effects of fish farming on the marine environment of the Western Isles. Marine Biological Consultants Ltd./Nature Conservancy Council. 45 pp.

Eastburn, R.L., T.R. Fritsche and C.A. Terhune, Jr. 1987. Human intestinal infection with Nanophyetus salmincola from salmonid fishes. American Journal of Tropical Medicine and Hygiene. 36(3):586-591.

Ecology. 1988a. 1988 Statewide water quality assessment, 305(b) report. Report prepared by Washington Department of Ecology, Olympia, WA.

Ecology. 1988b. 1988 Water Quality Index. Technical memorandum from David Hallock to John Bernhardt, Washington Department of Ecology, Olympia, WA. June 10, 1988.

Ecology. 1989. Draft sediment quality standards. Prepared by Washington Department of Ecology, Olympia, WA.

EDAW Inc., and CH2M Hill. 1986. Aquaclture siting study. Report prepared for the State of Washington Department of Ecology, Olympia, WA.

Edwards, D.J. 1978. Salmon and Trout Farming in Norway. Fishing News Books, Ltd. Farnham, UK.

Egidius, E. 1987. Vibriosis: pathogenicity and pathology. A review. Aquaculture. 67:15-28.

Egidius, E., R. Wiik, K. Andersen, K.A. Hoff and B. Hjeltnes. 1986. Vibrio salmonicida sp. nov., a new fish pathogen. International Journal of Systematic Bacteriology. 36:518-520.

Elliot, D.G. and E.B. Shotts, Jr. 1980. Aetiology of an ulcerative disease in goldfish, Carassius auraturs (L.): microbiological examination of diseased fish from several locations. Journal of Fish Diseases. 3:133-143.

Ellis, A.E. and R. Wooten. 1978. Costiasis of Atlantic salmon, Salmo salar L., smolts in seawater. Journal of Fish Diseases. 1:389-393.

Elston, R.A. 1984. Prevention and management of infectious diseases in intensive mollusc husbandry. Journal of World Mariculture Society. 15:284-393.

Elston, R.A., L. Harrell and M.T. Wilkinson. 1986. Isolation and in vitro characteristics of chinook salmon (Oncorhynchus tsawytscha) rosette agent. Aquaculture. 65:1-21.

Elston, R.A., M.L. Kent and L.W. Harrell. 1987. An intranuclear microsporidium associated with acute anemia in the chinook salmon, Oncorhynchus tshawytscha. Journal of Protozoology. 34(3):274-277.

Environmental Protection Agency. 1974. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. EPA 550/9-74-004.

Environmental Protection Agency. 1986. Quality criteria for water 1986. United States Environmental Protection Agency publication No. EPA 440/5-86-001. Washington D.C.

Environmental Protection Agency. 1987. Puget Sound Environmental Atlas. Prepared by Evans-Hamilton, Inc. Seattle, WA.

Eppley, R.W. and W.G. Harrison. 1974. Physiological ecology of Gonyaulax polyedra a red water dinoflagellate of southern California. pp. 12-22 In V.R. LoCicero (ed.), Proceedings of the first international conference on toxic dinoflagellate blooms. Massechusetts Science and Technology Foundation. Boston.

Evelyn, T.P.T. 1971. First records of vibriosis in Pacific salmon cultured in Canada, and taxonomic status of the responsible bacterium, Vibrio anguillarum. Journal of the Fisheries Research Board of Canada. 28:517-525.

Evelyn, T.P.T. 1988. Bacterial kidney disease in British Columbia, Canada: comments on its epizootiology and on methods for its control on fish farms. (In press.)

Evelyn, T.P.T., J.E. Ketcheson and L. Prosperi-Porta. 1984. Further evidence for the presence of Renibacterium salmoninarum in salmonid eggs and for failure of providone-iodine to reduce the intra-ovum infection rate in water-hardened eggs. Journal of Fish Diseases. 7:173-182.

Evelyn, T.P.T., J.E. Ketcheson and L. Prosperi-Porta. 1986. Use of erythromycin as a means of preventing vertical transmission of Renibacterium salmoninarum. Diseases of Aquatic Organisms. 2(1):7-11.

Fenchel, T.M. and R.J. Reidl. 1970. The sulphide system: a new biotic community underneath the oxidized layer of marine sand bottoms. Marine Biology. 7:255-268.

Ferguson, H.W., D.A. Rice and J.K. Lynas. 1986. Clinical pathology of myodegeneration (pancreas disease) in Atlantic salmon. Veterinary Record. 119:297-299.

FICUN. 1980. Guidelines for considering noise in land use planning and control. Federal Interagency Committee on Urban Noise, Washington D.C.

Forfar, J.O., A.J. Keay, A.F. Macabe, J.C. Gould and A.D. Bain. 1966. Liberal use of antibiotics and its effect in neonatal staphylococcal infection, with particular reference to erythromycin. Lancet. 11:295-300.

Forster, J. 1988. Personal communication of June 10. Sea Farms of Washington, Port Angeles, WA.

Fox, W.P. Modeling of Particulate Deposition under salmon net pens. 1988. Unpub. Rep. to Washington Dept. Fisheries. Parametrix, Inc. Sumner, WA.

Fraser, J. and G. Milner. 1974. Salmon net-pen culture at Squaxin Island Indian Reservation. Final report to EDA, OEO and BIA. Small Tribes of Western Washington.

Fryer, J.L. and J.E. Sanders. 1981. Bacterial kidney disease of salmonid fishes. Annual Review of Microbiology. 35:273-298.

Gibson, C. 1988. Personal communication of September 28. Sea Farms of Washington, Port Angeles, WA.

Gjedrem, T. 1981. Conservation of fish populations in Norway. In: Ryman, N. (ed.) Fish Gene Pools. Ecological Bulletin (Stockholm) 34:33-36.

Gonsolos, R.T. 1978. The status of Oregon coho and recommendations for managing the production, harvest and escapement of wild and hatchery reared stocks. Oregon Department of Fish and Wildlife, Columbia Region, Portland, Oregon. 59 pp.

Gowen, R. 1984. The ecology of phytoplankton in Scottish coastal waters with particular reference to toxic species and their importance to mariculture. Highlands and Islands Development Board, Oban. 92 pp.

Gowen, R., J. Brown, N. Bradbury, and D.S. McLusky. 1988. Investigations into benthic enrichment, hypernutrification and eutrophication associated with mariculture in Scottish coastal waters (1984 - 1988). Prepared for the Highlands and Islands Development Board, Crown Estates Commission, Nature Conservancy Council, Countryside Commission for Scotland, and Scottish Salmon Growers Association. 289 pp.

Gowen, R.J. and N.B. Bradbury. 1987. The ecological impact of salmonid farming in coastal waters: a review. Oceanography and Marine Biology Annual Review. 25: 562-575.

Gowen, R.J., N. Bradbury, and J. Brown. 1983. The ecological impact of salmon farming in Scottish coastal waters. International Council for the Exploration of the Sea C. M. 1985/F:35. 13 pp.

Gray, J.S. 1974. Animal-sediment relationships. Annual Reviews of Oceanography and Marine Biology. 12:223-261.

Greenberg, E.P., H.B. Kaplan, M. DuBois and B. Palhof. 1984. Persistence and distribution of marine vibrios in the hardshell clam. Pages 479-493 in R.R. Colwell, editor. Vibrios in the environment. John Wiley and Sons, New York, New York.

Hada, H.S., P.A. West, J.V. Lee, J. Stemmler and R.R. Colwell. 1984. Vibrio tubiashi sp. nov., a pathogen of bivalve mollusks. International Journal of Systematic Bacteriology 34:1-4.

Haegele, C.W., R.D. Humphreys, and A.S. Hourston. 1981. Distribution of eggs by depth and vegetation type in Pacific herring (clupea harengus pallasi) spawnings in southern British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. 38:381-386.

Hakanson, L. 1985. Environmental impact of fish cage farms. Preprint from symposium "Aquaculture - the industry of the future". IVA. Stockholm. November 13-14, 1985.

Hall, L.W., Jr. and A.E. Pinkney. 1985. Acute and sublethal effects of organotin compounds in aquatic biota: an interpretative literature evaluation. Critical Reviews in Toxicology. 14:159-209.

Hall, P. and O. Holby. 1986. Environmental Impact of a Marine Fish Cage Culture. ICES. C.M. 1986/F:46. 14 p.

Harrell, L., R.A. Elston, T.M. Scott and M.T. Wilkinson. 1986. A significant new systemic disease on net-pen reared chinook salmon (Oncorhynchus tshawytscha) brood stock. Aquaculture. 55:249-262.

Harrell, L.W., A.J. Novotny, M.H. Schiewe and H.O. Hodgins. 1976. Isolation and description of two vibrios pathogenic to Pacific salmon in Puget Sound, Washington. Fishery Bulletin. 74(2):447-449.

Harrell, L.W. and T.M. Scott. 1985. Kudoa thrysitis (Gilchrist) (Myxoporea: Multivalvulida) in Atlantic salmon, Salmo salar L. Journal of Fish Diseases. 8:329-332.

Harris, G.P. 1986. Phytoplankton Ecology, Structure, Function and Fluctuation. Chapman and Hall. London.

Hart, J.L. 1980. Pacific Fishes of Canada. Fisheries Research Board of Canada, Bulletin 180. 739p.

Hartwell, A.D. 1975. Hydrographic factors affecting the distribution and movement of toxic dinoflagellates in the western Gulf of Mexico. pp. 47-68 in V.R. LoCicero, ed. Proceedings of the First International Conference on Toxic Dinoflagellate Blooms. Mass. Sci. Tech. Found., Wakefield, MA.

Hasler, A.D., A.T. Scholz, and R.M. Horrall. 1978. Olfactory imprinting and homing in salmon. American Scientist 66:347-355.

Hayashi, F., K. Hardada, S. Mitsuhashi and M. Inoue. 1982. Conjunction of drug-resistance plasmids from Vibrio anguillarum to Vibrio parahaemolyticus. Microbiology and Immunology 26(6):479-485.

Hedrick, R.P., M.L. Kent, J.S. Foott, R. Rosemark and D. Manzer. 1985. Proliferative kidney disease (PKD) among salmonid fish in California, U.S.A., a second look. Bulletin of the European Association of Fish Pathologists. 5(2):36-38.

Hershberger, W.K. 1988. Personal communication of September 7. University of Washington, Seattle, WA.

Hochachaka, P.W. 1969. Intermediary metabolism in fishes. pp. 351-389 In W.S. Hoar and D.J. Randall (Eds.), Fish Physiology. Vol. 1. Academic Press, New York.

Hoffman, G.L. 1970. Intercontinental and transcontinental dissemination and transfaunation of fish parasites with emphasis on whirling disease (Myxosoma cerebralis). Pages 69-81 in S.F. Snieszka, editor. A symposium on diseases of fishes and shellfishes. American Fisheries Society. Special Publication No. 5, c1970. Washington, D.C.

Hoffman, G.L. 1984. Two fish pathogens, Parvicapsula sp. and Mitraspora cyprini (Myxosporea) new to North America. Symposia Biologica Hungarica. 23:125-135.

Hoffman, G.L. and G. Schubert. 1984. Some parasites of exotic fishes. Pages 233-261 in W.R. Courtenay and J.R. Stauffer, editors. Distribution, biology and management of exotic fishes. Johns Hopkins University Press. Baltimore, MD.

Hurlburt, E. 1988. Unpublished internal memorandum of October 31 concerning noise measurements of sand shrimp harvests using a motorized pump. Washington State Department of Fisheries, Olympia, WA.

Institute of Aquaculture. 1988. The reduction of the impact of fish farming on the natural marine environment. Report prepared by the Institute of Aquaculture, University of Stirling, Scotland. Prepared for the Nature Conservancy Council, Scotland. January, 1988.

Jacobsen, P. and L. Berglind. 1988. Persistance of oxytetracycline in sediments from fish feces. Aquaculture 70:365-370.

Jefferies, J. 1988. Personal communication of May 27. Washington Department of Wildlife. Tacoma, WA.

Johnsen, B.O. and A.J. Jensen. 1988. Introduction and establishment of Gyrodactylus salaris Malmberg. 1957, on Atlantic salmon, Salmo salar L., fry and parr in the River Vefsna, northern Norway. Journal of Fish Diseases. 11:35-45.

Johnson, M.W. 1932. Seasonal distribution of plankton at Friday Harbor, Washington. Univ. Wash. Publ. Oceanogr. 1:1-38.

Johnstone, A.K. 1984. Pathogenesis and life cycle of the myxosporean Parvicapsula sp. infecting marine cultured coho salmon. Ph.D. Dissertation, University of Washington, Seattle, WA.

Jones, K.J., P.A. Ayres, A.M. Bullock, R.J. Roberts and P. Tett. 1982. A red tide of Gyrodinium aureolum in sea lochs of the Firth of Clyde and associated mortalities of pond reared salmon. Journal of the Marine Biological Association of the United Kingdom. 62:771-782.

Jorgensen, B.B. 1977. Bacterial sulphate reduction within reduced microniches of oxidized marine sediments. Mar. Biol. 41:7-17.

Juelson, T. 1988. Personal communication of June 16. Washington Department of Wildlife. Olympia, WA.

Katz, S.E. 1984. Environmental impact assessment for the use of oxytetracycline to control gaffkemia infections in lobsters. Report available through Dockets Management Branch, HFA - 305, U. S. Food and Drug Administration, Room 4-625600, Fishers Lane, Rockville, MD 20857.

Kaysner, C.A. and S.D. Weagant. 1982. The incidence and seasonal distribution of Yersina enterocolitica and Vibrio parahemolyticus in a Puget Sound commercial oyster bed. U.S. Food and Drug Administration, Edro-Sarap. Research Technical Reports, Vol. 6, pages 171-220, June 1982.

Kennish, M.J. 1986. Ecology of Estuaries. Volume I. Physical and Chemical Aspects. CRC Press, Inc. Boca Raton, Florida.

Kent, M.L. and R.A. Elston. 1987a. Pancreas disease in Atlantic salmon reared in North America. Bulletin of the European Association of Fish Pathologists. 7:29-31.

Kent, M.L. and R.A. Elston. 1987b. Diseases of seawater reared salmon in Washington State. Proceedings, 18th Annual IAAAM Conference 1987. Monterey, CA. p 33-38.

Kent, M.L., C.F. Dungan, R.A. Elston and R. Holt. 1988a. Cytophaga sp. (Cytophagales) infection in seawater pen-reared Atlantic salmon Salmo salar. Diseases of Aquatic Organisms. (In press).

Kent, M.L., T.K. Sawyer and R.P. Hedrick. 1988b. Paramoeba pemaquidensis (Sacromastigophora: Paramoebideae) infestation of the gills of coho salmon Oncorhynchus kisutch reared in seawater. Diseases of Aquatic Organisms. (In press).

Kiefer, D.A. and C.A. Atkinson. 1984. Cycling of nitrogen by plankton: a hypothetical description based upon efficiency of energy conversion. Journal of Marine Research. 42:665 - 675.

Kiefer, D.A. and C.A. Atkinson. 1988. The calculated response of phytoplantkon to nutrients from a proposed salmon farm in Discovery Bay, Washington. Systems Science Applications, Redondo Beach California. For Jamestown Klallam Tribe and Sea Farm Washington. Sequim and Port Angeles Washington, respectively. 18 pp. plus appendix.

Kiefer, D.A. and C.A. Atkinson. 1989. The calculated response of phytoplankton in South Puget Sound to nutrient loading by the Swecker Salmon Farm. Prepared by System Science Applications, for Swecker Sea Farms Inc. and presented to the Washington State Shoreline Hearings Board. System Science Applications, Redondo Beach, California. 28p.

Kincaid, H.L. 1976a. Inbreeding in rainbow trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 33:2420-2426.

Kincaid, H.L. 1976b. Inbreeding depression in rainbow trout. Transactions of the American Fisheries Society 105:273-280.

Kozloff, E.N. 1987. Seashore life of the northern Pacific coast. University of Washington Press, Seattle, Washington.

Lagler, K.F., J.E. Bardach and R.R. Miller. 1962. Ichthyology. John Wiley & Sons, Inc., New York, NY.

Liao, P. and R. Mayo. 1974. Intensified fish culture combining water reconditioning with pollution abatement. Aquaculture 3:16-85.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, USA, in 1963-1964. FiskDir. Skr. (Ser. Havunders.) 14:229-556.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, U. S. A., in 1963-64. FiskDir. Skr. (Ser. Havunders) 14:229-556.

Lie, U. 1974. Distribution and structure of benthic assemblages in Puget Sound, Washington, USA. Marine Biology. 26:203-223.

Lie, U. 1974. Distribution and structure of benthic assemblages in Puget Sound, Washington, U. S. A. Marine Biology 26:203-223.

Lie, U. and R.A. Evans. 1973. Log-term variability in the structure of subtidal benthic communities in Puget Sound, Washington, USA. Marine Biology. 21:122-126.

Lindbergh, J. 1984. Potential interaction between net-pen farmed Atlantic salmon and native salmonid species in the Pacific Northwest. Unpublished report to Sea Farm of Norway, Inc, Greenwich, Conneticut.

Lindbergh, J. 1988. Personal communications of June 1 and September 28. Independent consultant. North Bend, WA.

Little, J.L. 1988. Report of floating salmon net pens. Prepared for the Jamestown Klallam Tribe.

Mahnken, C. 1988. Personal communication of September 13 and 28. National Marine Fisheries Service. Manchester, WA.

Margolis, L. 1982. Parasitology of Pacific salmon - an overview. Pages 135-225 in E. Meerovitch, editor. Aspects of Parasitology - a Festschrift dedicated to the fiftieth anniversary of the Institute of Parasitology of McGill University, 1932-1982. McGill University, Montreal, Canada.

Margolis, L., Ph.D., R.L. Raush, D.V.M., Ph.D. and E. Robertson M.D., F.R.C. P.(C). 1973. Diphyllobothrium ursi from man in British Columbia - first report of this tapeworm in Canada. Canadian Journal of Public Health, Nov/Dec.588-589.

Maser, C., B.R. Mate, J.F. Franklin, and C.T. Dyrness. 1981. Natural History of Oregon coast mammals. USDA Forest Service General Technical Report PNW-133. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Mattsson, J. and O. Linden. 1983. Benthic microfauna succession under mussels Mytilus edulis cultured on hanging long lines. Sarsia, 68:97-102.

McCarthy, D.H. 1975. Fish Furunculosis. Journal of the Institute of Fish Management. 6:13-18.

McCarthy, J.J., W.R. Rowland, and J.L. Haft. 1977. Nitrogeneous nutrition of the phytoplankton in Chesapeake Bay. 1. Nutrient availability and phytoplankton preferences. Limnology and Oceanography 22(6).

McCarthy, J.J. 1980. Nitrogen, In I. Morris (ed.), The Physiological Ecology of Phytoplankton, University of California Press, Berkeley.

McCarthy, J.J., W.R. Rowland, and J.L. Taft. 1977. Nitrogenous nutrition of the phytoplankton in Chesapeake Bay. Volume 1. Nutrient availability and phytoplankton preferences. Limnology and Oceanography 22(6):996.

McCormick, M. 1988. The public trust doctrine. Washington Coastal Currents, Washington Department of Ecology, 12:1-5.

McLellan, P. 1954. An area and volume study of Puget Sound, Washington. Technical Report No. 21. Prepared for Office of Naval Research, Seattle, WA.

McVicar, A.H. 1987. Pancreas disease of farmed Atlantic salmon, Salmo salar, in Scotland:epidemiology and early pathology. Aquaculture. 67:71-178.

Metro. 1988. Water quality status report for marine waters, 1987. Publication 171. Prepared by the Municipality of Metropolitan Seattle, Seattle, WA.

Meyers, T.R. 1979. A reo-like virus isolated from juvenile American oysters (Crassostrea virginica). Journal of General Virology. 43:203-212.

Meyers, T.R. 1984. Marine bivalve molluscs as reservoirs of viral pathogens: significance to marine and anadromous finfish aquaculture. Marine Fisheries Review.46(3):14-17.

Milleman, R.E. and S.E. Knapp. 1970. Biology of Nanophytes salmincola and "salmon poisoning" disease. Advances in Parasitology. 8:1-41.

Milner-Rensel Associates. 1986. Aquatic conditions at the Seafarm of Norway net-pen site in Port Angeles Harbor in April, 1986. Prepared for Sea Farm of Norway, Inc. and the City of Port Angeles Planning Department. 25 pp. and ppendices.

Mitoma, Y., T. Aoki and J.H. Crosa. 1984. Phylogenetic relationships among Vibrio anguillarum Plasmids. Plasmids 12:143-148.

Miyamoto, Y., T. Kato, Y. Obara, S. Akiyama, K. Takizawa and S. Yami. 1969. In vitro hemolytic characteristic of Vibrio parahaemolyticus: its close correlation with human pathogenicity. Journal of Bacteriology. 100:1147-1149.

Morrison, C.M., J.W. Cornick, G. Shum and B. Zwicker. 1984. Histopathology of atypical Aeromonas salmonicida infection in Atlantic cod, Gadus morhua L. Journal of Fish Diseases. 7:477-484.

Mottet, M.G. 1975. The fishery biology of Octopus dofleini (Wulker). Technical Report No. 16, Washington Department of Fisheries, Olympia, WA. 39 p.

Mottet, M.G. 1976. The fishery biology of sea urchins in the family Strongylocentrotidae. Technical Report No. 20, Washington Department of Fisheries, Olympia, WA. pp. 19-20.

Muller-Hackell, A. 1986. Control of water quality around a cage farm in the Norrby Archipelago (northern Bothnian Sea). Vatten 42:205-209.

Munro, A.L.S., A.E. Ellis, A.H. McVicar, H.A. McLay and E.A. Needham. 1984. An exocrine pancreas disease of farmed Atlantic salmon in Scotland. Heglolander Meeresunters. 37:571-586.

Munson, R.E. 1969. The horizontal distribution of phytoplankton in a bloom in Puget Sound during May, 1969. University of Washington, Department of Oceanography, unpublished paper in partial fulfillment of the Master of Science Degree. 30 pp. Seattle.

Muroga, K., M. Iida, H. Matsumoto and T. Nakai. 1986. Detection of Vibrio anguillarum from waters. Bulletin of the Japanese Society of Scientific Fisheries. 52(4):641-647.

Muroga, K., S. Takahaski, H. Yamanoi and M. Nishibuchi. 1979. Non cholera Vibrio anguillarum isolated from diseased ayu Plecoglossus altivelis. Bulletin of the Japanese Society of Scientific Fisheries. 45:1469-1473.

Murray, M. and J.C.M. Trail. 1986. Comparative epidemiology and control of trypanosomes. Pages 621-628 in M.J. Howell, editor. Parasitology - quo vadit. Proceeding of the Sixth International Congress of Parasitology. Australian Academy of Sciences, Canberra, Australia.

Nishitani, L. and K.K. Chew. 1984. Recent developments in paralytic shellfish poisioning research. Aquaculture 39:317-329.

Nishitani, L., G. Erickson, K.K. Chew. 1988. PSP research: Implications for Puget Sound in Vol. 2, pps. 392-399, Proceedings of the Puget Sound Water Quality Authority Research Conference, Seattle.

NMFS. 1983. Water quality surveyed in Clam Bay. Quarterly report (January-March, 1983) by Northwest Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic Atmospheric Administration, Seattle, WA.

Novotny, A.J. 1978. Vibriosis and furunculosis in marine cultured salmon in Puget Sound. Marine Fisheries Review. 40(3):52-55.

Nowell, A.R.M. and P.A. Jumars. 1984. Flow environments of aquatic benthos. Annual Reviews of Ecology and Systematics. 15:303-328.

Paerl, H.W. 1988. Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. Limnology and Oceanography. 33:823-847.

Pamatmat, M.M., R.S. Jones, H. Sanborn, and A. Bhaqwat. 1973. Oxidation of orgaic matter in sediments. EPA-660/3-73-005. U.S. Env. Prot. Agency, Washington, D.C.

Parametrix. 1988. Harding Creek Aquaculture Project, Kitsap County, Washington. Revised Final Environmental Impact Statement. Port Orchard, Washington.

Parker, M. and P. Tett. 1987. Special meeting on the causes, dynamics and effects of exceptional blooms and related events. Rapports et Proces-Verbaux des Reunions Vol. 187. Conseil International pour l'Exploration de la Mer. Copenhagen Denmark. 114 pp.

Parsons, T.R., M. Takahashi, and B. Hargrave. 1984. Biological Oceanographic processes. Third edition. Pergamon Press. Oxford. 330p.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Annual Reviews of Oceanography and Marine Biology. 16:229-311.

Pearson, T.H. and S.O. Stanley. 1979. Comparative measurement of the redox potential of marine sediments as a rapid means of assessing the effect of organic pollution. Mar. Biol. 53:371-379.

Pearson, T.H., J.S. Gray, and P.J. Johannessen. 1983. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. 2. data analyses. Marine Ecology - Progress Series. 12:237-255.

Pease, B. 1984. Unpub. Memorandum dated May 7 from B. Pease to R. Westley, Washington Department of Fisheries.

Pease, B.C. 1977. The effect of organic enrichment from a salmon mariculture facility on the water quality and benthic community of Henderson Inlet, Washington. Ph. D. Dissertation. University of Washington. Seattle, Washington.

Penczak, T., W. Galicka, M. Molinski, E. Kusto, and M. Zalewski. 1982. The enrichment of a mesotrophic lake by carbon, phosphorus and nitrogen from the cage aquaculture of rainbow trout, Salmo gairdneri. Journal of Applied Ecology. 19:371-393.

Penttila, D. 1978. Studies of the surf smelt (Hypomesus pretiosus) in Puget Sound. Technical Report No. 42, Washington Department of Fisheries, Olympia, WA. 47 p.

Peterman, R.M. 1982. Model of salmon age structure and its use in preseason forecasting and studies of marine survival. Canadian Journal of Fisheries and Aquatic Sciences. 39:1444-1452.

Phifer, L.D. 1933. Seasonal distribution and occurrence of planktonic diatoms at Friday Harbor, Washington. Univ. Wash. Publ. Oceanogr. 1:39-81.

Pietsch, J.P., D.F. Amend and C. Miller. 1977. Survival of infectious hematopoietic necrosis virus held under various environmental conditions. Journal of the Fisheries Research Board of Canada. 34(9):1360-1364.

Pingree, R.D., P.M. Holligan and G.T. Mardell. 1978. The effects of vertical stability on phytoplankton distributions in the summer on the northwest European shelf. Deep-Sea Research 25:1011-1028.

Platt, T., L.M. Dickie, and R.W. Trites. 1970. Spatial heterogeneity of phytoplankton in a near-shore environment. Journal of the Fisheries Research Board of Canada 27:1453-1473.

PSWQA. 1986. State of the Sound report. Prepared by the Puget Sound Water Quality Authority, Seattle, WA.

Quinn, T.P. 1988. Personal communication of September 13. University of Washington, Seattle, WA.

Redfield, A.C. 1958. The biological control of chemical factors in the environment. American Science. 46:205-222.

Refstie, T. and T. Gjedrem. 1975. Hybrids between Salmonidae species. Hatchability and growth rate in the freshwater period. Aquaculture 6:333-342.

Reisenbichler, R.R. and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, Salmo gairdneri. Journal of the Fisheries Research Board of Canada 34:123-128.

Rensel, J. 1988. Personal communication of October 18, 1988. Rensel Associates, Seattle, Washington.

Rensel, J. 1988a. Summary of water quality, nutrient and phytoplankton studies at a proposed net-pen site in northwest Discovery Bay, Washington. Presented to the Washington State Shoreline Hearing Board. Prepared for the Jamestown Klallam Tribe and Sea Farm Washington. 103 pp.

Rensel; J. 1988b. Environmental sampling at the American Aqua Foods net-pen site near Lone Tree Point in north Skagit Bay. Prepared by Rensel Associates, Seattle. for Pacific Aqua Foods, Vancouver, B.C. and the Washington Department of Natural Resources. 7 pp. and appendicies.

Rensel, J. 1988c. Phytoplankton and nutrient studies at Squaxin Island net-pens. Technical report prepared for Parametrix Inc. and The Washington Department of Fisheries. Technical Appendix to the Programmatic Environmental Impact Statement: Salmon Aquaculture in Puget Sound.

Rensel, J.E., R.P. Harris, T.T. Tynan. 1988. Fishery contribution and spawning escapement of coho salmon reared in net-pens in southern Puget Sound, Washington. North American Journal of Fisheries Management. 8:359-366.

Rensel, J.E., R.A. Horner, and J.R. Postel. In press. Phytoplankton blooms in Puget Sound, Washington, and their affect on salmon aquaculture: initial research. Northwest Environmental Journal. 22 pp.

Rensel, J.E. and E.F. Prentice. 1980. Factors controlling growth and survival of cultured spot prawn, Pandalus platyceros, in Puget Sound, Washington. Fish. Bull., U.S. 78:781-788.

Rhodes, D.C. 1974. Organism-sediment relationships on the muddy sea floor. Annual Reviews of Oceanography and Marine Biology. 12: 263-300.

Ridler, N. 1984. Socioeconomic aspects of sea cage salmon farming in the Maritimes. Canadian Journal of Fisheries and Aquatic Sciences. Vol 41.

Ritz, D.A., M.E. Lewis, and M. Shen. 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages. Marine Biology 103: 211-214.

Rosenberg, R. 1976. Benthic faunal dynamics during succession following pollution abatement in a Swedish estuary. Oikos 27:414-427.

Rosenthal, H.., D. Weston, R. Gowen, and E. Black. 1988. Report of the ad hoc Study Group on "Environmental Impact of Mariculture. ICES, Cooperative Research Report 154, Copenhagen, Denmark, 83 pp.

Ruttenber, A., B.G. Weniger, F. Sorvillo, R.A. Murray and S.L. Ford. 1984. Diphyllobothriasis associated with salmon consumption in Pacific Coast states. American Journal of Tropical Medicine and Hygiene 33(3):455-459.

Ryman, N. 1970. A genetic analysis of recapture frequencies of released young of salmon (Salmo salar L.). Hereditas 65:159-160.

Ryman, N. and G. Stahl. 1980. Genetic changes in hatchery stocks of brown trout (Salmo trutta). Canadian Journal of Fisheries and Aquatic Science 37:82-87.

Ryther, J.H. and W.M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine envirnoment. Science. (New York) 171:1008-1013.

SAIC. 1986. Recommended interim guidelines for the management of salmon net-pen culture in Puget Sound. Prepared by Science Applications International Corporation. Prepared for Washington Department of Ecology in conjunction with the Department of Fisheries, Agriculture and Natural Resources.

Sakazaki, R., K. Tamura, T. Kato, Y. Obara, S. Tamai and K. Hobe. 1968. Studies on enteropathogenic, facultatively halophilic bacteria, Vibrio parahaemolyticus. III. Enteropathogenicity. Japanese Journal of Medical Science and Biology. 21:325-331.

Sand-Jensen, K. 1977. Effect of epiphytes on eelgrass photosynthesis. Aquatic Botany 3: 55-63.

Sano, T., T. Nishimura, N. Okamoto, T. Yamazaki, H. Hanada and Y. Watanabe. 1977. Studies on viral diseases of Japanese fishes. VI. Infectious hematopoietic necrosis (IHN) of salmonids in the mainland of Japan. Journal of the Tokyo University of Fisheries. 63(2):81-85.

Scordino, J. 1988. Personal communication of September 27. National Marine Fisheries Service. Seattle, WA.

Scordino, Jr. 1989. Personal communication of January 9. National Marine Fisheries Service, Seattle, WA.

Scott, M. 1968. The pathogenicity of Aeromonas salmonicida (Griffen) in sea and brackish water. Journal of General Microbiology. 50:321-327.

Seidel, P. 1988. Personal communication of September 30. Washington Department of Fisheries, Olympia, WA.

Shimek, R.L. 1983. Biology of the northeastern Pacific Turridae. I. Ophiodermella. Malacologia. 23: 281-312.

Short, J.W. and F.P. Thrower. 1987. Toxicity of tri-n-butyl-tin to chinook salmon, Oncorhynchus tshawytscha, adapted to seawater. Aquaculture. 61:193-200.

Smith, P.R., G.M. Brazil, E.M. Drianan, J. O'Kelly, R. Palmer and A. Scallan. 1982. Lateral transmission of furunculosis in sea water. Bulletin of the European Association of Fish Pathologists. 3:41-42.

Smith, S.V. 1984. Phosphorus versus nitrogen limitation in the marine environment. Limnology and Oceanography. 29:1149-1160.

Spotte, S.H. 1970. Fish and Invertebrate Culture. Water Management in Closed Systems. Wiley-Interscience. New York.

Stahl, G. 1983. Differences in the amount and distribution of genetic variation between natural populations and hatchery stocks of Atlantic salmon. Aquaculture 33:23-32.

State of Washington. Department of Fisheries and Department of Agriculture. Aquaculture Disease Control, Chapter 220-77 WAC. Olympia, Washington.

Steidinger, K.A. and K. Haddad. 1981. Biologic and hydrographic aspects of red tides. Bioscience 31:814-819.

Stevens, J.S. 1980. The public trust: a sovereign's ancient prerogative becomes the people's environmental right. U.C. Davis Law Review 14:195-232.

Stevens, J.S. 1980. The public trust: a sovereign's ancient prerogative becomes the people's environmental right. U.C. Davis Law Review 14:195-232.

Stewart, K.I. 1984. A study on the environmental impact of fish cage culture on an enclosed sea loch. M. Sc. Thesis. The University of Stirling. Stirling. UK.

Stockner, J.G. 1979. Phytoplankton ecology of the Strait of Georgia, British Columbia. Journal of the Fisheries Research Board of Canada. 36:657-666.

Stokes, R.L. 1988. The economics of salmon farming: report to the Washington State Department of Fisheries. Prepared for the Washington State Department of Fisheries, Olympia, WA.

Strathmann, M.F. 1987. Reproduction and development of marine invertebrates of the Northern Pacific coast. University of Washington Press, Seattle, WA. xii + 670 pp.

Strickland, R.M. 1983. The fertile fjord: plankton in Puget Sound. Puget Sound Books. 145 pp.

Strumm, W. and J.J. Morgan. 1981. Aquatic Chemistry, 2nd edition, Wiley-Interscience, New York.

Stumm, W. and J.J. Morgan. 1970. Aquatic chemistry, an introduction emphasizing chemical equilibria in natural waters. John Wiley & Sons, Inc., New York, NY.

Taft, J.L. and W.R. Taylor. 1976. Phosphorous dynamics in some coastal plain estuaries, In M. Wiley (ed.), Estuarine Processes, Volume 1. Academic Press, New York.

Takashima, N., T. Aoki and T. Kitao. 1985. Epidemiological surveillance of drug-resistant strains of Pasteurella piscicida 20(2/3):209-217.

Tangen, K. 1987. Harmful algal blooms in Northern Europe; their cause and effect on mariculture. In Proceedings of Aqua Nor International Conference, session 2, The impact of toxic algae on mariculture. Trondheim. pp. 29-34

Tetra Tech, Inc. 1988. Characterization of spatial and temporal trends of water quality in Puget Sound. Final Report to: U.S. Environmental Protection Agency, Region X. Contract No. 68-03-3319 and 68-02-4341 under contract to Battelle Ocean Sciences, Duxbury, Mass.

Thom, R., R. Albright, C. Simenstad, J. Hampel, J. Cordell and K. Chew. 1984. Renton sewage treatment plant project: Seahurst baseline study, vol IV, Section 5, Intertidal and shallow subtidal benthic ecology. Fisheries Research Institute, University of Washington. Seattle.

Thom, R.M., A.E. Copping and R.G. Albright. 1988. Nearshore primary productivity in central Puget Sound: A case for nutrient limitation in the nearshore system of Puget Sound. In R.M. Thom, session chairman, Proceedings of the First Annual Meeting on Puget Sound Research. 2:378-391.

Tetra Tech. 1988. Characterization of spatial and temporal trends in water quality in Puget Sound. Final report to the Enviromental Protection Agency. Office of Marine and Estuary Protection. Region 10. Seattle, Washington.

Thompson, C.A. and C. Vanderzant. 1976. Zooplankton and phytoplankton from Galveston Bay: taxonomic distribution and coexistence with Vibrio parahaemolyticus. Journal of Food Science. 41:725-727.

Thompson, T.G. and L.D. Phifer. 1936. The plankton and the properties of the surface waters of the Puget Sound regions. University of Washington Publ. Oceanogr. 1:111-134.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Department of Fisheries and Oceans (Canada) Ottawa, Canada 291p.

Tibbs, J.F., R.A. Elston, R.W. Dickey, and A.M. Guarino. 1989. Studies on the accumulation of antibiotics in shellfish. Northwest Environmental Journal. Vol. 5, No. 1.

Tibbs, J.F., R.A. Elston, R.W. Dickey, and A.M. Guarino. 1988. Studies on the accumulation of antibiotics in shellfish. Abstract submitted to Northwest Environmental Journal.

Tison, D.L., M. Nishibuchi, J.D. Greenwood and R.J. Seidler. 1982. Vibrio vulnificus biogroup 2: new biogroup pathogenic for eels. Applied Environmental Microbiology. 44:640-646.

Toranzo, A.E. and F.M. Hetrick. 1982. Comparative stability of two salmonid viruses and poliovirus in fresh, estuarine and marine waters. Journal of Fish Diseases. 5:223-221.

Toranzo, A.E., J.L. Barja and F.M. Hetrick. 1982. Survival of Vibrio anguillarum and Pasteurella piscicida in estuarine and fresh waters. Bulletin of the European Association of Fish Pathologists. 3:43-45.

Toranzo, A.E., J.L. Barja, S.A. Potter, R.R. Colwell, F.M. Hetrick and J. H. Crosa. 1983. Molecular factors associated with virulence of marine vibrios isolated from striped bass in Chesapeake Bay. Infection and Immunity 39:1220-1227.

Toranzo, A.E., P. Combarro, M.L. Lemos and J.L. Barja. 1984. Plasmid coding for transferable drug resistance in bacteria isolated from cultured rainbow trout. Applied and Environmental Microbiology 48:872-877.

Towne, Richards & Chaudiere, Inc. 1988. Acoustical evaluation salmon net pen project Hartstene Island, Washington. Prepared for Swecker Sea Farms, Inc, Rochester, WA.

Traxlor, G.S. and G.R. Bell. 1988. Pathogens associated with impounded Pacific herring (Clupea harengus pallasi Valenciennes) with emphasis on viral erythrocytic necrosis (VEN) and atypical Aeromonas salmonicida. Diseases of Aquatic Organisms (in press).

Trussel, R.P. 1972. The percent un-ionized ammonia in aqueous ammonia solutions at different pH levels an temperatures. Journal of the Fisheries Research Board of Canada. 29:1505-1507.

Tubiash, H.S., S.V. Otto and R. Hugh. 1973. Cardiac edema associated with Vibrio anguillarum in the American oyster. Proceedings of the National Shellfisheries Association. 63:39-42.

U.S.D.A. 1988. Aquaculture: situation and outlook report: Aqua 1. Prepared by Economic Research Serivce, Rockville, MD

U.S.E.P.A. 1986. Quality criteria for water. Environmental Protection Agency, Washington D.C.

U.S.F.D.A. 1983. Environmental assessment for National Academy of Sciences/National Research Council, Drug Efficacy Study Group. Finalization for Oxytetracycline Bureau of Vetrinary Medicine. Prepared by Environmental Impact Staff, U. S. Food and Drug Administration, Washington D.C.

URS Co. 1986. Southern Puget Sound water quality assessment study, final report: Comprehensive circulation and water quality study of Budd Inlet. Prepared for the Washington State Dept. of Ecology. Seattle.

Waknitz, F.W. 1988. Personal communication of November 18, 1988. National Marine Fisheries Service, Hatchery Manager, Manchester, Washington.

Walters, C.J., R. Hilborn, R.M. Peterman, and M.J. Staley. 1978. Model for examining early ocean limitation of Pacific salmon production. Journal of the Fisheries Research Board of Canada. 35:1303-1315.

Waples, R. 1988. Personal communication of September 30. National Marine Fisheries Service, Seattle, WA.

Ward, W.D. and L.J. Hoines. 1987. 1986 Fisheries statistical Report. Wahsington Dept. Fisheries. Olympia, WA.

Warren-Hansen, I. 1982. Evaluation of matter discharged from trout farming in Denmark. In J.S. Alabaster (ed.), Report of the EIFAC Workshop on Fish-farm Effluents, Technical paper No. 4. Silkeborg, Denmark, 26-28 May 1981.

Washington Department of Agriculture. 1986. Washington seafood marketing study: report to the Legislature. Prepared by Agriculture Research Division, Olympia, WA.

Washington Department of Fisheries. 1988. Hatchery production and commercial catch statistics. Unpublished computer printout. WDF, Olympia, WA.

Watkins, W.D. and Cabelli, V.J. 1985. Effect of fecal pollution on Vibrio parahaemolyticus densities in an estuarine environment. Applied and Environmental Microbiology 49:1307-1313.

Wekell, M. 1989. Personal communication. U. S. Food and Drug Administration, Seafood Products Research Group, Bothell, WA.

Welch, E.B. 1980. Ecological Effects of Waste Water. Cambridge University Press. Cambridge. 337 pp.

Weston, D.P. 1986. The environmental effects of floating mariculture in Puget Sound. Prepared by the University of Washington, School of Oceanography for the Washington Departments of Fisheries and Ecology. 148 pp.

Weston, D.P., and R.J. Gowen. 1988. Assessment and prediction of the effects of salmon net-pen culture on the benthic environment. Unpublished report to Washington Department of Fisheries, Olympia, WA.

Wheaton, F.W. 1985. Aquacultural Engineering. Robert E. Kriego Publishing Co., Malaba, FLA.

White, A.W. 1987. Blooms of toxic algae worldwide: Their effects on fish farming and shellfish resources. pp. 9-14. In: The impact of toxic algae on mariculture, Aquanor 87. Trondhein Norway.

Whittington, R.J., N. Gudkovs, M.J. Carrigan, L.D. Ashburner and S.J. Thurstan. 1987. Clinical, microbiological and epidemiological findings in recent outbreaks of goldfish ulcer disease due to atypical Aeromonas salmonicida in south-eastern Australia. Journal of Fish Diseases. 10:353-362.

Wiik, R. and E. Egidius. 1986. Genetic relationships of Vibrio salmonicida sp. nov. to other fish-pathogenic vibrios. International Journal of Systematic Bacteriology. 36:521-523.

Winter, D.F., K. Banse and G.C. Anderson. 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. Marine Biology 29:139-176.

Woodin, S.A. 1974. Polychaete abundance patterns in a marine soft-sediment environment: the importance of biological interactions. Ecological Monographs. 44: 171-187.

Word, J. O., P. L. Striplin, K. Keeley, J. Ward, P. Sparks-McConkey, L. Bentler, S. Hulsman, K. Li, J. Schroeder, and K. Chew. 1984. Subtidal benthic ecology. In: Renton Sewage Treatment Plant Project: Seahurst Baseline Study. Q. L. Stober and K. Chew, Principal Investigators. Final Report for Municipality of Metropolitan Seattle. Seattle, Washington.

Yamanoi, H., K. Muroga and S. Takahashi. 1980. Physiological characteristics and pathogenicity of NAG vibrio isolated from diseased ayu. Fish Pathology. 15:69-73.

Yoder, W.G. 1972. The spread of Myxosoma cerebralis into native trout populations in Michigan. Progressive Fish-Culturist 34:103-106.