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One side says "fish-farming
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Other side says report shows
"there are lots of concerns"

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Draft Programmatic
Environmental Impact Statement

Fish Culture in Floating Net Pens

Washington Department of Fisheries

Technical Appendices

January 1989

Draft Programmatic
Environmental Impact Statement

Fish Culture in Floating Net Pens

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Technical Appendices

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APPENDIX A

Assessment and Prediction of the Effects of Salmon Net-Pen Culture
on the Benthic Community

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- A. Assessment and Prediction of the Effects of Salmon Net-Pen Culture on the Benthic Community
- B. Modeling of Particulate Deposition Under Salmon Net-Pens
- C. Phytoplankton and Nutrient Studies Near Salmon Net-Pens at Squaxin Island, Washington
- D. Infectious Diseases of Salmon in the Pacific Northwest
- E. The Economics of Salmon Farming
- F. Permits That May Be Required for Aquaculture Projects

NOTE: Appendices A and E were completed under separate contracts with the Department of Fisheries.

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ASSESSMENT AND PREDICTION OF THE EFFECTS OF
SALMON NET-PEN CULTURE ON THE BENTHIC ENVIRONMENT

by

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ABSTRACT

Sediment chemistry and macrofaunal communities were examined in the vicinity of two salmon mariculture facilities in Puget Sound. The Clam Bay farm is a relatively large operation containing 200 to 400 tons of salmon, and has been in operation for about 13 years. Deposition of feed and feces beneath the pens has created an area characterized by high levels of organic carbon and nitrogen and depressed sediment reduction-oxidation potentials. This area extends under the pens and out to a distance of 15 to 60 m from the farm perimeter. The macrofaunal community shows dramatic alterations in this area including the disappearance of most species characteristic of the natural community and high abundances of nematodes and an opportunistic polychaete. More moderate changes in the infaunal community extend at least 150 m from the farm.

The Squaxin Island farm is a comparatively small facility (20 to 40 tons of fish on site) and has been operating only since early 1987. Unlike the Clam Bay site, there was little effect of the farm on sediment chemistry, even directly under the pens. The infaunal community shows evidence of disturbance in an area extending from the pen perimeter out to a distance of 6 m. Within this zone the community appears to have been undergoing gradual change over the 18 months of farm operation.

On the basis of these investigations, macrofaunal community composition appears to be a more sensitive indicator of benthic impacts than measurement of sediment chemical parameters alone. Among the sediment parameters evaluated, redox potential appears to be a valuable tool for rapid and cost-effective impact assessment, at least in coarse-grained sediments.

A model which predicts dispersion of feed and feces from a farm site was tested for agreement with actual conditions at the Clam Bay and Squaxin sites. The model was found to be reliable to within a factor of two or less in predicting the magnitude of organic loading to the seafloor. At the Clam Bay site and, to a lesser extent, at Squaxin Island the areas which the model predicted to receive the greatest input of feed and feces were the same areas showing the highest degree of sediment enrichment. On a broader scale, the model appeared reliable in identifying the areal extent of impact from net-pen culture. After tests at eight farms the model has predicted enhanced carbon fluxes up to 70 m (and usually less than 30 m) from the pen perimeter. These predictions are consistent with the results from this study and other investigations. The model is useful in identifying sites that would be clearly unsuitable for culture or others where environmental impacts are likely to be negligible. There are, however both inherent unknowns and oversimplifying assumptions in the model, which should be recognized to avoid indiscriminant application of the

model and misinterpretation of the results. The data base of current velocity and direction on which model predictions are based is rarely, if ever, available for siting decisions, but would be valuable both to environmental managers and farm operators.

**ASSESSMENT AND PREDICTION OF THE EFFECTS OF
SALMON NET-PEN CULTURE ON THE BENTHIC ENVIRONMENT**

INTRODUCTION

Cultivation of salmon in estuaries and coastal embayments generates substantial quantities of particulate organic wastes consisting principally of feces and uningested feed. It has been estimated that the production of 1 kg of salmon generates 0.5 to 0.7 kg of particulate waste (Weston, 1986; Gowen and Bradbury, 1987). For large farms, which produce several hundred tons of salmon annually, the quantity of particulate waste settling to the seafloor is considerable. Accumulation of organic waste on the sea bed has been found to alter some aspects of sediment chemistry and benthic macrofaunal community composition in the vicinity of salmonid culture operations. The changes in sediment chemistry include increases in carbon, nitrogen and phosphate content (Hall and Holby, 1986), depression in sediment reduction-oxidation potentials (Brown *et al.*, 1987), and changes in the rates of nutrient cycling (Kaspar *et al.*, 1988). Shifts in the species composition and relative abundances of benthic macrofauna have been reported, occasionally with an azoic zone directly beneath the farm (Pease, 1977; Brown *et al.*, 1987). Waste accumulation on the seafloor can have implications for the viability of the farm itself. The release of hydrogen sulfide from anoxic sediments and/or related changes in water quality can adversely effect the health of the cultured fish (Arizono, 1979) and has been the reason for the closure of some operations (Braaten *et al.*, 1983).

At the present time there is a rapid growth in the farming of salmon. The results of this growth will be the expansion of existing farms, some to an annual production of 2,000 to 3,000 tons, and the establishment of multiple farms in individual embayments. As development proceeds potential pollution problems require careful scrutiny, and it has recently been stated that there is a need for models which can

be used to predict ecological impact before establishment of a farm (Rosenthal et al., 1987). The development of such models, together with an understanding of the effects of organic wastes on the benthos, is essential to ensure that this form of mariculture does not cause broad ecological change. An additional application of such model would be in resource management, to ensure that farming is not conducted in areas which, through ecological change, can not sustain the long-term use of the site.

This paper describes an assessment of the intensity and spatial extent of impact on the benthos of two farm sites in Puget Sound, Washington. The sites chosen for study differ greatly in physical conditions, farm size and duration of operation, and potentially offer a broad range in the scale of impact. The study was also intended to further test a sedimentation model designed to predict the dispersal of solid wastes from fish farms (Gowen et al., in press). A preliminary test of the model (Gowen et al., 1988), using sediment redox potentials as an indicator of organic pollution, suggested that the model could be used to predict the spatial extent and severity of ecological disturbance of the benthos and in the selection of suitable sites.

MATERIALS AND METHODS

Field sampling and model verification was performed at two salmon net-pen operations in Puget Sound. The Clam Bay farm is a large operation with an annual production of 617 tons and containing 200 to 400 metric tons of salmon at any given time. The farm has been in operation at the same site continuously since the early 1970's. The Squaxin Island farm holds 20 to 30 tons of salmon and has only been in operation since 1987. There are 53 additional pens located 250-500 m south of the Squaxin Island farm. These pens are used to hold juvenile salmon on a seasonal basis, and were largely unused during the period of investigation. Physical characteristics of each site and details of the Clam Bay and Squaxin farms are given in Table 1.

Sampling stations were established at each farm at predetermined distances along 3 transect lines extending out from the pens, varying in length from 30 to 165 m (Figure 1). Field activities included deployment of current meters and sediment traps, collection of sediments for chemistry and grain size analysis, measurement of dissolved oxygen in near-bottom waters, and sampling of benthic macrofauna.

Current measurements - Two Aanderaa current meters were deployed at each of the farm sites, and set to record at 15 minute intervals for a period of 60 days. The meters were placed 2.5 and 5.5 m above the seafloor at the Squaxin Island and Clam Bay sites, respectively.

Sediment traps - Sediment traps were constructed of PVC piping, 15 cm in diameter and 45 cm in length. An array of three traps were placed under the pens and at each station along transects CB1 and SQ1. The distances between the sea bed and the mouths of the traps were 0.5 and 5.5 m at the Squaxin and Clam Bay sites, respectively. Prior to deployment 250 g

Table 1
Physical characteristics of the farms
and surrounding environments

<u>PARAMETER</u>	<u>CLAM BAY</u>	<u>SQUAXIN ISLAND</u>
Depth of water (m at mean lower low water)	10 - 26	4.7 - 5.0
Distance between bottom of pens and sea bed (m at mean lower low water)	6 - 22	1.7 - 2.0
Area of cages (m ²)	14,560	1,184
Duration of operation (years)	13	1.5
Biomass held on farm (metric tons)	200 - 400	20 - 30
Feed provided (kg·day ⁻¹)	2200 - 5900	400 - 600

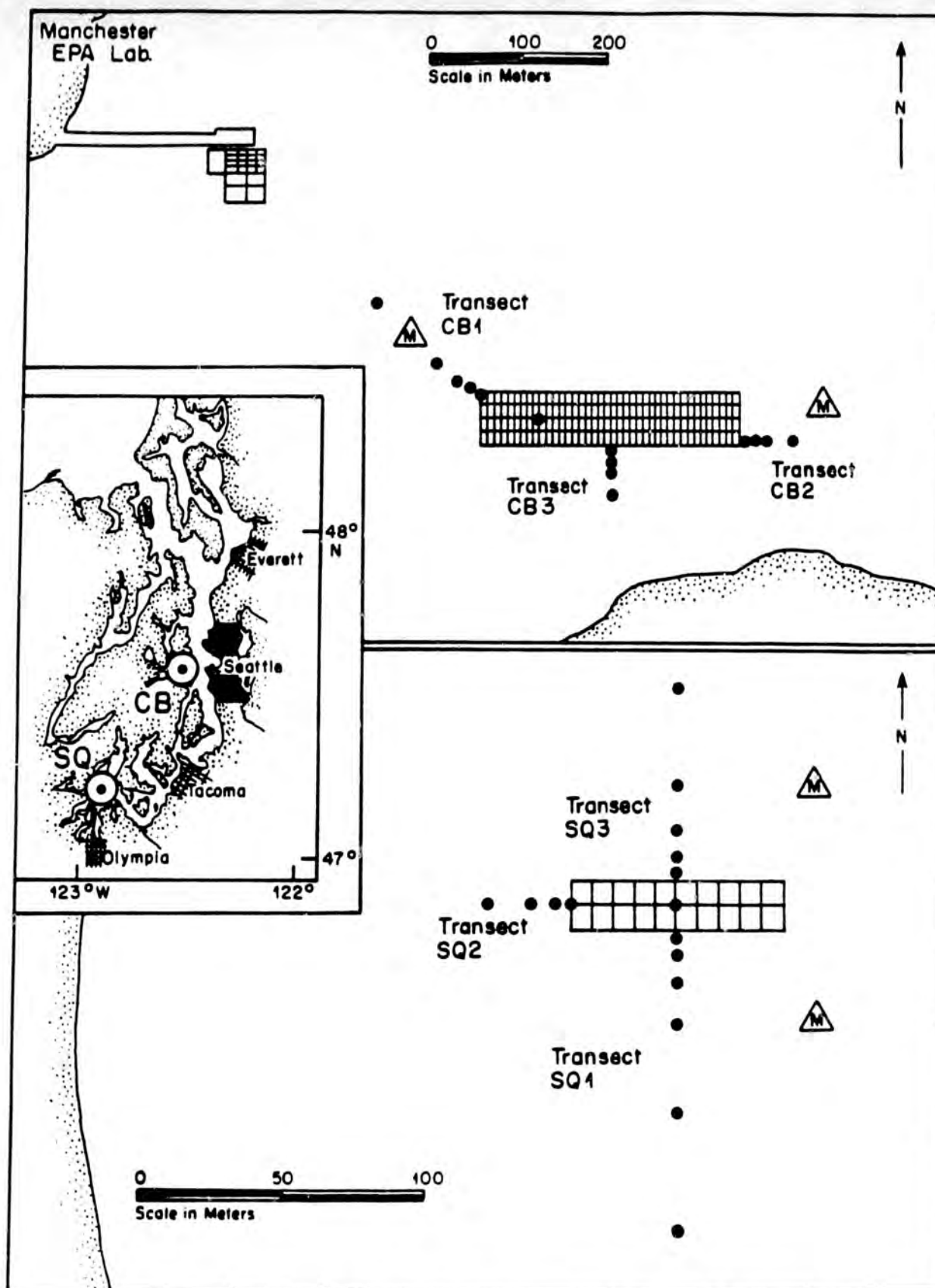


Figure 1. Locations of the two Puget Sound farm sites investigated. Sampling stations are indicated by dots under the pens and along three transects at each site. Locations of the Aanderaa current meters indicated by M symbol.

of reagent grade salt was added to each trap to retard microbial activity and reduce loss of material by resuspension. The traps were deployed for 9 days at the Clam Bay site and 15 days at Squaxin Island. Mercuric chloride was added to the traps at the time of recovery to inhibit microbial activity prior to analysis. The total amount of particulate material retained in the traps was estimated by filtering duplicate aliquots of the homogenized trap contents on to combusted and preweighed 45 um silver filters. The material retained on the filters was analyzed for carbon and nitrogen in a Carlo Erba Model 1106 CHN microanalyzer following vapor phase acidification to remove inorganic carbon (Hedges and Stern, 1984).

Sediment sampling - The upper 1 cm sediment stratum was collected by SCUBA diver (Clam Bay) or Van Veen grab (Squaxin Island). The sediment was analyzed for carbon and nitrogen content in the same manner as the sediment trap material, except that a Perkin Elmer 240 elemental analyzer was used. Sediment redox potentials were measured in diver-collected cores following the method of Pearson and Stanley (1979). Grain size analysis was performed by dry sieving followed by pipette analysis of the silt and clay fraction.

Dissolved oxygen - Near-bottom water samples were collected 5 to 10 cm above the sediment-water interface by SCUBA divers, and analyzed by the Winkler titration method (Strickland and Parsons, 1972).

Benthic macrofauna - Macrofauna samples were collected at each farm site in connection with independent investigations. The Squaxin samples were collected as part of the operator's routine monitoring program which was scheduled so as to sample concurrently with the present investigation. The Clam Bay samples were collected as part of an EPA-funded study by the University of Washington to examine the effects of organic enrichment on benthic communities (Weston, 1988).

At the Squaxin Island farm macrofaunal samples were collected at each station along transect SQ1. Three 0.008-m² cores were collected by diver at each station. The contents of two of the cores were washed on a 1.0-mm screen, while the third core was washed on stacked 0.5 and 1.0-mm screens. The Clam Bay macrofauna samples were collected one year prior to the present investigations at stations closely approximating those of transect CB1. Three samples were collected at each station using a 0.06-m² spade corer, and washed on a 0.5 mm screen sieve.

The predicted dispersal of feed and feces from the net-pens was determined using the sedimentation model of Gowen *et al.* (in press). The model uses a value of 4 cm·sec⁻¹ for the settling velocity of feces (Warrer-Hansen, 1982), and a settling velocity for uneaten feed that was determined in a settling column using feed from the specific farm. The area occupied by the farm was divided into a grid of 1 m squares, and waste production was assumed to be evenly distributed over the farm area. Solid waste production (in units of g organic carbon·m⁻²·hr⁻¹) was calculated as a proportion of the feed provided. The amount of waste feed was assumed to be 15%, although the actual wastage varies greatly among farms and is generally unquantified (see p. 54 for complete discussion). The fecal production was estimated to be 30% of the ingested feed (Penczak *et al.*, 1982). Hourly values of current velocity and direction were used to calculate the horizontal displacement of feed and feces in each array element using the equations:

$$I + \frac{(D) \times (V \cos \theta)}{U}$$

$$J + \frac{(D) \times (V \sin \emptyset)}{U}$$

where I and J are the co-ordinates of the waste within the array at the start of each hour. D (water depth under pens) divided by U (settling velocity of feed and feces) determines the time during which horizontal displacement takes place. $V \cos \emptyset$ and $V \sin \emptyset$ provide the components of the horizontal displacement of a particle. Thus, the above equations give the X and Y co-ordinates of a particle on the sea bed in relation to the position of the farm at the end of each hour. The model was run using current data over one or more spring-neap tidal cycles and integrated the dispersal and input of organic carbon waste over this time period.

RESULTS

CLAM BAY SITE

Fourteen stations were sampled in the vicinity of the Clam Bay farm site, ranging from directly under the net-pens to a distance of 165 m from the perimeter of the complex (Table 2). The bottom topography at the farm site was steeply sloped, with water depths increasing to the north and east. Water depths near the southwest corner of the cage complex were 10 m at MLLW in comparison to 26 m at the northeast corner. Sampling in the deeper areas was not possible by SCUBA diving, thus all samples were collected at depths of 19 m or less. Seawater temperature and salinity of near bottom waters were 13°C and 30 ppt, respectively.

Sediments were primarily medium sands (0.25 - 0.5 mm diameter) to the east and south of the pen complex with finer sands (0.125 - 0.25 mm) to the northwest. Silts and clays comprised less than 5% of the sediment throughout the study area. Shell and gravel comprised a large fraction of the sediment (19%) only at stations to the east of the farm site.

Water Currents

Two current meters were deployed near the Clam Bay farm site. The first was positioned 100 m east of the net-pen complex, 5.5 m above the seafloor and 23.5 to 27 m below the surface (depending on tidal stage). The second was located 100 m northwest of the farm, 5.5 m above the seafloor and 9.5 to 13 m below the surface. Data collected during the period July 6 through August 4, 1988 were analyzed and presented in Figure 2. The current regimes showed pronounced differences at the two sites as a result of either depth-related differences in current flow, or, more probably, local variations attributable to the close proximity and curvature of the shoreline.

Table 2
Clam Bay station summary

<u>Station or Transect</u>	<u>Distance from net-pens (m)</u>	<u>Water depth (m at MLLW)</u>	<u>Substrate</u>
A	0	15	
Transect CB1			
	0	16	
	15	16	
	30	16	
	60	15	
	165	15	0.3% shell/gravel 95.7% sand 4.0% silt and clay
Transect CB2			
	0	13	
	15	14	
	30	15	
	60	19	19.4% shell/gravel 77.1% sand 3.5% silt and clay
Transect CB3			
	0	13	
	15	12	
	30	11	1.8% shell/gravel 98.2% sand 0% silt and clay
	60	10	

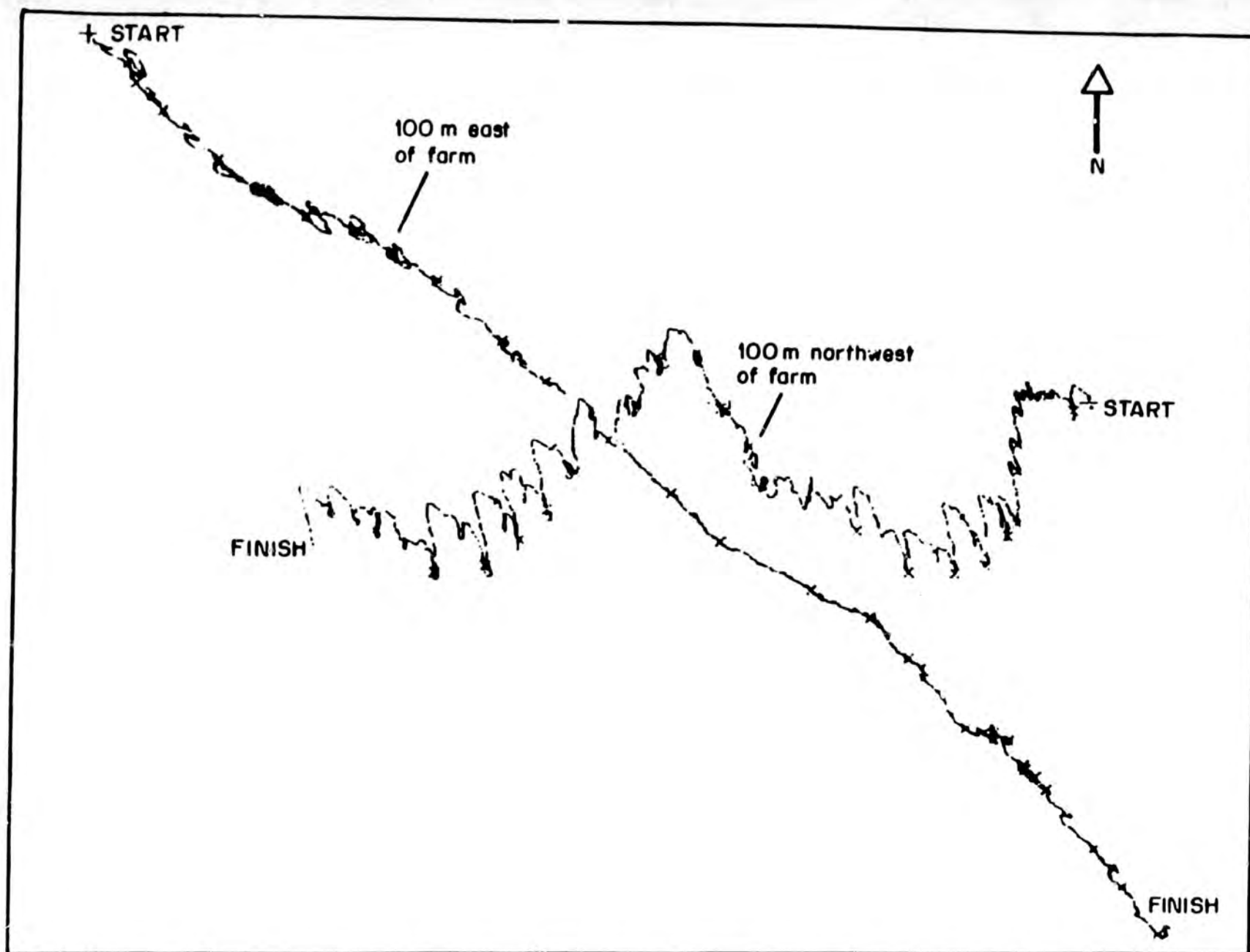


Figure 2. Progressive vector diagrams based on the two current meter records from the Clam Bay site. X symbols indicate 24-hour intervals.

The current data are presented in the form of progressive vector diagrams. These diagrams were created by drawing a vector for each of the 690 current observations such that the orientation of the vector corresponds to the direction of the current and the vector's length corresponds to current velocity. The vectors are then arranged in a head-to-tail fashion with "start" and "finish" indicating the first and last records, respectively. East of the farm site (Figure 2) most of the vectors were oriented to the southeast, indicating current flows primarily in this direction with little evidence of tidal oscillation. The constancy factor at this site was 94.7%. (A constancy factor of 100% would indicate currents consistently in one direction; a constancy factor of 0% would indicate that currents flowed in all directions with equal frequency). The mean current velocity over the period of observation was $9 \text{ cm}\cdot\text{sec}^{-1}$, although velocities as high as $36 \text{ cm}\cdot\text{sec}^{-1}$ were recorded. These current data were collected to model the dispersal of solid wastes sinking from the pens, so the measurements were taken at a depth of about 25 m. Current velocities at the depth of the net-pens (0-4 m) are likely to be somewhat different.

Northwest of the farm site there was a strong tidal influence with currents flowing alternately to the northwest and to the south. The net current flow was to the west with a relatively low constancy factor of 65.6%. Current velocities were slightly lower than those recorded by the other meter. Mean velocity was $6 \text{ cm}\cdot\text{sec}^{-1}$ with a maximum of $31 \text{ cm}\cdot\text{sec}^{-1}$.

Sediment chemistry

Total organic carbon and total nitrogen in surficial sediments exhibited similar patterns of enrichment throughout the study area (Figures 3 and 4). The highest levels of enrichment were found under the southern perimeter of the farm site (CB3-0 m) and 15 m east of the site (CB2-15 m). To the east of the farm site (CB2) the area of enrichment extended to

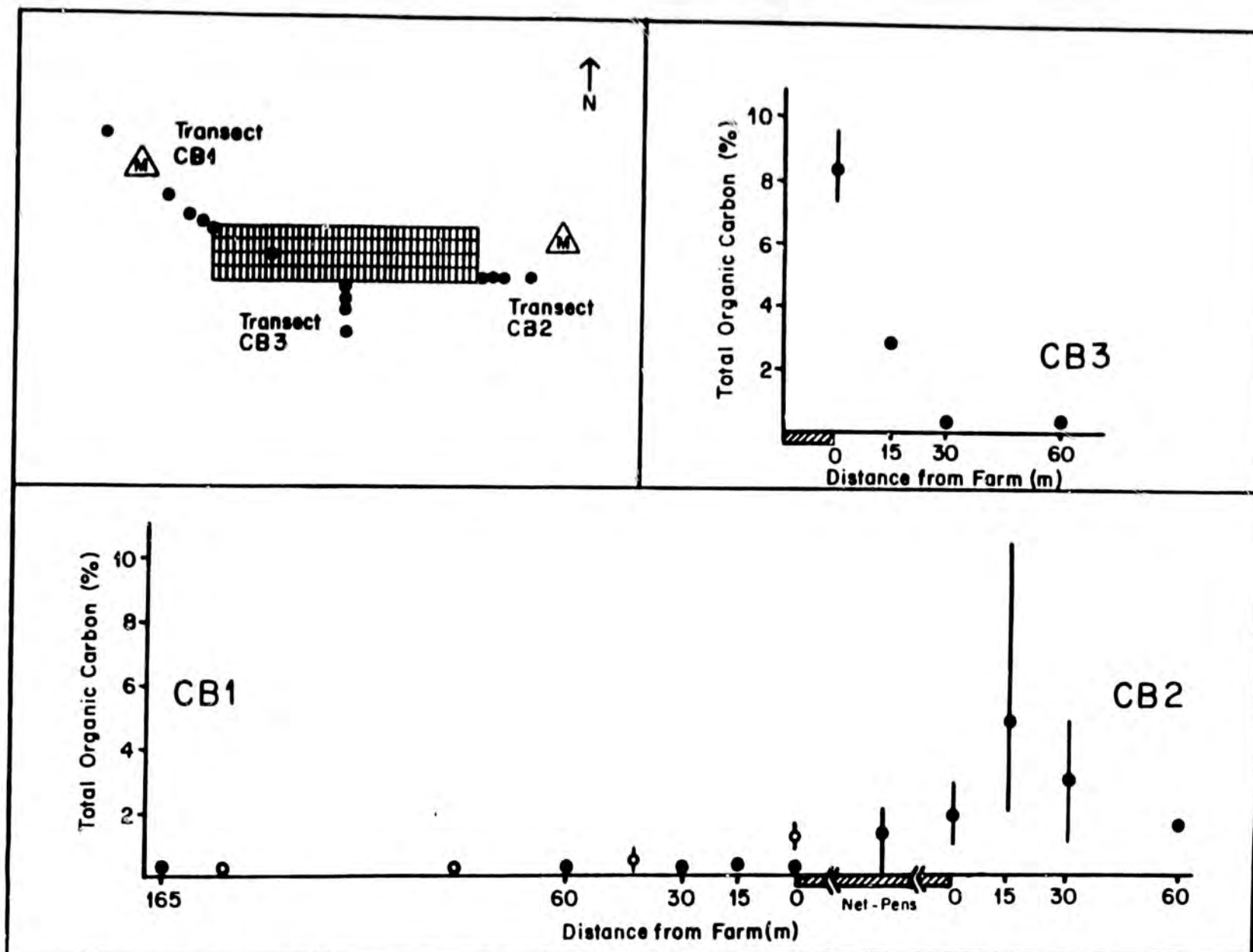


Figure 3. Total organic carbon concentrations in sediments surrounding the Clam Bay farm. Range bars are not shown if less than the size of the mean symbol. Open circles show data collected one year earlier as part of a separate investigation.

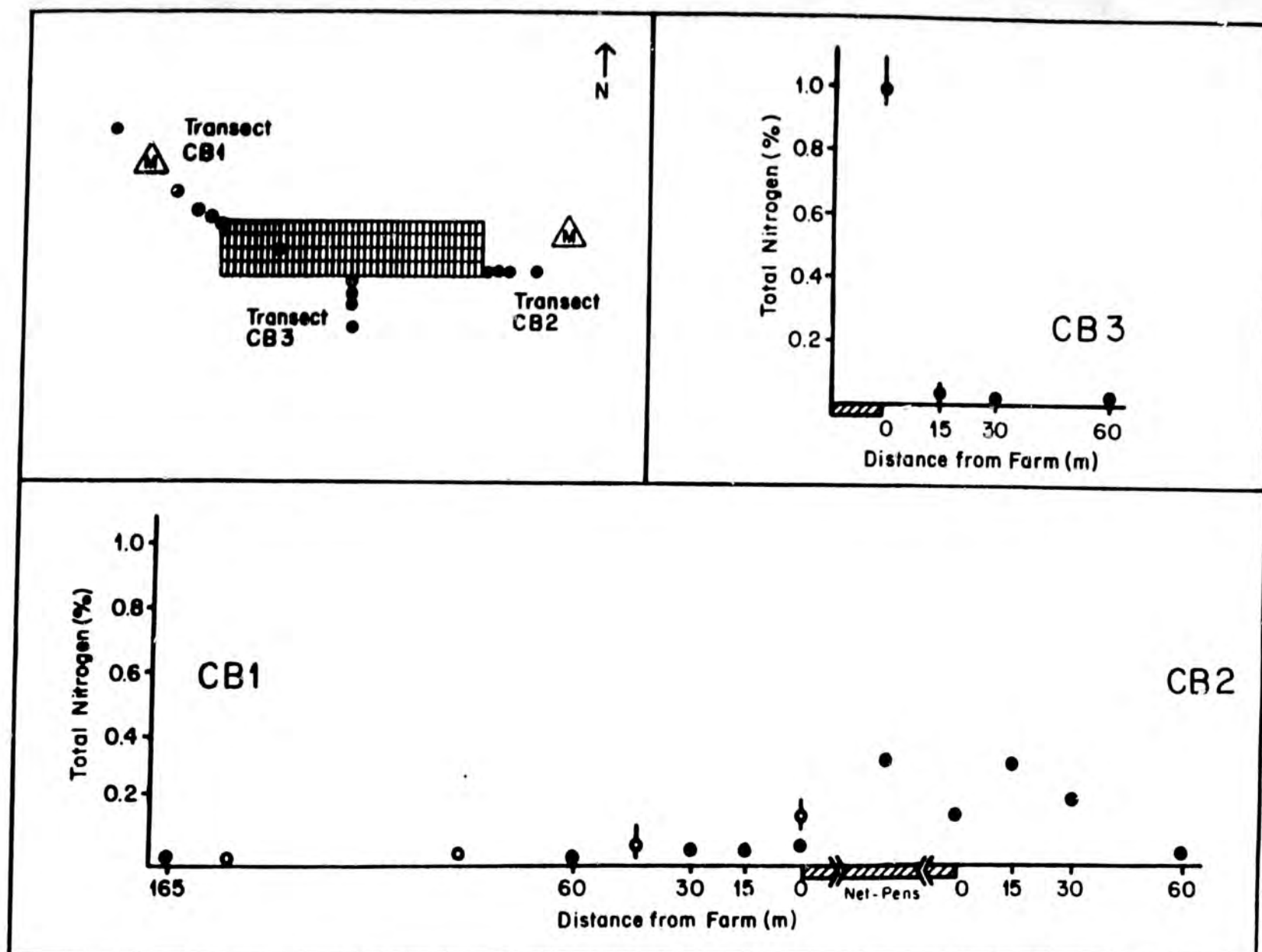


Figure 4. Total nitrogen concentrations in sediments surrounding the Clam Bay farm. Range bars are not shown if less than the size of the mean symbol. Open circles show data collected one year earlier as part of a separate investigation.

a distance of at least 30 m (nitrogen) to 60 m (carbon). To the south enrichment was limited to within 15 m of the net-pens. Northwest of the farm nitrogen showed a statistically significant enrichment to a distance of 30 m (Kolmogorov-Smirnov two-sample test among all possible sample pairs, $\alpha < 0.05$), but carbon levels remained uniformly low throughout the transect. The area northwest of the net-pens had also been sampled in July 1987 as part of an independent study (Weston, 1988). The results of the current sampling were generally similar to the results from the previous year except in close proximity to the net-pens. Within 45 m of the farm carbon and nitrogen concentrations were substantially reduced relative to their levels one year earlier. This reduction is not due to stocking density since the total biomass of fish in the farm was actually 20% greater during the present investigation than one year earlier, but other factors such as small differences in station location or sampling artifacts (diver vs. box corer) may explain this apparent decrease.

The reduction-oxidation potential (E_h) is a quantitative measure of the reducing or oxidizing intensity of sediments. Positive E_h values are generally characteristic of sediments which have a large grain size, are well oxygenated, and/or are poor in organic matter. Negative E_h values are measured in sediments which are rich in organic matter, consist largely of fine sediments, and/or are poorly oxygenated. Sediments receiving high inputs of feed and feces from an aquaculture facility would be expected to have more negative E_h values relative to background conditions assuming grain size is comparable.

At the Clam Bay farm site trends in E_h values closely mirrored gradients in total organic carbon and total nitrogen. Background values were generally about 350 mv at the sediment water interface and 250-300 mv at a depth of 4 cm in the sediment column (Figure 5). With increasing proximity to the pen site, E_h values were reduced throughout the sediment column. The area of depressed potentials extended from 30 m

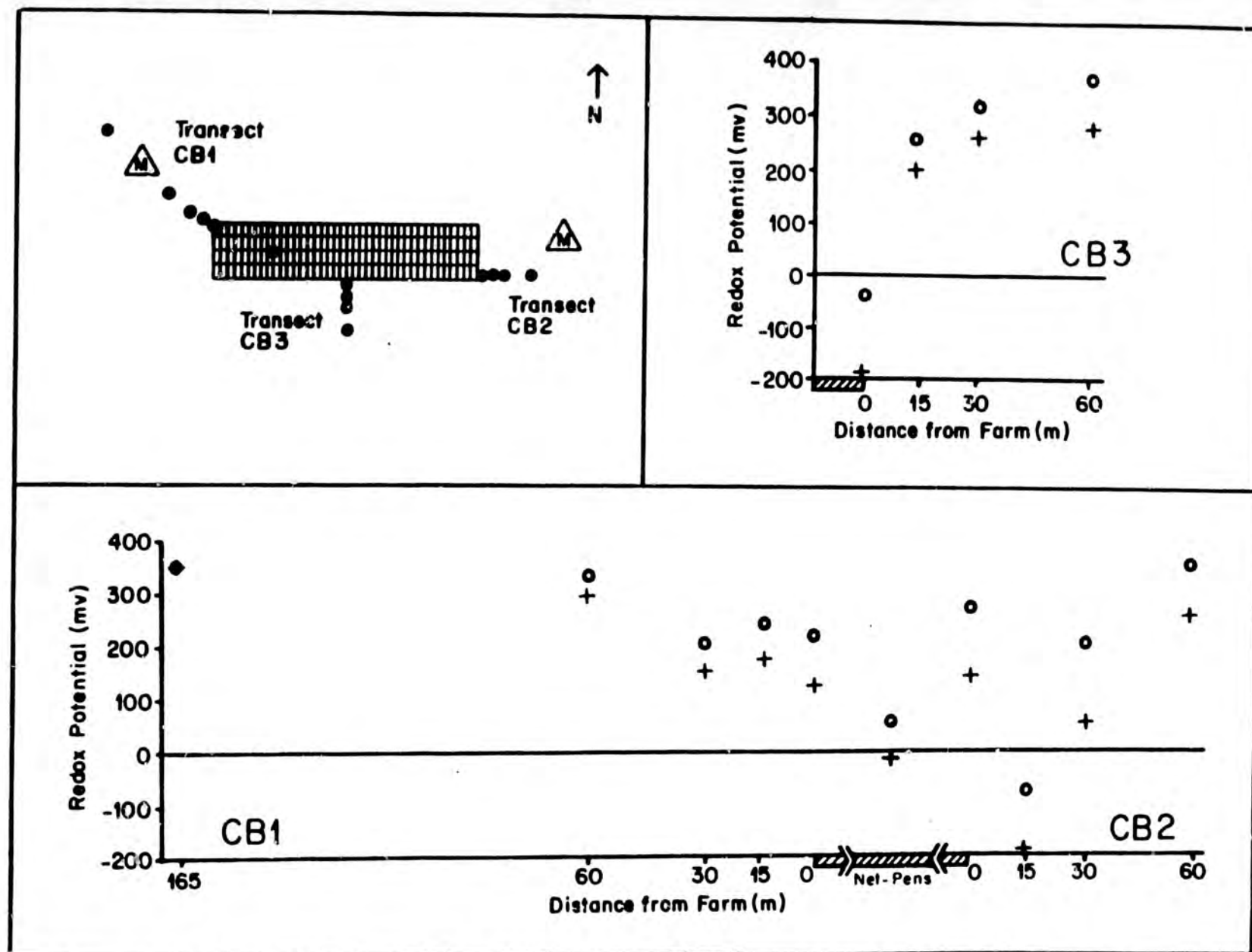


Figure 5. Reduction-oxidation potentials in sediments surrounding the Clam Bay farm. Open circles represent potentials at the sediment-water interface; cross symbols represent potentials at a depth of 4 cm in the sediment.

northwest of the net-pens, to 30 m east of the net-pens, to 15-30 m south. Reducing conditions at the sediment-water interface were evident only 15 m east of the net-cage complex and directly under the southern perimeter.

Dissolved oxygen

Dissolved oxygen concentrations at a height of 5 to 10 cm above the sediment-water interface were uniformly about 8 $\text{mg}\cdot\text{l}^{-1}$ throughout the study area (Figure 6). The dissolved oxygen sampling design was necessarily less than ideal, since the various stations were sampled over a 6 hr. period and it is not possible to differentiate between upcurrent and down-current sites. Nevertheless the data should show if the enriched sediments caused a dramatic depletion in dissolved oxygen of the overlying water as has been observed elsewhere (Brown *et al.*, 1987). No such depletion was evident, presumably because of the high current velocities of the site.

Sediment traps

Seven sediment trap arrays were deployed along transect CB1, but because of limitations in bottom time and air supply, the divers were only able to retrieve one array directly under the net-pens (Station A) and the array at the farm perimeter (CB1-0 m). Duplicate samples from the three traps within each array were analyzed, resulting in six estimates of deposition rates at each station.

Directly under the net-pens the estimated sedimentation rate was $52.1 \text{ kg dry wt.}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ (range of six samples = 46.6 - 55.2). At the pen perimeter the sedimentation rate was $29.7 \text{ kg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ (range 27.8 - 30.8). The particulate material collected directly under the net-pens was approximately twice as enriched in organic carbon as that collected in the trap at the farm perimeter (25.9% and 12.0%, respectively). The

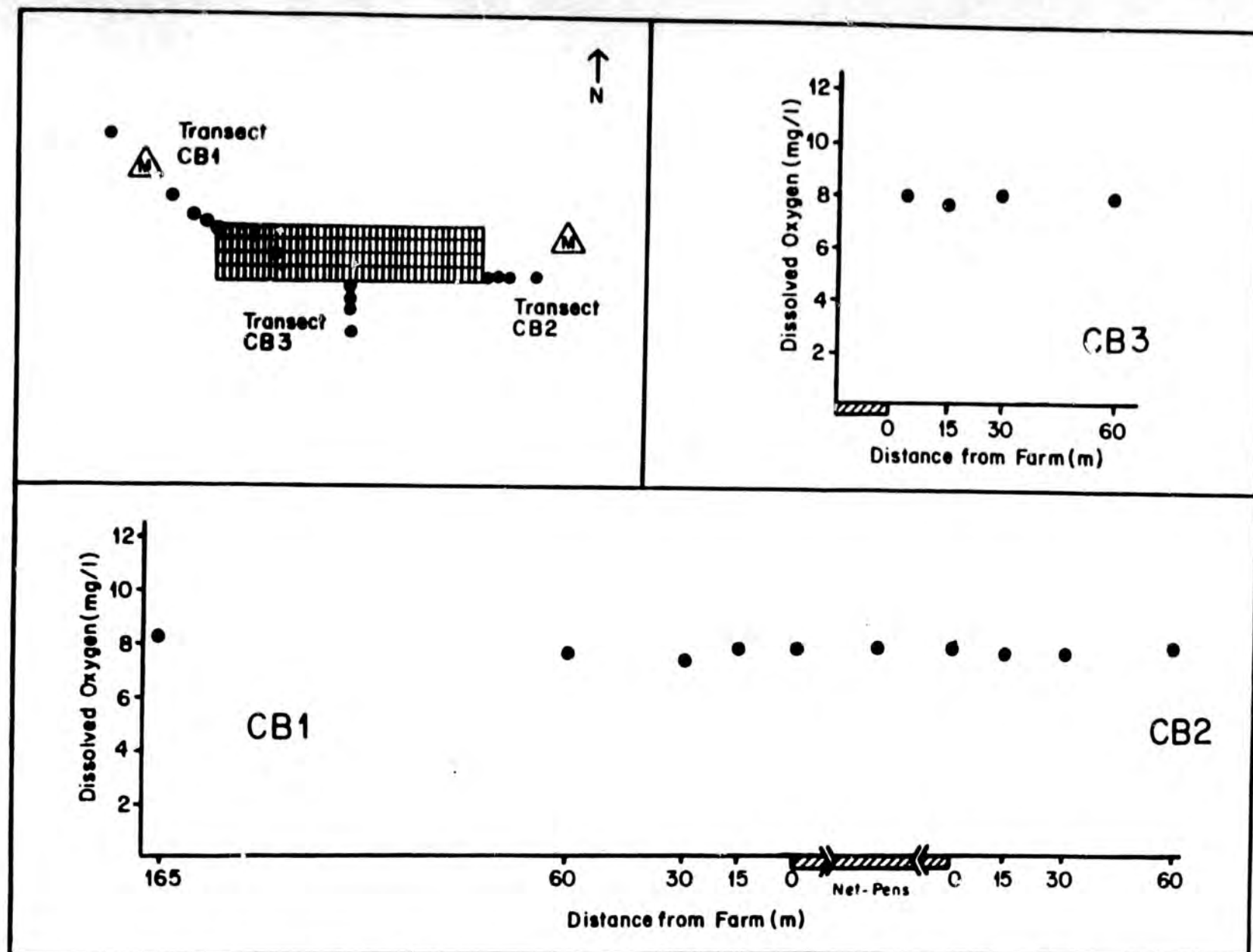


Figure 6. Dissolved oxygen concentrations in near-bottom water surrounding the Clam Bay farm site.

estimated flux of organic carbon to the seafloor was 13.3 kg C·m⁻²·yr⁻¹ under the net-pens and 3.6 kg C·m⁻²·yr⁻¹ at the perimeter.

Macrofauna

Macrofauna were collected one year earlier at four stations along transect CB1 at points close to but not identical to those sampled during the present study (i.e., distances from the farm perimeter of 0, 45, 90, 150 and 450 m vs. 0, 15, 30, 60 and 165 m in the present study). Extensive data analysis is still in progress, so preliminary conclusions are limited to assessment of abundance, biomass, species richness and the density of indicator species.

Figure 7a illustrates typical qualitative changes in species number, biomass and species abundance along a gradient of organic enrichment (Pearson and Rosenberg, 1978). At low levels of organic input, a transition zone develops in which abundance, biomass and species richness gradually decrease from levels typical of the unpolluted environment. In this transition zone there may be a slight species richness and biomass peak attributable to a phenomenon known as "biostimulation". In this area the organic input provides a rich food source, yet the rate of input is not so great that it interferes with the mechanics of suspension feeding nor causes serious oxygen depletion. At a somewhat higher rate of input, total macrofaunal abundance attains a maximum value. Biomass may also be slightly elevated, but the number of species is very low. The increased abundance and biomass results from the proliferation of a few opportunistic species. With still higher rates of organic input there is a complete absence of benthic macrofauna. The rate of organic input is so great that oxygen levels in bottom waters and sediments decrease (or sulfide levels increase) to such an extent that aerobic organisms can not survive.

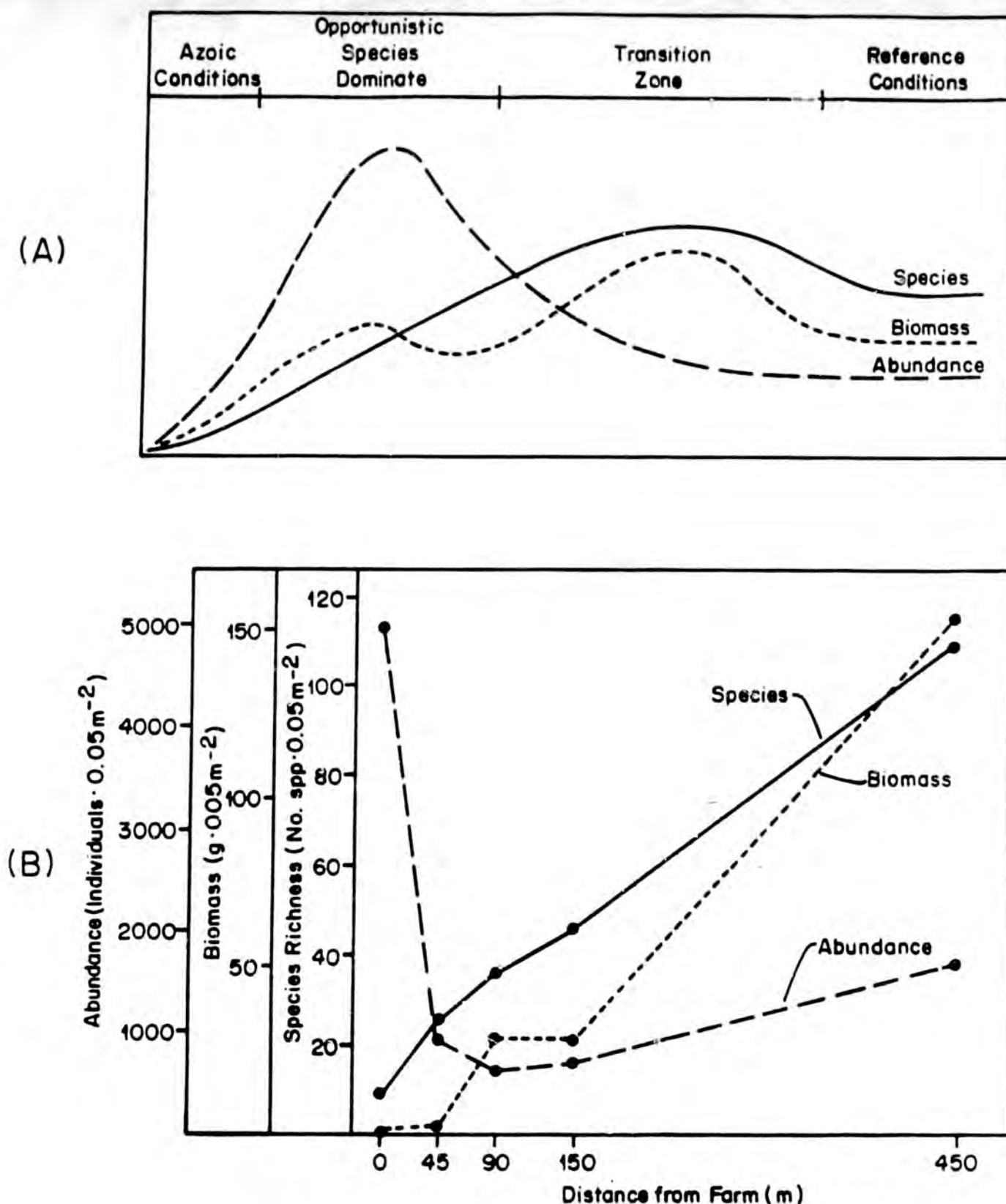


Figure 7. Trends in species richness, biomass and macrofaunal abundance along gradients of organic enrichment. (A) Generalized trends based on Pearson and Rosenberg (1978); (B) Data collected along transect CB1 at the Clam Bay farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

Trends in species number, abundance and biomass are shown along transect CB1 for comparison with the ideal model (Figure 7b). Total macrofaunal abundance was elevated 4-fold at the perimeter of the net-pen complex, and decreased to near background levels within 45 m. This peak in abundance was due almost entirely to the contributions of nematodes and the polychaete Capitella cf. capitata. Areal species richness increased consistently along the length of the transect. Biomass was much reduced to a distance of at least 45 m from the pens, for despite the high density of individuals, the organisms were relatively small. Moderate biomass levels were found between 90 and 150 m. The highest biomass was observed at 450 m from the pen site due to the appearance of several large deep-burrowing organisms including bivalves, sipunculans and echiurans.

Capitella cf. capitata is widely recognized as an indicator of organic enrichment and has been found in the vicinity of net-pens throughout the world (Kitamori, 1977; Pease, 1977; Ervik et al., 1985; Brown, 1987). The species was present in densities of over 12,000 indiv. $\cdot$ m⁻² adjacent to the net-pens, and remained in high densities up to 150 m or more from the farm site (Figure 8).

The macrofaunal data from Clam Bay are generally consistent with the ideal model of changes along an enrichment gradient. No azoic conditions were observed, although no samples were collected directly under the pen complex. The data indicate dramatic community alterations beneath the facility perimeter, including the disappearance of most species characteristic of undisturbed Clam Bay habitats. Moderate disturbance with gradually improving conditions was evident between 45 and 150 m from the farm. Normal conditions were reached at some point between 150 and 450 m from the farm.

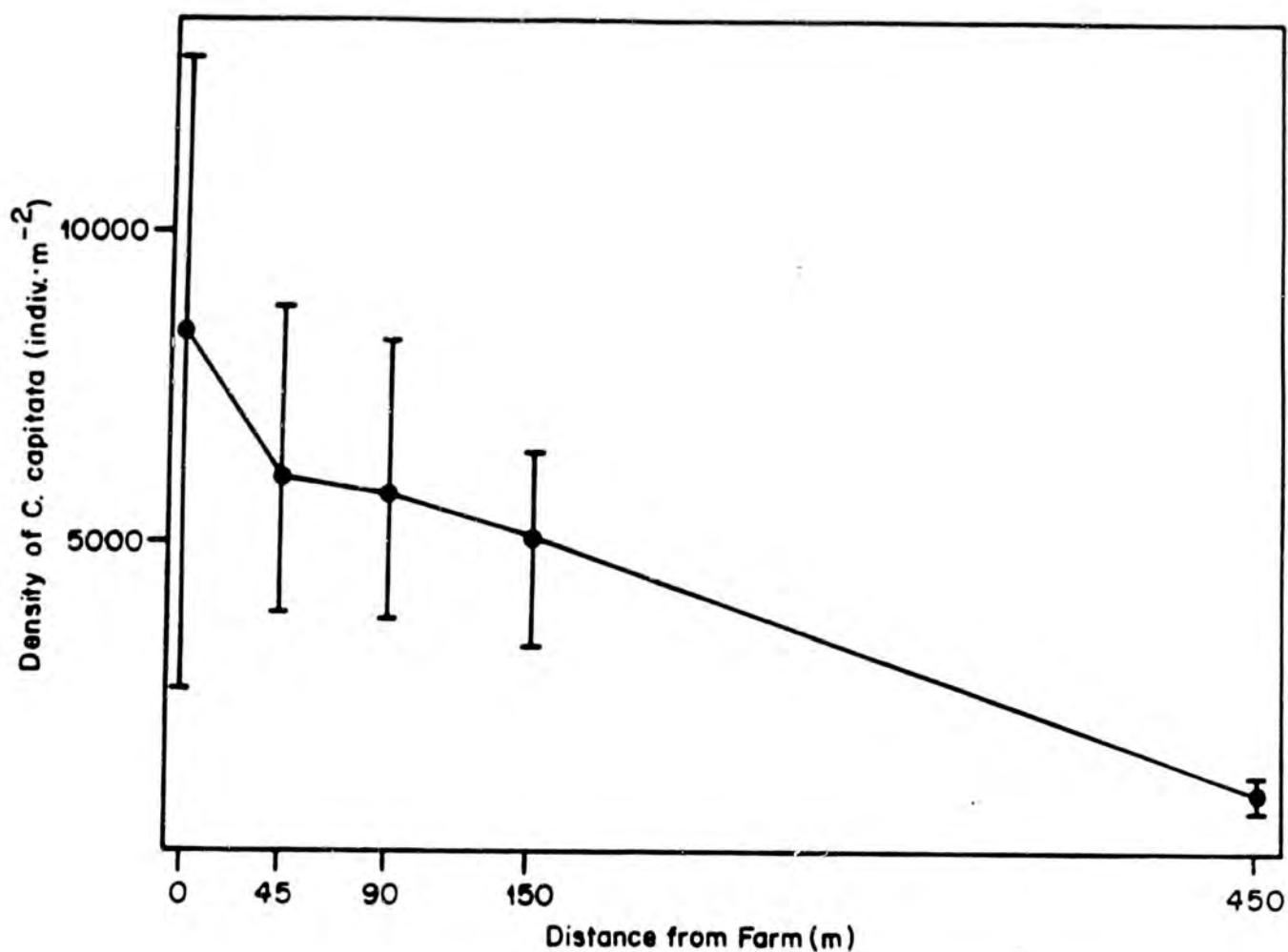


Figure 8. Density of the opportunistic polychaete *Capitella* cf. *capitata* along transect CB1 at the Clam Bay farm site. Vertical bars represent range of the three samples at each station.

Dispersion model

The sedimentation model was run based on the data of Table 3. Standing stock and feeding rate were provided by the farm operator, and based on monthly mean values of these parameters over the previous twelve months. The organic carbon content of the feed was measured directly as was the settling velocity of the feed pellets. Settling velocity of feces was taken from the literature (Warrer-Hanson, 1982). Literature values of feed wastage range from 1 to 30% (VKI, 1976; Penczak, *et al.*, 1982; Braaten, *et al.*, 1983; Gowen, *et al.*, 1985), and lacking a measurement specific to the Clam Bay facility, a wastage of 15% was assumed arbitrarily.

The dispersion model predicted that the area directly under the net-pens would be subject to the greatest rate of solid waste deposition (Figure 9). Areas to the north and west of the farm should receive very little feed and fecal matter, with the vast majority of the material moving towards the south and east. The area delimited by the $1 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ isopleth extends 70 m from the farm at its most distant point.

There is extraordinary agreement between the rate of organic carbon flux predicted by the model and that measured in the sediment traps. Directly under the net-pens at the trap location the predicted rate is $11.1 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$, in comparison to the measured rate of $13.3 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$. At the northwest corner of the farm site the predicted and measured rates were 2.5 and $3.6 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, respectively.

The dispersion model predicts a deposition rate, and thus a rigorous test of the model would also require rate measurements, such as those obtained from the sediment traps. In the strict sense, a static measurements such as organic carbon concentration or redox potential can not be used to test the model since no information is available on *in situ* post-depositional processes. Nevertheless, since sediment trap data were so limited, the assumption was made that post-

Table 3
Data used in dispersion model at the Clam Bay farm site

Farm size:	280 m by 52 m with long axis oriented east-west
Depth of pens:	4 m
Standing stock:	352 metric tons
Feeding rate:	4409 kg·day ⁻¹
Organic carbon content of feed:	48%
Feed wastage:	15%
Settling velocity of feed:	10 cm·sec ⁻¹
Settling velocity of feces:	4 cm·sec ⁻¹
Water depth (approx. average of MLLW and MHHW along sampling transects):	18 m
Current data:	July 6 - August 4, 1988; meter located 100 m east of farm site.

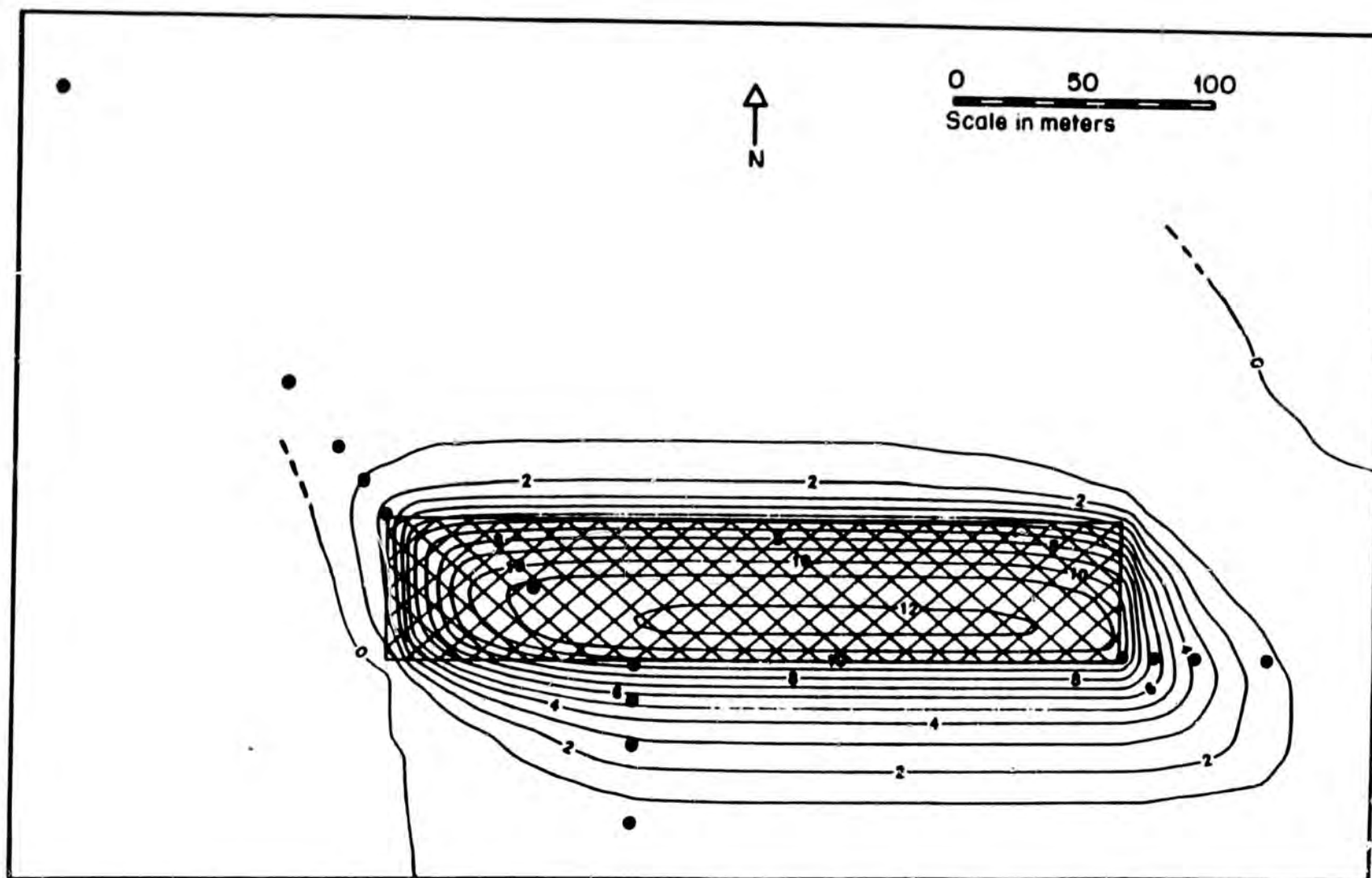


Figure 9. Model predictions of organic carbon loading to the seafloor at the Clam Bay farm site. Contour units are $\text{kg C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$. Dots indicate locations of sampling stations used for model verification.

depositional processes (e.g., mineralization, resuspension) were uniform throughout the study area, and a test was made of the model's ability to identify areas of greatest organic enrichment (Figure 10). There was a significant correlation between predicted deposition rates and measurements of both sediment organic carbon content and redox potential (Spearman rank correlation, $\alpha \gg 0.01$). The model, therefore, performed well in identifying those areas surrounding the Clam Bay farm which experienced the greatest degree of organic enrichment.

SQUAXIN ISLAND SITE

Sixteen stations were sampled in the vicinity of the Squaxin Island farm site (Table 4). Water depths in the area were uniformly 5 m at mean lower low water. The bottom of the net-pens were 2 m above the seafloor at this tidal stage and approximately 6.5 m above the seafloor at mean higher high water. Seawater temperatures were approximately 15°C; salinity was 30.5 ppt.

The substrate was principally silt with varying amounts of sand (14 - 30%) and shell fragments (1 - 40%). Shell debris was so dense at some sites that the collection of undisturbed sediment cores was difficult or impossible. There was no visible evidence of culture-related disturbance on the sediment surface (e.g., Beggiatoa mats, feed or fecal material).

Water Currents

Current meters were moored 60 m to the south and to the north of the eastern end of the net-pen complex. Both were positioned 2.5 m above the seafloor and 2.5 to 7 m below the surface (depending on tidal stage), and left in place from June 6 to August 5 1988.

Both meters showed strong north-south tidal oscillations,

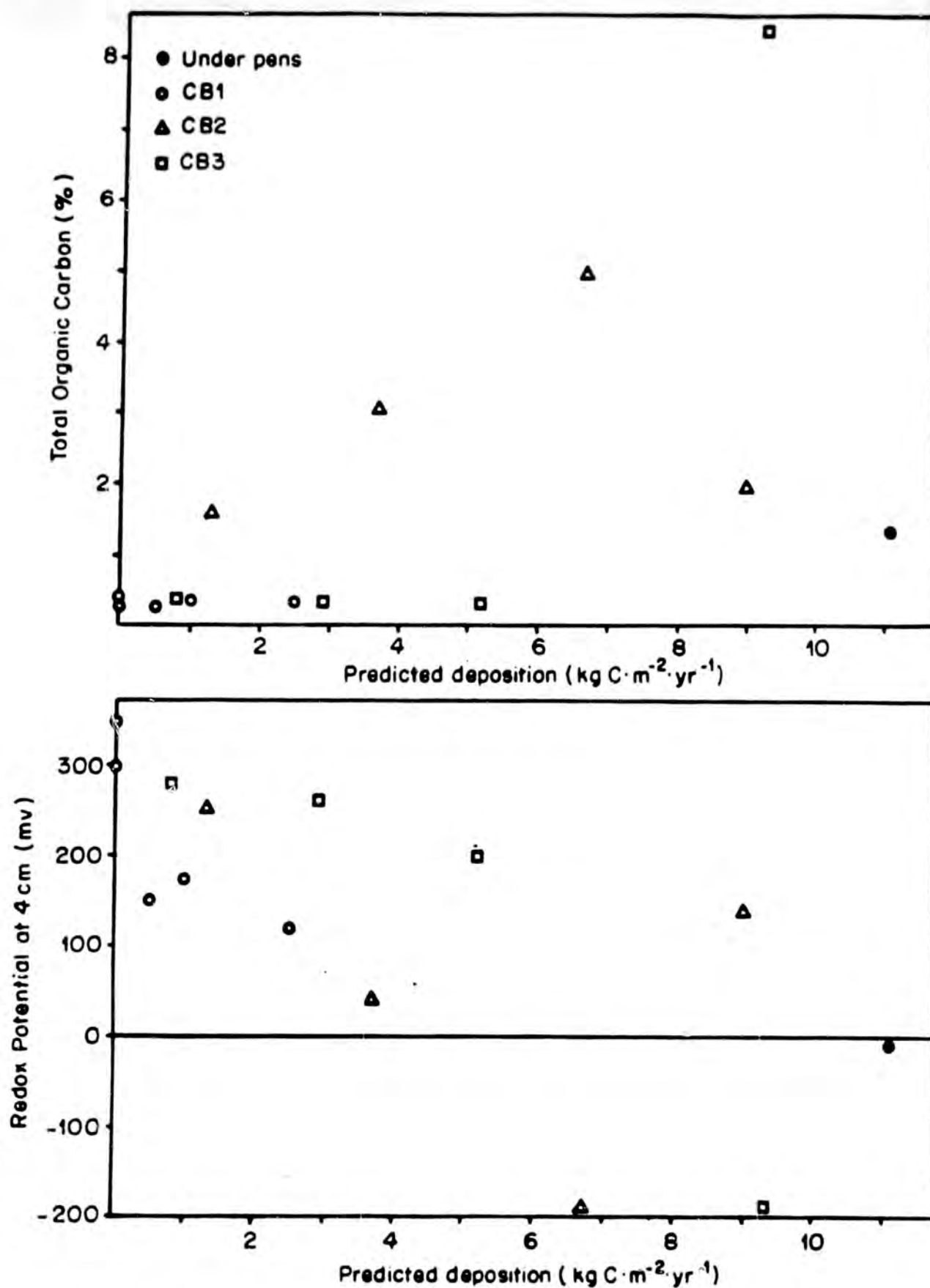


Figure 10. Comparisons of predicted carbon deposition based on the sedimentation model with field measurements of total organic carbon and redox potentials at the Clam Bay farm site.

Table 4
Squaxin Island station summary

<u>Station or Transect</u>	<u>Distance from net-pens (m)</u>	<u>Water depth (m at MLLW)</u>	<u>Substrate</u>
A	0	5	
Transect SQ1	0	5	1.1% shell/gravel 14.3% sand 84.6% silt and clay
	6	5	11.2% shell/gravel 13.6% sand 75.2% silt and clay
	15	5	3.1% shell/gravel 16.9% sand 80.0% silt and clay
	30	5	2.8% shell/gravel 18.0% sand 79.2% silt and clay
	60	5	46.4% shell/gravel 32.2% sand 21.4% silt and clay
	100	5	
Transect SQ2	0	5	
	6	5	
	15	5	
	30	4	41.2% shell/gravel 29.8% sand 29.0% silt and clay
Transect SQ3	0	5	
	6	5	
	15	5	
	30	5	
	60	5	0.4% shell/gravel 17.3% sand 82.3% silt and clay

with the southerly flow predominating (Figure 11). A significant westerly component was evident only in the meter located south of the farm site. The constancy factors were 90.9 and 83.3% for the northern and southern locations, respectively. Current velocities at the northern site averaged $6 \text{ cm} \cdot \text{sec}^{-1}$ over the 60 day deployment with a maximum recorded velocity of $31 \text{ cm} \cdot \text{sec}^{-1}$. Current velocities of 15 to $18 \text{ cm} \cdot \text{sec}^{-1}$ were generally observed at least twice daily. Currents at the southern meter location were slightly slower, averaging $7 \text{ cm} \cdot \text{sec}^{-1}$ with a maximum recorded velocity of $23 \text{ cm} \cdot \text{sec}^{-1}$.

Sediment chemistry

Sediments at the Squaxin Island farm were much finer-grained than at the Clam Bay facility, and thus had considerably greater levels of organic carbon and total nitrogen. Sediment carbon concentrations were typically 2 to 3% at the Squaxin site in comparison to 0.3% in undisturbed areas of Clam Bay. The Squaxin site also differed from Clam Bay in that there were no gradients in sediment carbon or nitrogen concentration that could be attributed to farm activities (Figures 12 and 13). The degree of sediment enrichment was more or less uniform throughout the study area, and the slight variations were unrelated to farm proximity. There was no evidence of sediment enrichment above background levels even directly under the net-cages. One sample collected at the southern pen perimeter showed an organic carbon concentration approximately triple typical values, but this high concentration was not reflected in the two other samples at the same station.

Sediments at a depth of 4 cm (and probably much shallower) were highly reducing due to the fine grain size and reduced porosity of the Squaxin Island sediments (Figure 14). Reduction-oxidation potentials at the sediment-water interface ranged from 50 to 425 mv. This extreme variability is probably a consequence in the sharp gradient of redox potentials

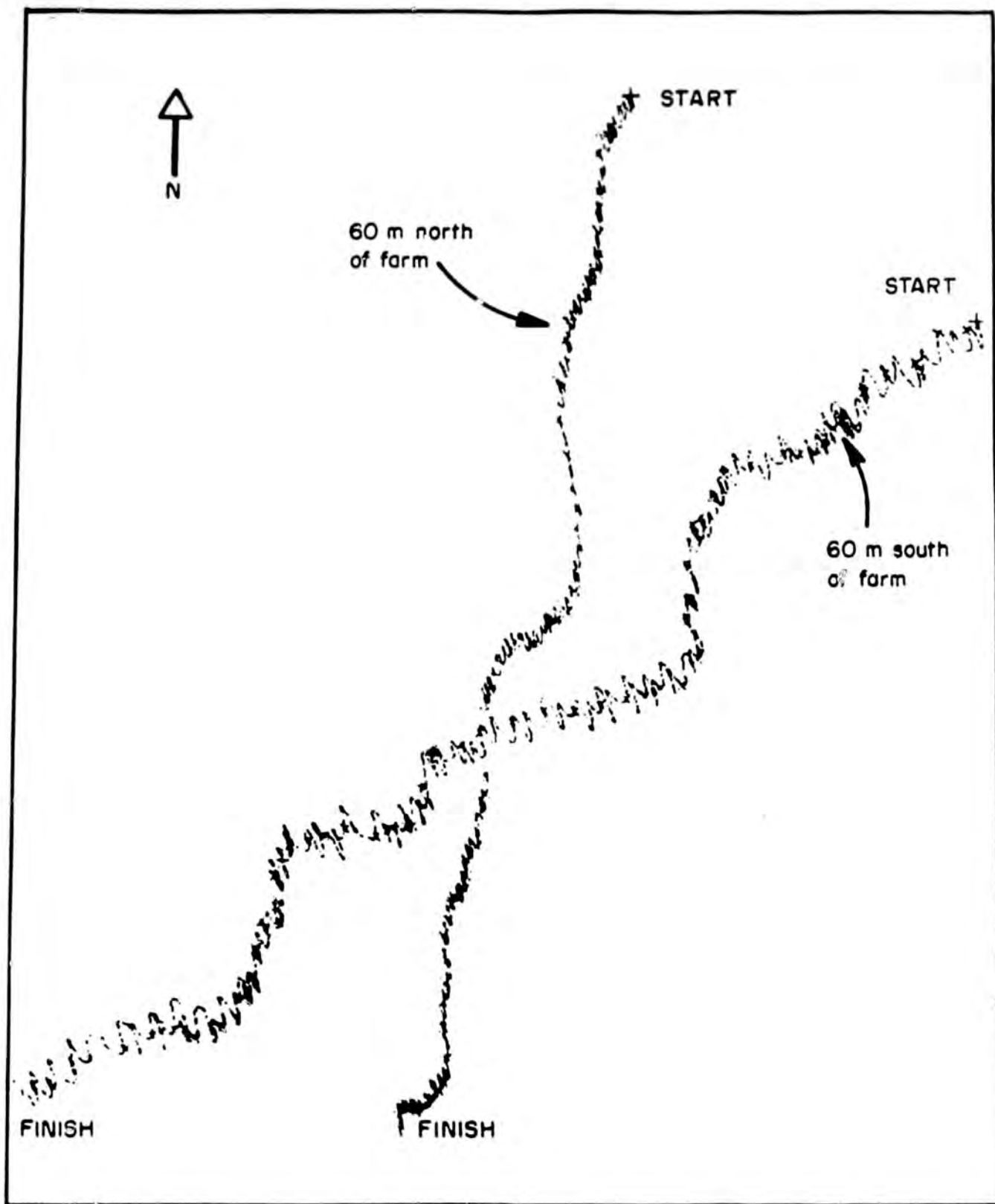


Figure 11. Progressive vector diagrams based on the two current meter records from the Squaxin Island site. X symbols indicate 24-hour intervals.

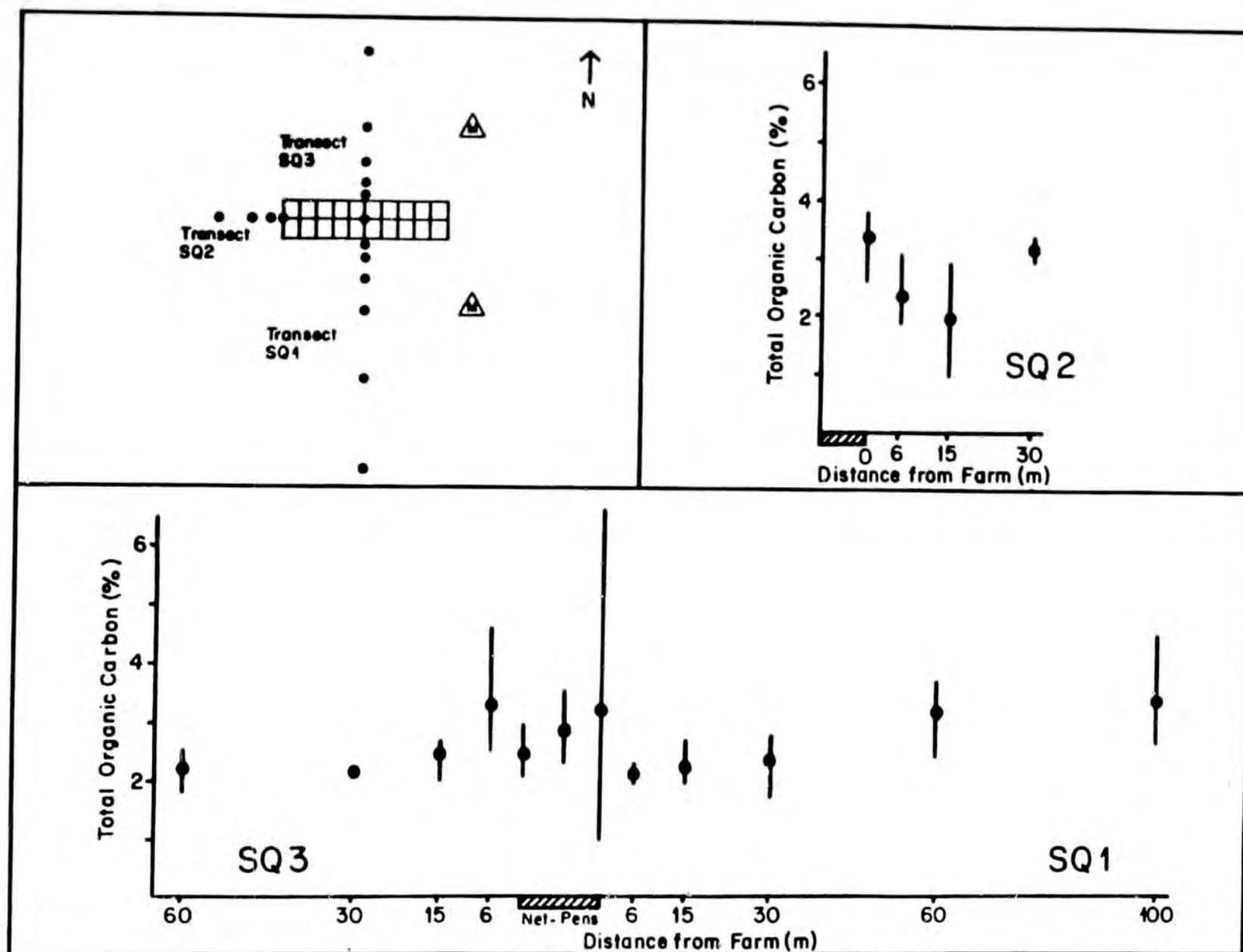


Figure 12. Total organic carbon concentrations in sediments surrounding the Squaxin Island farm. Range bars not shown if the range is less than the size of the mean symbol.

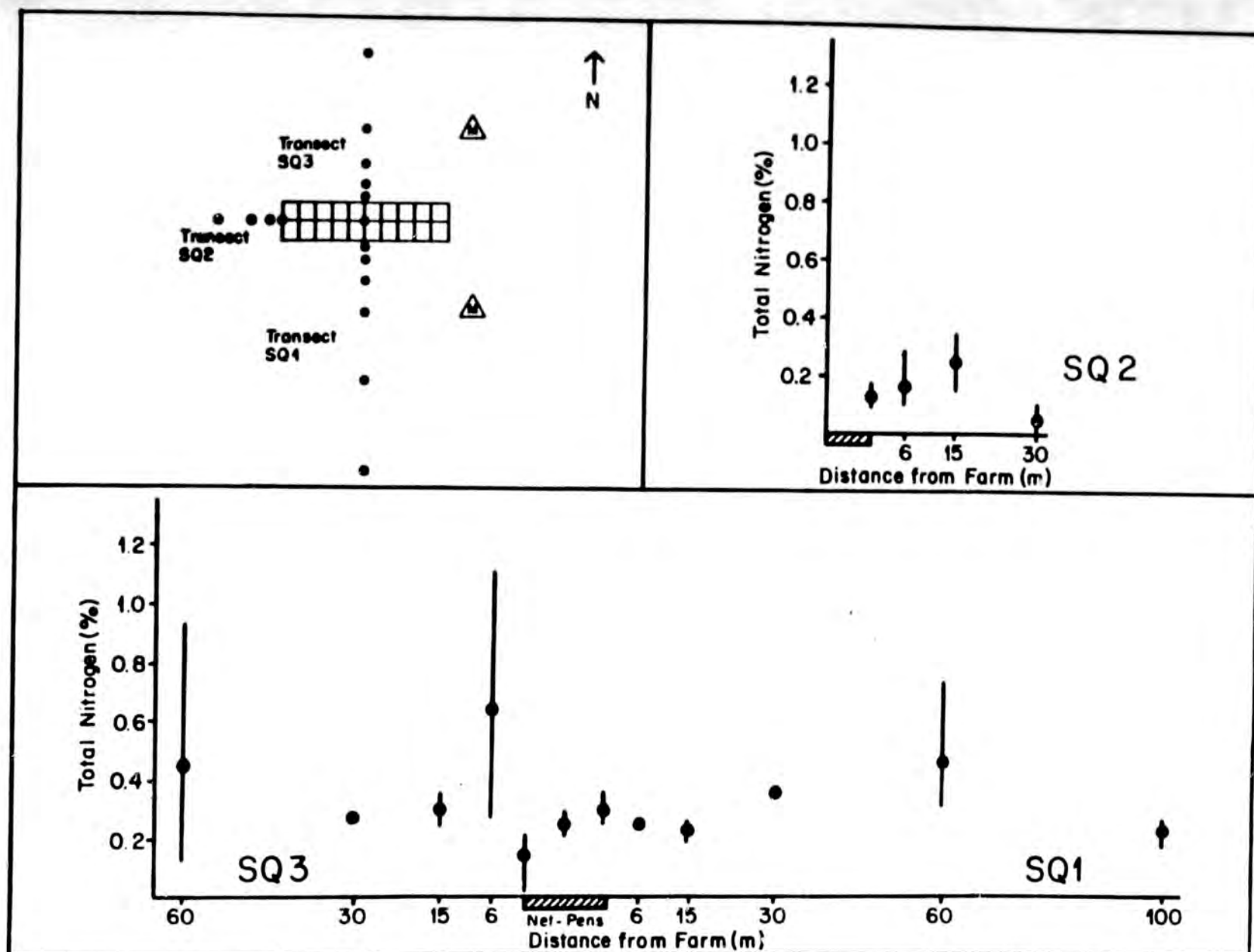


Figure 13. Total nitrogen concentrations in sediments surrounding the Squaxin Island farm. Range bars not shown if the range is less than the size of the mean symbol.

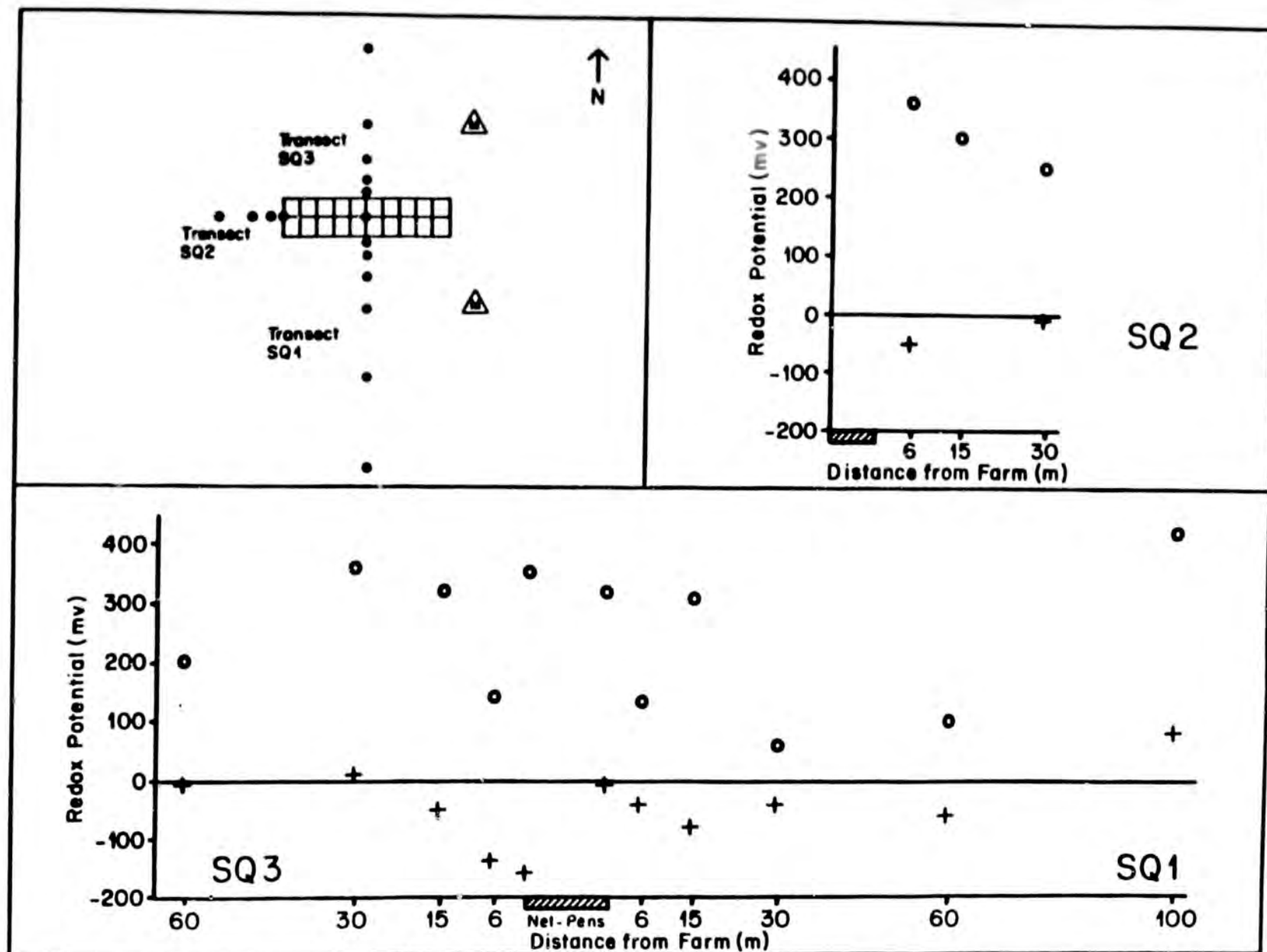


Figure 14. Reduction-oxidation potentials in sediments surrounding the Squaxin Island farm. Open circles represent potentials at the sediment-water interface; cross symbols represent potentials at a depth of 4 cm in the sediment.

in the upper few millimeters of the sediment column, and thus the measured potential can vary widely depending upon whether the probe is held a millimeter or two above or below the ill-defined "interface". Variability of the redox potential at a depth of 4 cm is probably due to the difficulty of collecting an undisturbed core with the high concentration of shell fragments, compounded by the difficulty of inserting the probe into the core without encountering an obstruction and further disturbing the core.

Redox potentials showed no pattern among the sampling stations that could be attributed to the presence of the farm. Unlike in Clam Bay, redox potentials were not consistently lower near the net-cages, except perhaps along transect SQ3.

Dissolved oxygen

Dissolved oxygen concentrations at 5 to 10 cm above the substrate were typically about $10 \text{ mg} \cdot \text{l}^{-1}$, and showed no depression near the farm site (Figure 15). Two samples had an unexpectedly high dissolved oxygen concentration indicative of either analytical error or an abrupt gradient in dissolved oxygen with distance above the seabed. The same qualifications expressed at Clam Bay regarding non-synoptic sampling apply here as well, but it does appear that farm activities are not depleting oxygen in the near-bottom waters.

Sediment traps

Seven sediment trap arrays were placed at the stations along transect SQ1, but only four could be recovered after the 15-day deployment (Table 5). Results from the array directly under the pens are problematic in that these traps captured only half the material of the other traps, and the material retained was comparatively low in organic carbon content. Since the mouths of the traps were only 1.5 m below the bottom of the net-pens at MLLW it was expected that a large amount of

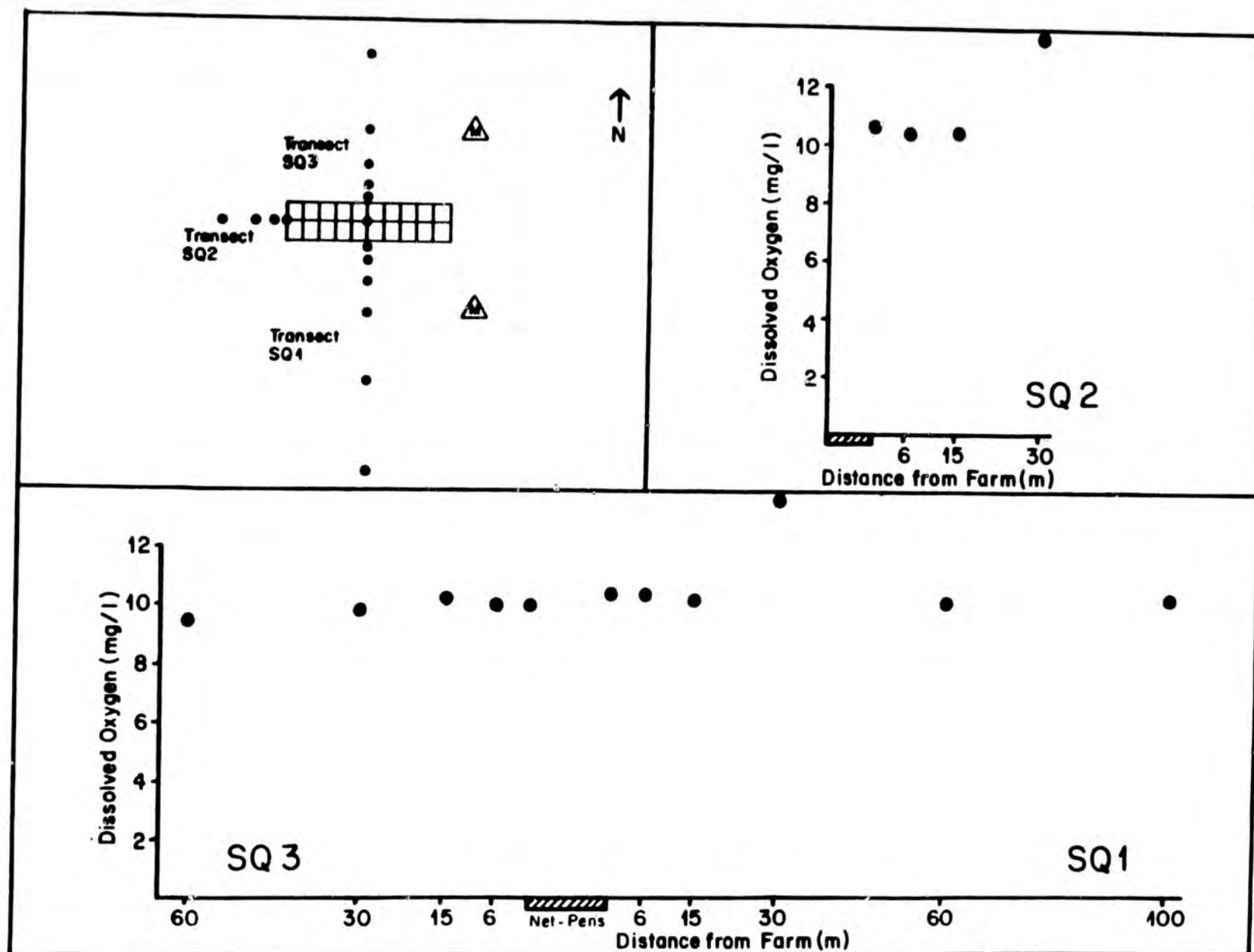


Figure 15. Dissolved oxygen concentrations in near-bottom water surrounding the Squaxin Island farm site.

Table 5
Sediment trap contents at the Squaxin Island farm
(Six measurements at most stations)

Distance from pens (m)	Sedimentation rate (kg·m ⁻² ·yr ⁻¹)	Nitrogen content (%)	Carbon content (%)	Carbon flux (kg·m ⁻² ·yr ⁻¹)
under pens	62.8	0.75	6.12	3.8
	65.2	1.29	7.85	5.1
	59.4	0.56	5.02	3.0
	58.0	0.63	5.19	3.0
	38.9	0.85	7.43	2.9
	<u>41.1</u>	<u>0.99</u>	<u>7.62</u>	<u>3.1</u>
MEANS	54.2	0.84	6.54	3.5
0	115.7	0.49	4.56	5.3
	88.0	0.43	3.95	3.5
	113.4	0.99	8.72	9.9
	<u>119.7</u>	<u>0.66</u>	<u>6.23</u>	<u>7.5</u>
MEANS	109.2	0.64	5.87	6.6
15	109.1	0.42	4.71	5.1
	118.4	0.39	4.21	5.0
	116.9	0.51	4.40	5.1
	111.3	0.64	4.15	4.6
	99.4	0.85	6.79	6.7
	<u>106.0</u>	<u>0.60</u>	<u>5.20</u>	<u>5.5</u>
MEANS	110.2	0.57	4.91	5.3
30	112.4	0.47	3.95	4.4
	98.9	0.35	2.13	2.1
	106.9	0.40	3.70	4.0
	108.7	0.48	5.22	5.7
	109.2	0.34	2.57	2.8
	<u>107.7</u>	<u>0.27</u>	<u>1.64</u>	<u>1.8</u>
MEANS	107.3	0.39	3.20	3.5

organic-rich material would have been collected. It is possible that this array may have become entangled in its own rope or in the nets during a very low tide, and turned on to its side at some time prior to recovery. This was the only array retrieved by a rope rather than by diver, and thus it is not known if it was properly positioned at the time of recovery.

On the basis of data from the other sediment traps, the sedimentation rate was about $110 \text{ kg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in the area from the farm perimeter to a distance of 30 m. Lacking data from greater than 30 m from the farm, it is difficult to establish whether the measured sedimentation rate reflects natural conditions or an enhanced sedimentation due to the presence of the farm. The organic carbon and nitrogen content of the trapped material was significantly different among traps (Kruskal-Wallis one way analysis of variance, $\alpha < 0.05$), and, in fact, the traps nearest the pens contained solids with a higher concentrations of both organic carbon and total nitrogen.

In comparison to the Clam Bay site, sedimentation rates at the Squaxin Island farm were two to three times greater (30 to $52 \text{ kg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ vs. 107 to $110 \text{ kg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$). The collected material at Squaxin Island, however, contained only half the carbon and nitrogen concentration of the Clam Bay material. The fact that Clam Bay traps contained material with a relatively high organic content (30 to 100 times greater than background levels in surficial sediments) suggests that the collected material was largely farm-derived. At the Squaxin site the measured sedimentation rate was relatively high, yet since the organic content of the trapped material was only slightly greater than background concentrations in surficial sediments (1.5 to 2-fold), it is likely that the bulk of the collected material originated from natural sources.

Macrofauna

Macrofauna samples have been collected at most stations along transect SQ1 as part of routine monitoring by the farm operator. Baseline samples were collected in January 1987 after installation of the pens but prior to stocking with fish. Additional samples were collected in August 1987, January 1988, and August 1988. Intercomparisons among sampling events is complicated by variations in sample design between sampling periods and between replicates. In January 1987 each station was sampled with 3 cores of 5 cm diameter, each of which was sieved through a 0.5-mm screen. In all other sampling periods 10 cm diameter cores were used, two of which were sieved on a 1.0-mm screen and one of which was sieved on stacked 0.5 and 1.0-mm screens. Therefore, when comparing among sampling periods it should be recognized that the January 1987 sampling would tend to under-estimate species richness and abundance because of the smaller area sampled, but over-estimate these parameters because of the finer mesh size. All data are expressed on a "per three sample basis" which, in all but the January 1987 sampling, should be interpreted to include the material retained on a 1.0-mm screen in two samples per station and on a 0.5-mm screen in one sample.

baseline samples (1/87) and those collected after 6 months of operation (8/87) demonstrated that the five monitoring stations were comparable in species richness and faunal composition and thus suitable for inter-station comparisons (Figure 16). In January 1988 after 12 months of operation there was a dramatic decrease in the species richness and abundance at the station under the perimeter of the pens and, to a lesser extent, at the station 6 m from the pens. This same decrease near the pens relative to the other stations along the transect was evident again after 18 months of operation (8/88). At this time macrofauna present under the pen perimeter included only the polychaetes Capitella cf. capitata (4 individuals), Nephtys cornuta fransiscana

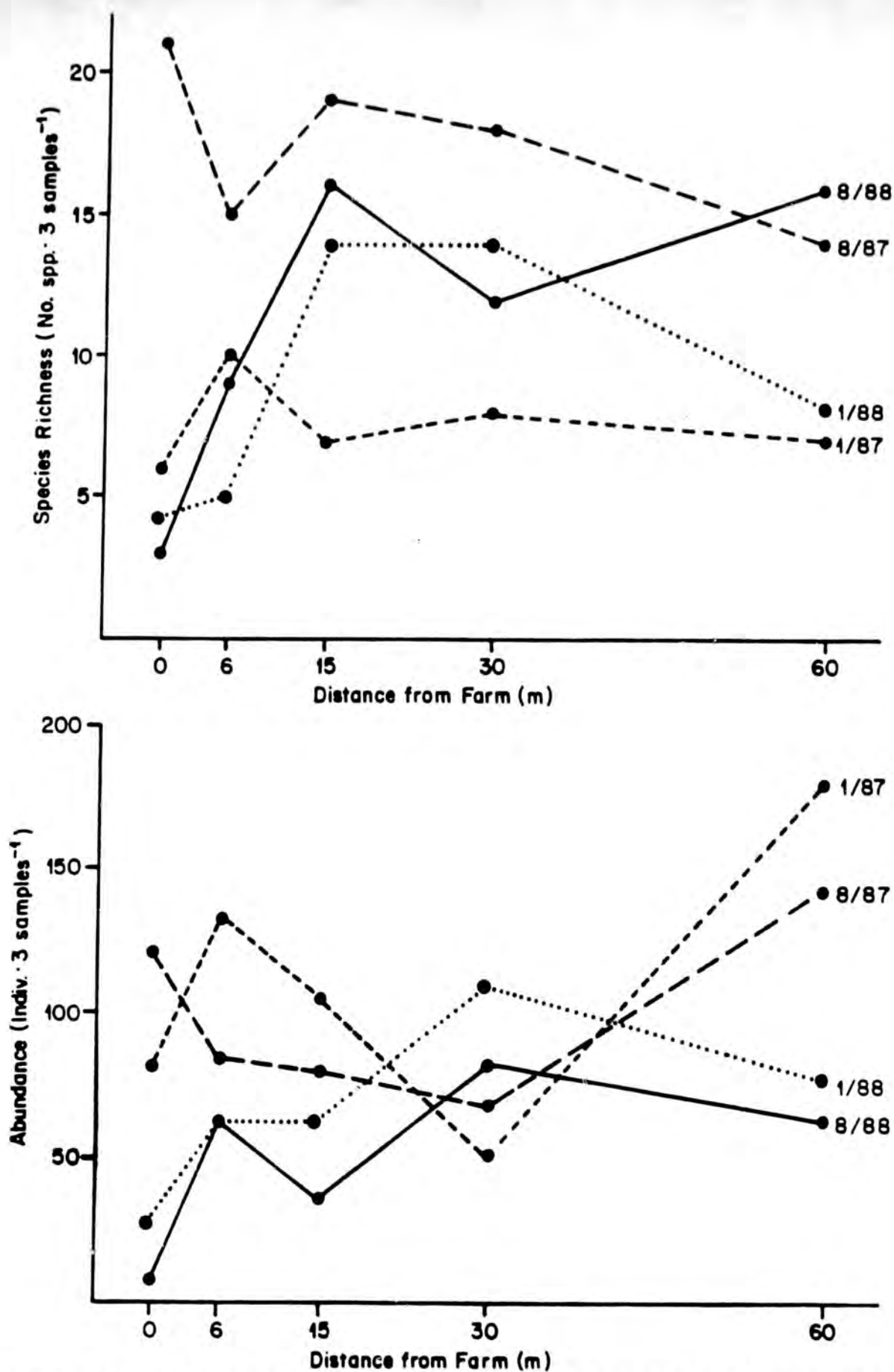


Figure 16. Trends in species richness and macrofaunal abundance along transect SQ1 at the Squaxin Island farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

(3 indiv.) and Glycinde picta (1 indiv.). The depauperate fauna 0-6 m from the pens, an area which was formerly comparable to the other sites, indicates a localized impact of farm operation.

The distribution of Capitella cf. capitata (Figure 17) also suggests enrichment 0-6 m from the pen perimeter. No C. capitata were found throughout the sampling transect during the baseline sampling (1/87). In all subsequent sampling periods, however, the species has been found in high densities at the 6 m site and at much lower densities at the pen perimeter and 15 m. Maximum density (945 individuals per three replicates, or $1875 \text{ indiv} \cdot \text{m}^{-2}$) was obtained in the most recent sampling (8/88).

Dispersion model

The dispersion model was run using the data of Table 6. The standing stock value used was based on the biomass present at the time of sampling. This value may seasonally vary by up to 50% depending on stocking and marketing cycles. No data were available on the actual amount of feed provided, so it was assumed that the fish were fed at a rate of 2% of their body weight per day, a rate typical of salmonid net-pen culture and the target rate of the Squaxin pen operators. All other model parameters were determined as described for the Clam Bay farm.

As a result of the shallow water depths, the sedimentation model predicted that the vast majority of feed and fecal waste would reach the bottom directly under the pens or within 5 m of the farm perimeter (Figure 18). A maximum loading rate of $14 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ was predicted for most of the area under the farm. Lesser rates of deposition were predicted to the north and south, with essentially no accumulation of wastes to the east and west. Loading rates of $1 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ or greater were limited to the area 15 m north and 28 m south of the farm site.

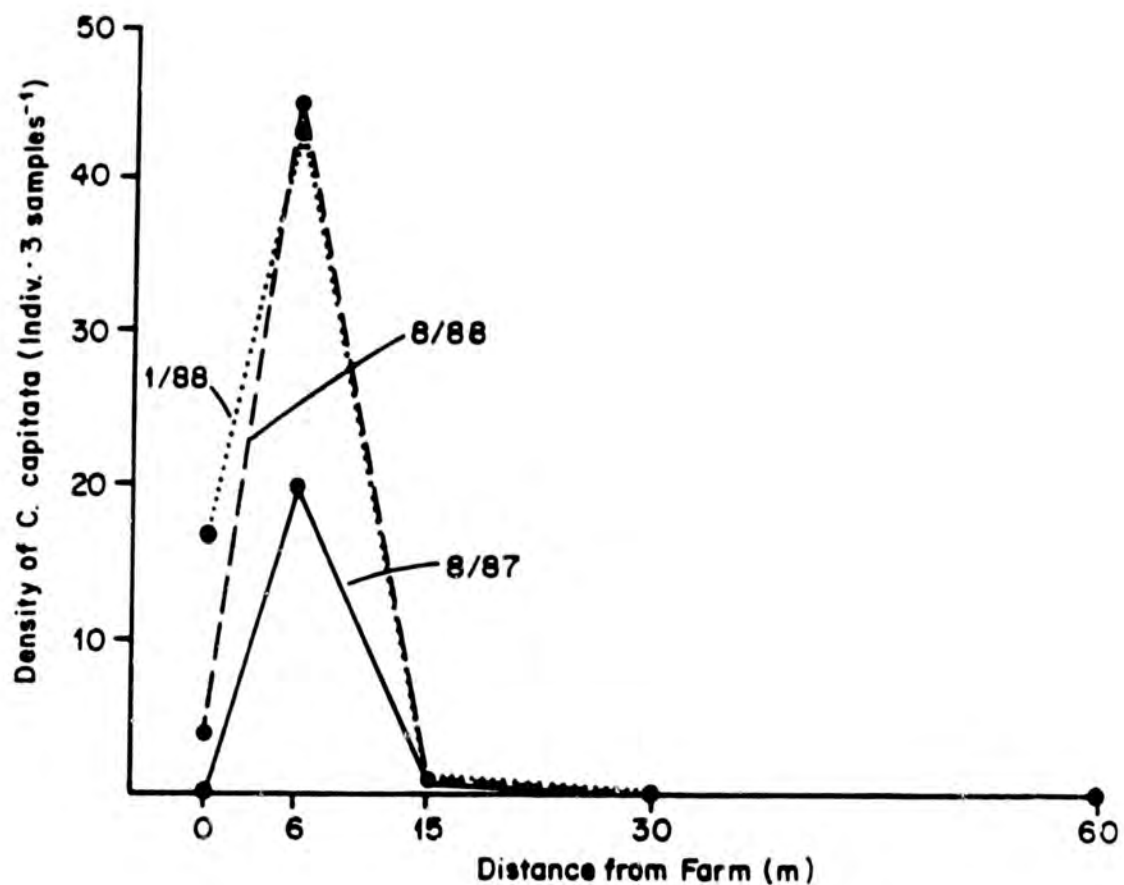


Figure 17. Density of the opportunistic polychaete Capitella cf. capitata along transect SQ1 at the Squaxin Island farm site. Inter-replicate variability is not shown in order to simplify the graphical presentation.

Table 6
Data used in dispersion model at the
Squaxin Island farm site

Farm size:	74 m x 16 m with long axis oriented east-west
Depth of pens:	3 m
Standing stock:	20 metric tons
Feeding rate:	400 kg·day ⁻¹
Organic carbon content of feed:	50%
Feed wastage:	15%
Settling velocity of feed:	14 cm·sec ⁻¹
Settling velocity of feces:	4 cm·sec ⁻¹
Water depth (approx. average of MLLW and MHHW along sampling transects):	7 m
Current data:	June 6 - August 5, 1988; meter located 60 m north of farm site.

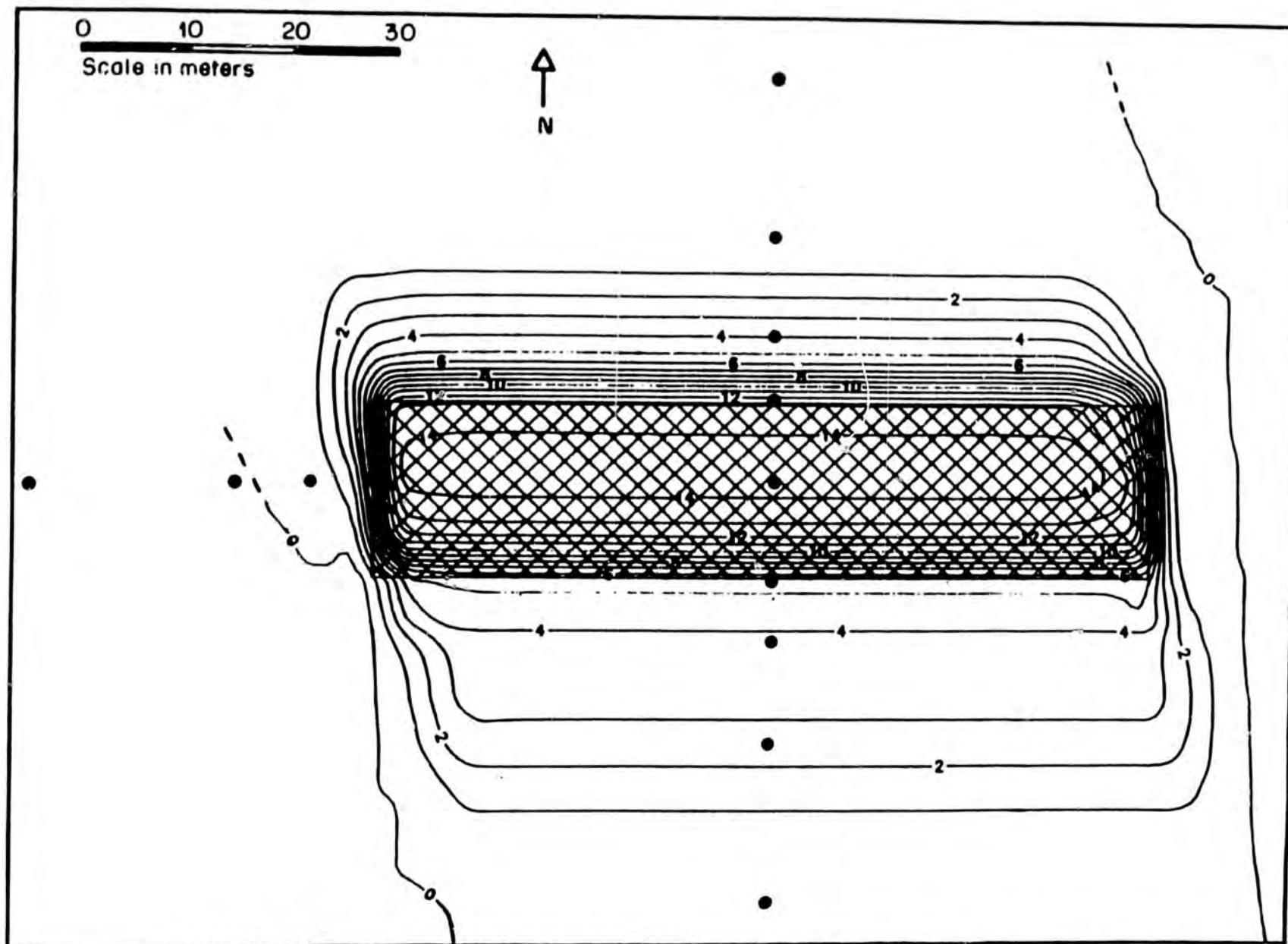


Figure 18. Model predictions of organic carbon loading to the sea-floor at the Squaxin Island farm site. Contour units are $\text{kg C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$. Dots indicate locations of sampling stations used for model verification. Stations 60 and 100 m from farm are not shown.

The predicted carbon fluxes at 0, 15 and 30 m south of the farm were 5.7, 2.5 and $<1 \text{ kg C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$, respectively. Over the same distance actual rates of carbon flux as measured by the sediment traps were 6.6, 5.3 and $3.5 \text{ kg C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$. It should be recognized, however, that the model predicts deposition of solid wastes originating from farm activities, whereas the sediment traps do not differentiate between farm-derived particulates and deposition unrelated to the culture operation. It was noted above that the bulk of the material collected in the traps at the Squaxin Island site probably originated from natural sources such as resuspension of bottom sediments or terrigenous run-off. A true test of the model would require that the contribution of the natural sources be subtracted from the total material retained in the traps. The strength of the natural "noise", however, is so great compared to the pen "signal", that many more traps would have to be deployed to discriminate between these two sediment sources. The traps located farthest from the farm (60 and 100 m), which presumably would best represent the natural carbon flux, were not recoverable, so the magnitude of carbon flux typical for the area may be substantially less than the $3.5 \text{ kg C}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ measured at the 30 m trap. Model predictions vary from actual measurements by a factor of about 2 or less, depending on the particular trap and the assumed magnitude of the natural carbon flux.

The model was further evaluated by comparing predictions of deposition with sediment organic carbon concentration and redox potential (Figure 19). It should again be recognized that this comparison requires that the untested assumption be made that post-depositional processes are similar at all sampling sites. There was no significant relationship between model predictions and sediment carbon content, although predicted carbon flux was correlated with sediment redox potential (Spearman rank correlation, $\alpha > 0.05$). This correlation was largely attributable to the influence of the 0 and 6 m stations along transect SQ-3, an area which the model

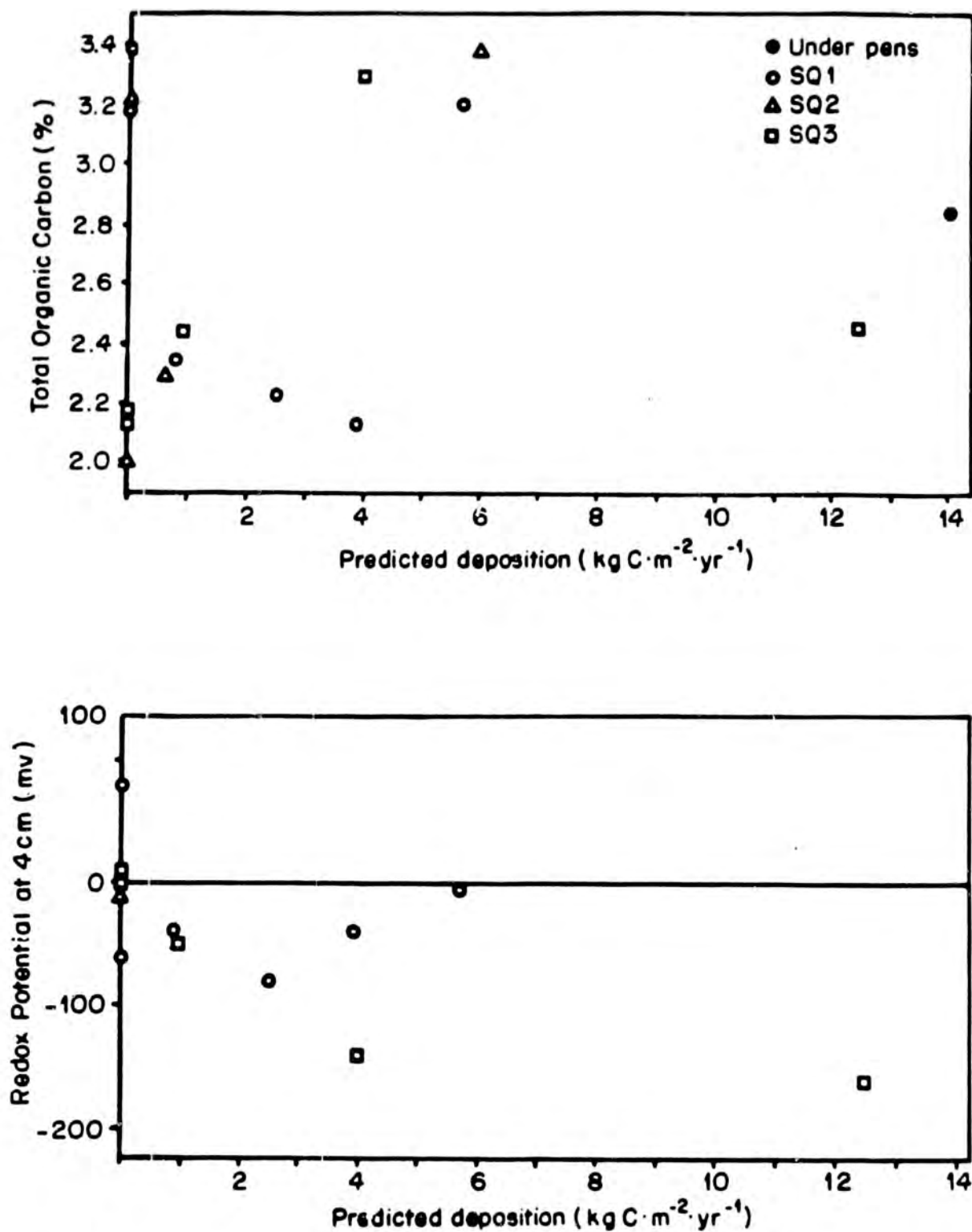


Figure 19. Comparisons of predicted carbon deposition based on the sedimentation model with field measurements of total organic carbon and redox potentials at the Squaxin Island farm site.

predicted to be among the most enriched and which also was found to have the lowest redox potentials.

DISCUSSION

CLAM BAY SITE

The various chemical parameters used to measure the effects of the farm operation on the sediments of Clam Bay showed good agreement, and provided a clear picture of the areal extent of impact. The culture of fish at the Clam Bay site has resulted in a measurable enrichment of the sediments directly under the pens and to a distance of approximately 30 m from the perimeter of the pens. The exact distance of impact depended upon the direction and the chemical parameter used as indicator of impact, but in all cases varied from 15 to 60 m. Within this area deposition of feed and feces has resulted in increased concentrations of total organic carbon and total nitrogen. Degradation of these organic wastes has depleted pore water oxygen, resulting in more negative reduction-oxidation potentials. At a few sites reducing conditions were found throughout the entire sediment column, although at most stations oxidizing conditions persisted to a depth of at least 4 cm. The enriched sediments did not measurably decrease oxygen concentrations in the overlying water at a height of 5 to 10 cm above the seafloor, although this does not exclude the possibility that reduced dissolved oxygen levels may be observed if measurements had been made on a scale of millimeters rather than centimeters.

The biological data (available only to the northwest of the farm) showed a severely disturbed community at the pen perimeter. This assemblage was comprised almost entirely of nematodes and Capitella cf. capitata. If the assumption could be made that a similar fauna existed wherever organic carbon concentrations were comparable (and given similar substrate type), then such a community might also be found 15 to 30 m south of the pens and at least 60 m to the east. Beyond this zone of severe disturbance, moderate effects of the farm were

evident in communities 45 to 150 m from the site. This area was characterized by reduced species richness, biomass, and C. capitata densities in excess of 5000 indiv. $\cdot$ m⁻².

All previous studies of the benthic effects of net-pen farming have reported localized impacts comparable to those found at Clam Bay. Brown et al. (1987) found normal conditions appearing at some point between 15 and 120 m from a farm in Scotland. In a survey of numerous Scottish farms, effects such as depressed reduction-oxidation potentials and appearance of Beggiatoa were commonly found up to 30 m from the farm site (Earll et al., 1984). Doyle et al. (1984) found effects extending 25 to 45 m from a site in Ireland. The extent of effects at the Clam Bay site is comparable to these earlier studies based solely on sediment chemistry as a measure of effect. The biological indicators of disturbance, however, suggest effects extended to at least 150 m from the farm, approximately five times the distance typically reported.

SQUAXIN SITE

The effects of the Squaxin Island site on the benthos were more subtle and evident almost entirely on the basis of the biological data alone. There was little or no evidence of farm effects in the sediment organic carbon, nitrogen, redox, and dissolved oxygen data. One of the three samples collected below the southern pen perimeter showed a three-fold enrichment in organic carbon, but since such enrichment was not evident in the other samples at this site, the effects were presumably very patchy. The best physical/chemical evidence of farm impacts was provided by the elevated concentrations of organic carbon and nitrogen in material collected by the sediment traps nearest the pens. The macrofaunal data indicated reduced species richness and/or abundance from the pen perimeter to a distance of 6 m, and a peak in C. capitata abundance at a distance of 6 m. C. capitata, an indicator of enriched sediments, first appeared in the area 6 months after

culture began, and was increasingly abundant 12 and 18 months after the initiation of culture. For comparison, Brown et al. (1987) reported changes in sediment chemistry and appearance of *C. capitata* 3 months after initiation of culture in a Scottish loch. Mattson and Linden (1983) monitored benthic conditions after installation of mussel longlines and found a period of 6 to 15 months were required for replacement of the original fauna with an assemblage characteristic of enriched conditions.

The limited measurable physical/chemical effects of culture and the highly localized biological effects at the Squaxin site are surprising given that the bottom of the pens are only 2 m above the seafloor at low tide. There are two possible explanations for this observation. First, the current velocities at the Squaxin site are surprisingly high, and only slightly less than near-bottom currents at Clam Bay. The 15 to 18 $\text{cm}\cdot\text{sec}^{-1}$ measured twice daily at the Squaxin site may promote dispersal of the solid wastes, particularly if the narrow distance between the nets and the seafloor promotes a channeling effect and an acceleration of currents directly under the pens. Secondly, the Squaxin pens have only been in place for 18 months in comparison to approximately 13 years for the Clam Bay farm. Benthic conditions at the Squaxin site may continue to deteriorate with time, but a recent change in farm operation may slow or halt this deterioration. The operators of the Squaxin site have recently decided to curtail aquaculture operations and use the pens primarily for delayed release. The seasonal nature of use should minimize further effects on the benthos.

ASSESSMENT TECHNIQUES

It should be noted that at both Clam Bay and the Squaxin sites, the macroinfaunal data showed evidence of alteration in areas where sediment chemistry data failed to show farm effects. Biological data appeared to be a more sensitive

indicator of disturbance, and therefore suggest that chemical information alone can not adequately define the extent of benthic impacts from net-pen culture. The biota are certainly better integrators of temporal variation, and they also undoubtedly are responding to chemical and physical parameters unmeasured in conventional surveys.

The reduction-oxidation measurements proved valuable, particularly at the Clam Bay site where redox potentials closely mirrored gradients in organic carbon and nitrogen. Redox measurements have several advantages over carbon and nitrogen analysis, most notably the fact that results are obtained in the field immediately after sampling and there are no analytical costs once the pH meter and redox electrode are acquired. Redox measurements worked well in the sandy sediments of Clam Bay where vertical gradients in sediment redox potentials were gradual, but were more problematic in the muddy sediments of the Squaxin sediments. In these fine-grained sediments much of the vertical change in redox potentials occurs in a thin veneer of sediments at the sediment-water interface. Measured potentials (and the identification of culture effects) become highly susceptible to minute variations in the extent to which the probe is inserted. Conventional redox probes are approximately 1 cm in diameter and do not permit the fine-scale resolution necessary in muddy sediments. Micro-electrodes are available, but are expensive and subject to frequent breakage.

MODEL EVALUATION

The **dispersion** model was tested on its ability to predict: 1) the absolute loading of particulate wastes; and 2) the relative loading among numerous sites. The former evaluation was done by comparing the quantity of material retained in the sediment traps with the quantity that the model predicted would accumulate at the trap location. At the Squaxin site natural deposition made discrimination of the pen

contribution difficult, but the predicted loading appeared to differ from measured values by factors of 2 or less. In Clam Bay the predictions were in good agreement with the measured loadings, differing by factors of 1.2 and 1.4 in the two trap arrays.

It should be recognized that there are inherent difficulties of measuring actual carbon flux and there are many potential artifacts associated with the use of sediment traps (Butman, 1986). Nevertheless, if the sediment trap data can be taken as an accurate representation of actual carbon flux, then model errors of only 1 to 2-fold demonstrate remarkably good predictive capability of the model.

The second test of the model was to compare predicted loadings at all stations with measured values of sediment carbon content and redox potential. At both farm sites the model predictions of carbon flux showed a statistically significant correlation with redox potential. Sediment carbon content was correlated with model predictions only at the Clam Bay site. The better model performance at Clam Bay than at Squaxin Island was probably due to the greater amount of sediment resuspension at the latter site. The sediment trap data and the lack of pronounced physical/chemical gradients with distance from the farm both suggest a high degree of sediment transport and resuspension. Under such conditions it is not surprising that the sites predicted to have the greatest carbon input rate failed to show the highest levels of sediment enrichment. This illustrates the shortcomings of using static measurements (sediment carbon concentration) as a test of rate measurements (model predictions of carbon flux).

The model predictions were correlated with sediment redox potential at both of the sites examined, and with carbon concentration at one of the two sites. The performance of the model in Puget Sound is in general agreement with tests of the model in Scotland where, out of six farms, the model predictions correlated with measured redox potentials at all six farms and with carbon at two farms (Gowen *et al.*, 1988).

Ideally, the model should be capable not only of predicting the extent of chemical change in sediments but also the degree of biological disturbance. Such predictions are much more difficult for the biological effects of a given rate of carbon flux is likely to be habitat specific. Communities of sandy substrates may not respond to a given flux in the same manner as mud bottom communities. The model has not been refined to the point where reliable biological predictions are possible, but some preliminary observations have been made. In model tests in Scotland, it was found that severely disturbed sites, defined as containing four or fewer macro-faunal species, had predicted loadings of at least 1.8 to 4 kg C·m⁻²·yr⁻¹ (Gowen et al., 1988). At the Squaxin Island farm four or less species were found where the predicted loading was 5.7 kg C·m⁻²·yr⁻¹ and undisturbed communities were present where predicted loadings were 2.5 kg C·m⁻²·yr⁻¹ or less. At Clam Bay the fewest number of species (9) were found where the predicted deposition was 2.5 kg C·m⁻²·yr⁻¹, although more moderate impacts were evident at lower rates of carbon flux. Other than order-of-magnitude approximations, the existing data base is inadequate to determine a threshold carbon flux beyond which biological effects are likely. Nevertheless, such estimates may be possible with additional refinement of the model and recognition of the habitat-dependence of biological impacts.

The model has performed well in both Puget Sound and Scotland, yet it has inherent limitations which should be recognized:

- 1) As discussed earlier, the model does not take into consideration any post-depositional processes that may occur, or differences in the rate of these processes among sites. For example, the model only predicts the point at which a settling particle impacts the bottom and not any reuspension or transport that may occur later. Model predictions would be invalidated if the degree of

resuspension varied throughout the study area as might be the case with differing substrate types or pen-related alteration of current flow.

- 2) The model, as currently formulated, is incapable of coping with variations in bottom topography. At the Clam Bay site a single water depth (18 m) had to be assumed despite the fact that water depths varied from 10 to 30 m over the predicted area of deposition. The net effect is that in shallow areas the model over-estimates the lateral extent of deposition, and under-estimates the lateral extent in deep areas. This shortcoming could be remedied but would dramatically increase the computational requirements of the model.
- 3) An arbitrary assumption had to be made that feed wastage at both farm sites was 15%. Puget Sound farm operators typically claim a wastage factor of about 5%. The magnitude of predicted organic carbon loading to the bottom is dependent upon the degree of wastage assumed as demonstrated by Figure 20. (Note also in this figure the depth-dependence of the loading with reference to the limitation under point #2 above.) A reduction in the wastage factor from the 15% employed in this analysis to the 5% claimed by Puget Sound operators would result in a decrease in predicted organic carbon loading of about 15%. In fact, there is probably no reliable estimate of wastage in Puget Sound or throughout the industry in general. Until there are reliable estimates of feed wastage, neither this nor any other model will be able to predict loading with a high degree of accuracy. The wastage-dependence of loading shown in Figure 20 also illustrates the effect that the operator's feeding practices can have on waste production, and the environmental benefits to be gained by reducing wastage.

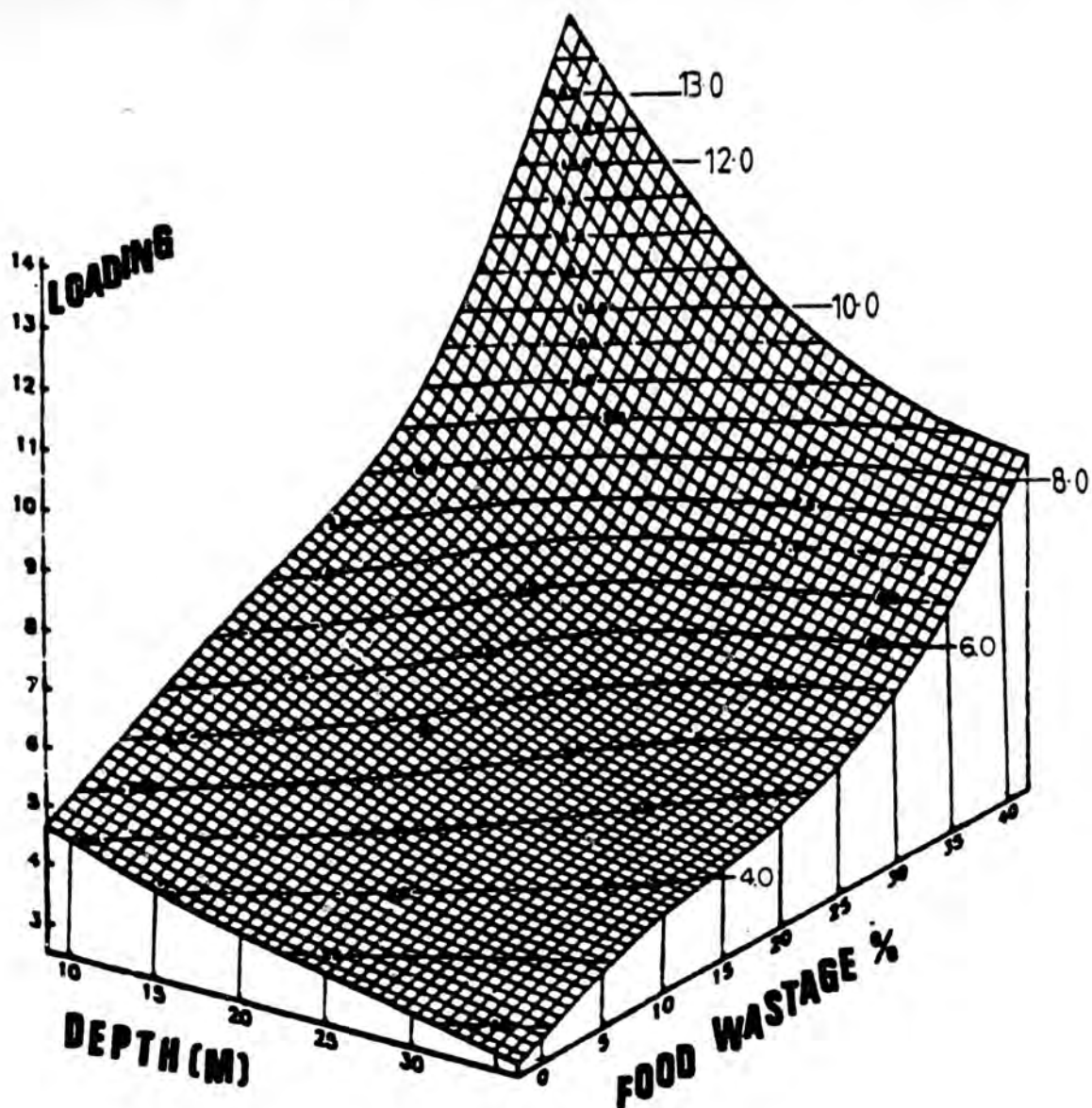


Figure 20. The relationship between food wastage, depth and organic loading to the sediment for a hypothetical set of current data. Loading rates are given as $\text{g C} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$. (From Gowen *et al.*, 1988).

- 4) The model requires the designation of a single settling velocity for feed and a second settling velocity for feces. As noted by Thomson (1986), however, the size and density of particulates released from a net-pen are likely to depend upon the species and size of the fish, the type and pellet size of the feed, and the amount of physical disturbance induced by either water current or fish activity. In addition to these potential variables, particulate wastes are not uniform in size or density, and thus can not be adequately characterized by a single settling velocity, or even the two velocities of the model. Settling velocities of culture wastes are best described by a frequency distribution, and the model therefore requires that a major oversimplifying assumption be made.
- 5) It is not possible to describe variations in the flow field attributable to the presence of the pen structures, and how these variations may influence deposition. If the model is used for siting in a pre-development stage, the installation of the pen structures may modify the predicted magnitude and distribution of waste loadings. The effect of pen installation on waste dispersion is, however, likely to be small in most cases particularly when the pens occupy a small proportion of the total water column.
- 6) The hydrographic input to the model is based on current records at a single point, and there is no allowance for changes of the flow field along a particle's trajectory. The current velocity and direction measured at the meter mooring may not be representative of current regimes on other sides of the farm complex or over the entire area of deposition. At the Clam Bay farm the two current meters gave very different pictures of current patterns. The model was run using data from the eastern meter since

this site would be less subject to the complications of bay geomorphology, but the model results would have been somewhat different had data from the other meter been used. The effects of lateral variation of currents on model predictions are especially pronounced at Clam Bay because of the atypically large size of the farm and shoreline effects on current patterns. At the Squaxin Island site and at other farms of small to moderate size the effect of lateral variations in current patterns may be negligible and ignoring these variations in the model may be justified.

- 7) The model, as presently formulated, is incapable of dealing with depth-related variation in current flow. With increasing water depth, the probability increases that currents measured at a single depth are unrepresentative of the multiple current regimes a particle encounters during settling to the seafloor. In the present study the meters were positioned at a depth approximating half the distance between the bottom of the pens and the substrate. In some situations multiple current meters at several depths may be necessary to accurately predict waste dispersal.
- 8) The model has no mechanism by which to consider duration of culture. The magnitudes of organic carbon loading were comparable at the Squaxin and Clam Bay sites, yet the effects on sediment chemistry were much greater at Clam Bay. This difference, which may be due to the short period of time that the Squaxin site has been in use, can not be incorporated into the model.

Despite the limitations of the model, it represents the best means currently available to predict the magnitude and extent of culture impact on the seafloor. The model has performed well both in the present study and in previous tests

in Scotland, yet because of its limitations and the necessary simplifying assumptions, the model should be used cautiously as a predictive tool. As indicated by the probable high degree of transport and/or resuspension at the Squaxin Island site, consideration must be given to site-specific conditions which violate model assumptions and therefore make predicted loadings subject to error. On a fine scale (predicting carbon flux at a specific point), model loading predictions appear to be reliable to within a factor of two in most cases. While this is generally adequate for site assessment, the potential error should be recognized and compensated for in identifying areas of potential impact.

On a broader scale (predicting the affected area), model predictions appear very reliable, for at five sites examined in Scotland, the model predicted that the $1 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ isopleth would extend up to 15 to 30 m from the farm perimeter. In the present study, the model predicted this rate of loading up to 28 and 70 m from the Squaxin and Clam Bay sites, respectively. Areal extents of impact of this magnitude are consistent with observations from the present study and other studies reported in the literature.

The current information collected as input to the model is extremely useful both from the perspectives of environmental protection and farm husbandry. The current meters deployed in this study measured velocity and direction every 15 minutes for a period of 60 days. Such information is invaluable not only to predict the dispersal of solid wastes but to determine mooring requirements, rates of water renewal in the pens, and duration of slack water (which may be the limiting water quality parameter in maintaining suitable growing conditions).

The model is useful in condensing a massive data set of current measurements into a single summary figure interpretable by non-specialists. It should therefore be helpful in

explaining probable impacts in public hearings and similar forums.

The model is also helpful in identifying sites which would be clearly unsuitable for culture. Given the current state of knowledge it is not possible to define the impacts of a given loading rate, however severe biological disturbance has been observed in Scotland where predicted loadings were as low as $1.8 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$. At some unquantified level below this loading, development of a site is unlikely to have significant effects on the benthos. At most farms examined in Washington and Scotland, loading rates directly under the pens range from 6 to $14 \text{ kg C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$. Where loading rates are far in excess of these values, the generation of hydrogen sulfide by enriched sediments and the consequent effects on the cultured fish themselves would be of serious concern.

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APPENDIX B

Modeling of Particulate Deposition Under Salmon Net-Pens

**MODELING OF PARTICULATE DEPOSITION
UNDER SALMON NET-PENS**

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INTRODUCTION

One of the observed effects of some salmon net-pen facilities on the environment has been organic enrichment of the underlying soils from the deposition of fish feces and uneaten feed. Under separate report to the Department of Fisheries, Drs. Donald Weston and Richard Gowen have examined deposition rates, chemical changes and biological impacts under two net-pens sited in Puget Sound. Their evaluation included a predictive deposition model developed by Gowen.

A separate modeling approach has been used in the evaluation of several proposed net-pens recently by Parametrix, Inc. The purposes of this report are: (1) to run the Parametrix model for the same sites modeled by Gowen and comment on the comparative results, and (2) modify configuration, orientation and density of the pens and evaluate the sensitivity of predicted deposition rates to these variables.

MODEL DESCRIPTION

The Parametrix model is a modification of a model developed by EPA (1982) to predict the deposition of particulates from sewage treatment plant outfalls in coastal waters. This model has already been applied to several proposed net-pens in the State of Washington. The model relies on average speed and frequency along the principal and minor axes to predict excursion distances from the pens and areal deposition rates for settleable materials of distinct settling velocity. A sloping bottom can be accounted for in the model. Comparison of the Parametrix model with Gowen's model will be saved for the Discussion.

The Parametrix model includes evaluation of post-depositional processes related to decay of the organic material. The organic material will decay as it accumulates on the sea floor. When the rate of deposition matches the rate of biodegradation, a steady-state accumulation of organic material will result. Decay of organic material will create an oxygen demand in the bottom waters in the vicinity of the net-pens. The EPA methods are used to predict the resulting steady D.O. depletion in the near-bottom waters.

RESULTS: CLAM BAY SITE

Currents. Like Gowen's model, the Parametrix model is based on the current meter located 100 m east of the farm site (#F2053). The current rose from this meter is shown in Figure 1. Each of the current measurements has been catalogued into one of eight 45° directional "bins." The percentage of currents falling within each bin and the average speed of those currents are indicated by the rose. The length of each rose petal is proportional to the percentage of currents in that direction. The current rose for the Clam Bay site used in the model indicates the predominant current direction falls within the bin from 90° to 135° (ESE). The average currents along the major and minor axes of the net-pens used in the model are adjusted for the frequency and strength of currents

in each direction (for example, the fastest currents occur from 315° to 360° but are not very frequent, thus are not weighted as high as the easterly currents).

Wasteload and Settling Velocities. The method of determining wasteload and settling velocities used by Gowen is different than that used for this model. The wasteload assumed for this model study is consistent with the wasteloads assumed in earlier modeling efforts by Parametrix for net-pens in Puget Sound (Harding Creek, Discovery Bay, and North Skagit Bay). The Gowen model is based on a carbon mass balance, whereas the Parametrix model accounts for total solids. The results modeled herein are converted to carbon for comparison with Gowen's results in the summary results, based on 48 percent carbon content for feed, and 80 percent for feces.

The wasteload and settling velocities assumed for the Parametrix model are based on an annual production of 617 metric tons, Gowen's published data for European farms, and other European researchers (Gowen 1987). Lost feed would be about 10 percent of the total feed. The data used in this modeling are tabulated below:

<u>Waste Component</u>	<u>Total Solids Loading</u>	<u>Total Carbon Loading</u>	<u>Percent</u>	<u>Settling Velocity</u>
Uneaten Feed	430 kg/d	206 kg/d	40%	10 cm/s
Large Feces	325	260	30	5
Small Feces	325	260	30	2
Total	1,080 kg/d	726 kg/d	100%	

By comparison, Gowen's model assumed 317 kg C/day lost feed and 540 kg C/day feces, for a total loading of 857 kg C/day.

Model Runs. The model was run for the existing pen size and orientation and four other configurations as summarized below:

<u>Run</u>	<u>Description</u>
1	Existing pen size and orientation
2	Rotate existing pens 90°
3	3 round pens with same total surface area
4	Increase pen width by 50 %
7	Decrease fish production 50 %

The results of each model run are summarized below and in the Figures attached at the end of this report (except Run 7 which would have the same areal coverage as Run 1, with 50 percent of the deposition rate). The table below includes only the maximum predicted impact, which would be concentrated directly under the pens. Total accumulation is based on a steady-state decay of organic material. The model output is provided at the end of this report for all runs.

Run	Total Deposition kg/m ² /yr	Organic Deposition kg C/m ² /yr	Total Accumulation kg/m ²	D.O. Depletion mg/L
1	14.7	9.3	4.0	0.13
2	9.8	6.1	2.7	0.04
3	10.6	6.5	2.9	0.08
4	10.8	6.9	2.9	0.11
7	7.4	4.6	2.0	0.07

RESULTS: SQUAXIN SITE

Currents. The model runs for the Squaxin site are based on the meter #F2057 located 60 meters north of the existing pens. The current rose for this meter is shown in Figure 2. The rose reveals a predominant NNW by SSE current axis. The SSE component is slightly less frequent, but much stronger than its counterpart. Current speeds used in the model are handled similar to the Clam Bay site.

Wasteload and Settling Velocities. The Squaxin site is much smaller than the Clam Bay site. The assumed wasteloads and settling velocities are tabulated below:

Waste Component	Mass Loading	Mass Percent	Settling Velocity
Uneaten Feed	40 kg/day	40 %	10 cm/sec
Large Feces	30	30	5
Small Feces	30	30	2
Total	100 kg/day	100 %	

Model Runs. The model was run for the pen configurations as summarized below:

Run	Description
5	Existing pen size and orientation
6	Rotate existing pens 90°

The results of each model run are summarized below and in the figures and printouts attached at the end of this report.

Run	Total Deposition kg/m ² /yr	Total Accumulation kg/m ²	D.O. Depletion mg/L
5	11.9	3.3	0.02
6	17.2	2.7	0.05

DISCUSSION

Comparison with Gowen Model. The basic calculation in both models, horizontal displacement of settleable particles, is governed by the same function of settling velocity and current velocity. However, Gowen's model simulates individual particle trajectories for each current velocity from the current meter data, whereas the Parametrix deals only with averages. Accordingly, the Gowen model requires more input data and is capable of producing a larger number of sediment contours and more precise deposition pattern.

Unlike the Parametrix model, Gowen's model does not consider sloping topography, multiple settling velocities or post-depositional biological processes. However, Gowen's model could certainly be modified to include these additional features. Although these features are desirable, the uncertainties regarding wasteload and post-depositional processes exceed the precision achieved by these features.

Neither model accounts for dissolution, suspension or resuspension of particles by high currents. However, a very detailed field investigation of the spatial distribution of currents near each site would be necessary to predict impacts at remote locations if material is resuspended. Resuspension and maintenance of fish feces in suspension under turbulent conditions would be a valuable future research topic.

Comparison of Model Results. Gowen's model produces a more detailed map showing deposition contours ranging from 0 to 12 kg C/m²/yr for Clam Bay, with 1 kg C/m²/yr intervals. The Parametrix model reveals only 3 contours, with an average of 9.3 kg C/m²/yr centered under the pens (Run 1). Gowen's assumed wasteload was greater than that assumed for the Parametrix model. Given the uncertainties regarding wasteload assumptions (discussed below) and the greater resolution possible with Gowen's model, the results appear compatible.

As discussed in the model description, the Parametrix model accounts for the post-depositional process of decay. The assumptions made are generally conservative, but may be useful for management uses. The accumulation mass and thickness would be masked in areas where natural deposition is also occurring. In each case modeled, the predicted D.O. impact would be negligible, which is consistent with the observations of Weston. The D.O. function in the model would be useful to flag potential problems, but could not be relied on for an accurate prediction if oxygen problems are anticipated.

Sensitivity Analysis. The results of Runs 1 through 4 and 7 indicate the sensitivity of deposition to various factors. Runs 1 through 4 represent an equal number of fish, or wasteload. Run 7 reveals that the most effective way to reduce deposition is to reduce the wasteload.

For a given wasteload, the greatest mitigation is achieved by orienting the pens perpendicular to the predominant current direction (a reduction of 33 percent in this case: see Runs 1 and 2). In this respect, the Squaxin site is already mitigated, as evidenced by a like increase by rotating the pens by 90 degrees (see Runs 5 and 6). Of course, engineering and navigation considerations may not allow this mitigation measure.

Separation of the pens into several pods may also mitigate deposition. Essentially, the impact would be spread over a greater area. In this example, a reduction of 28 percent would be achieved by the configuration chosen for Run 3. The reduction at any proposed site would be site specific and a function of the size and separation of the individual pens.

Run 4 increased the dimension perpendicular to the predominant current by 50 percent. A reduction in deposition of approximately 25 percent is anticipated. Again, the reduction obtained at any site would be specific to that site. An increase in the dimension parallel to the predominant current would have little effect.

CONCLUSIONS

The primary conclusions of this analysis follow:

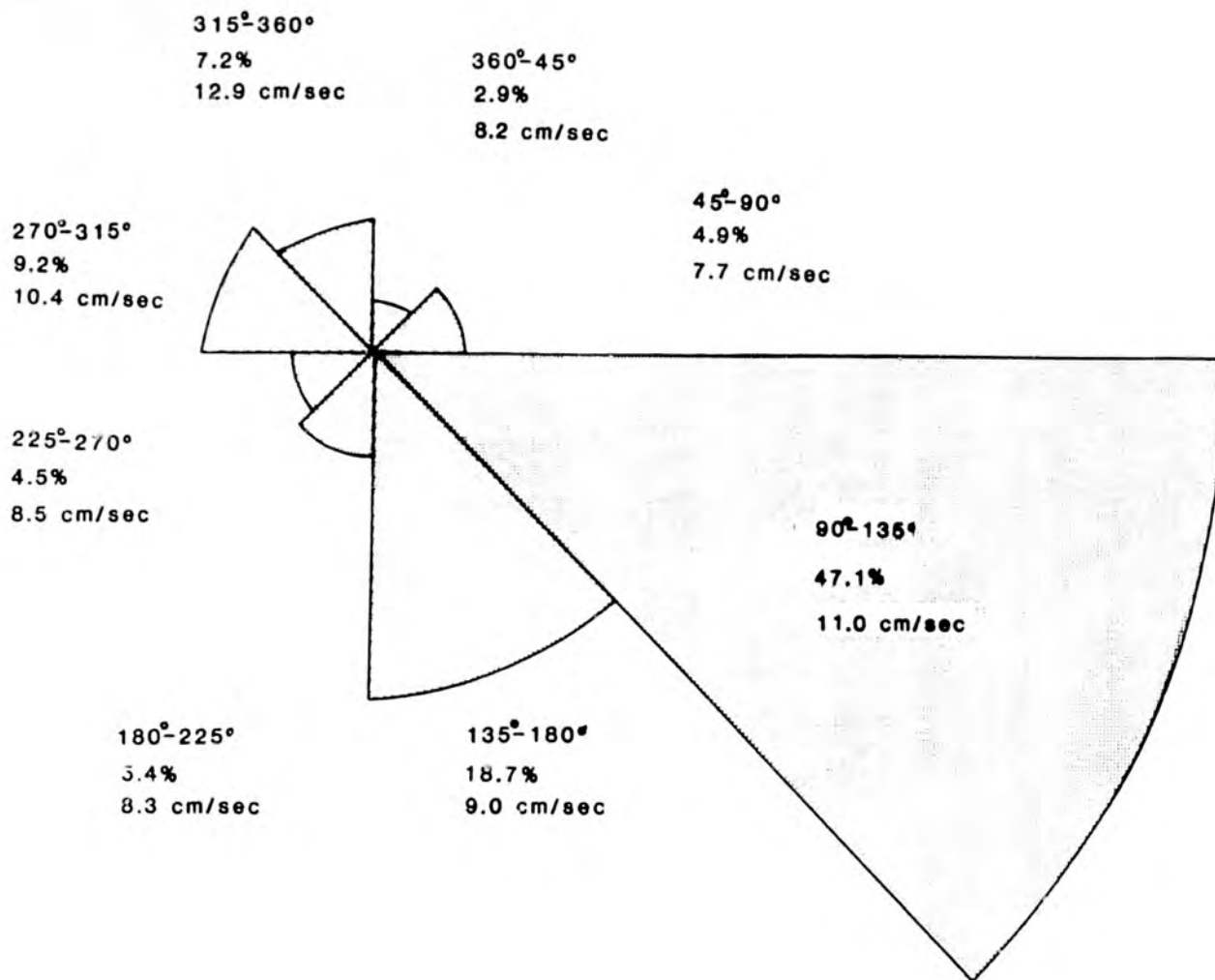
1. Gowen's model produces a deposition map of better resolution than the Parametrix model. The Parametrix model crudely accounts for uniformly sloping bottom topography and post-depositional decay, and can accept any number of settling speeds or vertical variation of current speed.
2. Improvements could and should be made to both models regarding suspension and resuspension of depositional materials.
3. Current speed and direction relative to the pens are critical to deposition. Fecal material from the pens may remain suspended at some threshold current speed. If current speeds are below this threshold level, pen orientation to the axis of predominant currents is critical.
4. The greater resolution of Gowen's model or any other modeling improvements (such as multiple settling velocities or complex topography) are secondary to the need for more defined criteria regarding wasteload, as discussed below.

The most settleable particles are the uneaten feed. However, lost feed ratios reported in the literature range from 1 to over 30 percent of the applied feed. Run 7 revealed

the importance of the predicted wasteload in predicting deposition rates. Until more accurate criteria for wasteload are developed, which seems unlikely, less subtle improvements to the models are ineffective. The models may provide useful management tools, particularly when comparing alternative sites and pen configurations, or establishing best management practices to limit feed wastage.

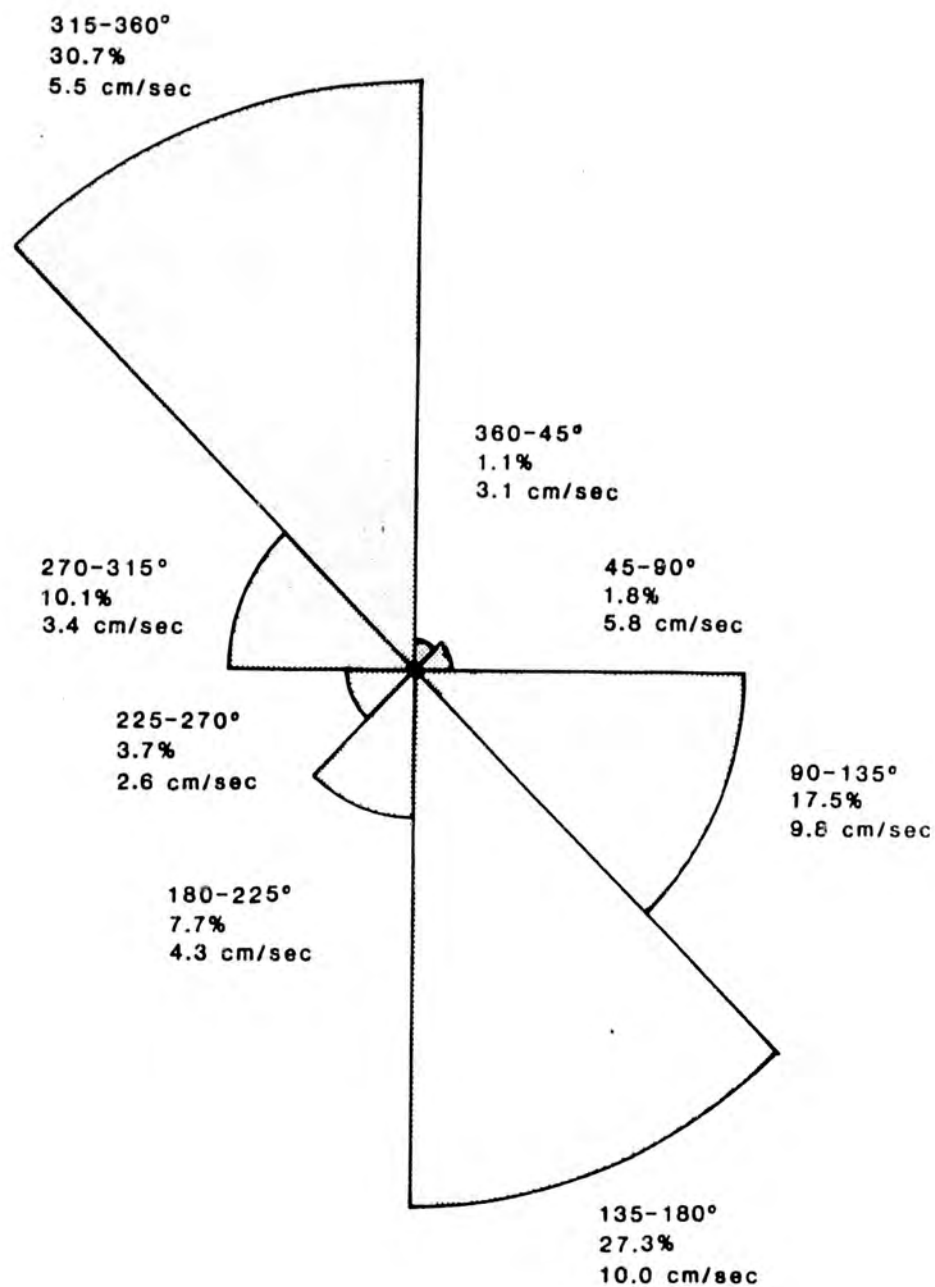
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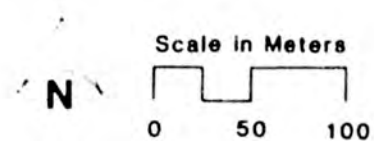
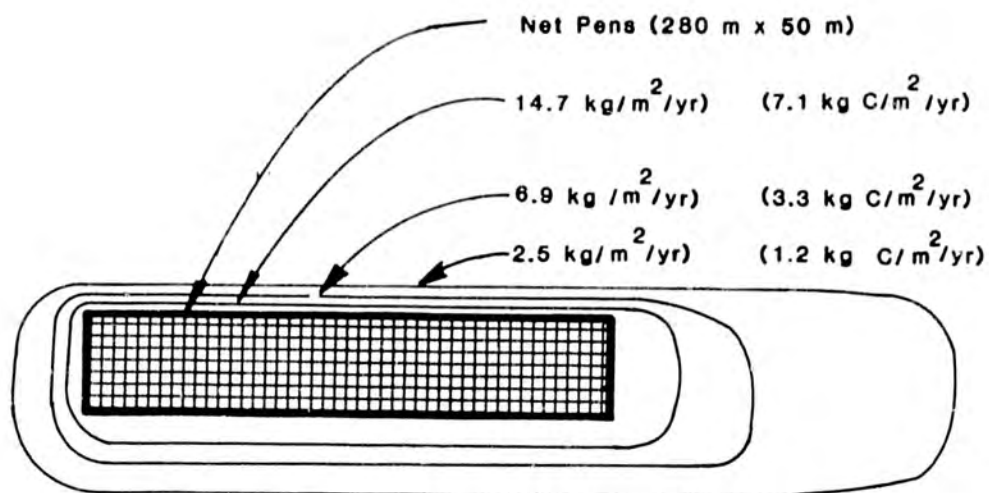
Note: Current Rose Indicates
Percentage and Mean
Speed of Currents Within
Directional "Bina." Length
of Rose is Proportional
to Percentage.

Figure 1:
Current Rose For
Clam Bay Site,
Meter F2053



Note: Current Rose Indicates
Percentage and Mean
Speed of Currents Within
Directional "Bins." Length
of Rose is Proportional
to Percentage.

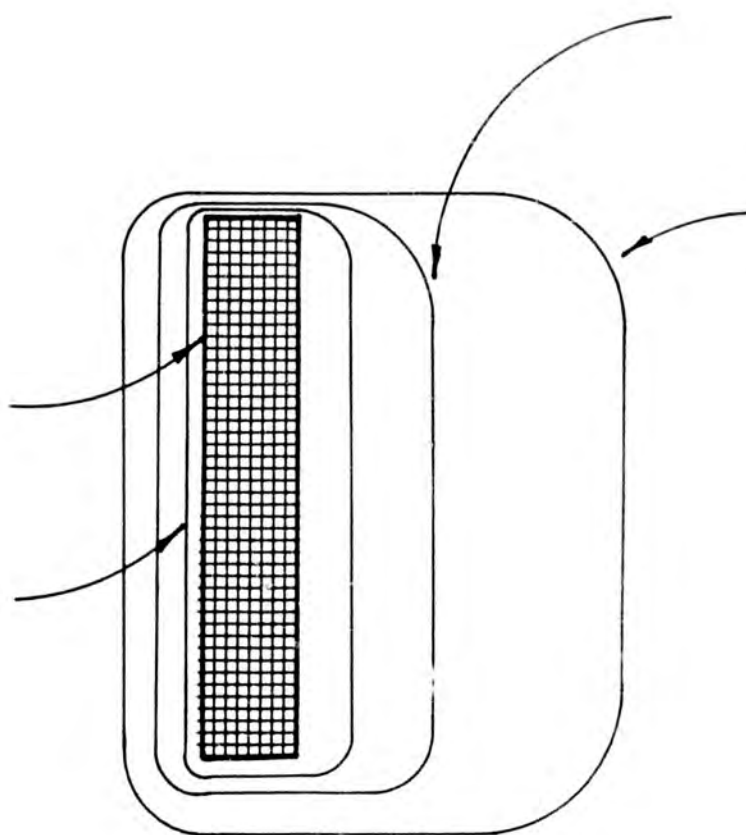
Figure 2:
Current Rose
For Squaxin Site,
Meter F2057



Run 1:
Clam Bay,
Existing Configuration

Net Pens
(50m X 280m)

$9.8 \text{ kg/m}^2/\text{yr}$
 $4.7 \text{ kg C/m}^2/\text{yr}$



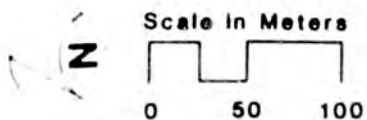
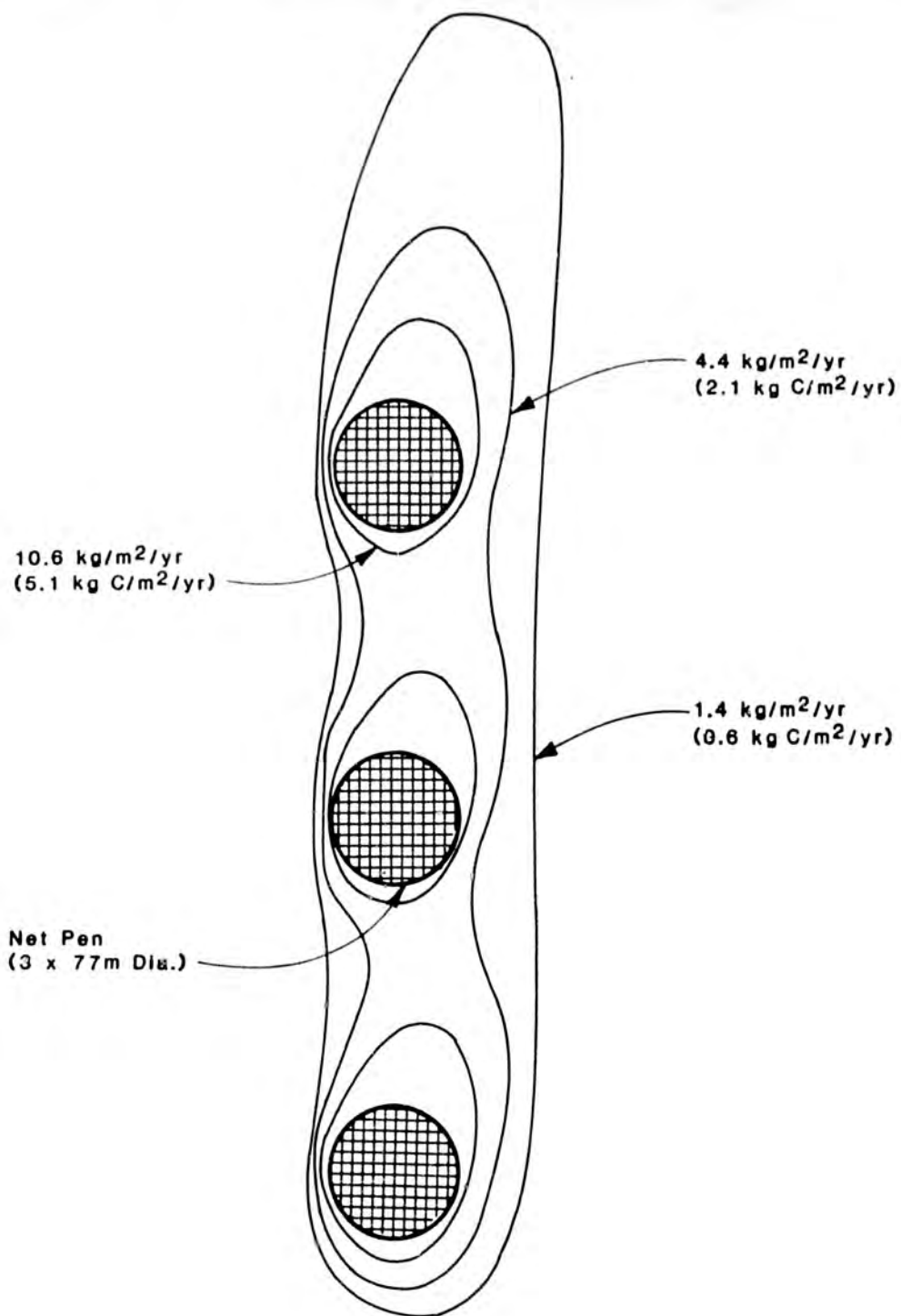
$4.2 \text{ kg/m}^2/\text{yr}$
 $(2.0 \text{ kg C/m}^2/\text{yr})$

$01.3 \text{ kg/m}^2/\text{yr}$
 $(0.6 \text{ kg C/m}^2/\text{yr})$



Scale in Meters
0 50 100

Run 2:
Clam Bay
Rotate 90°



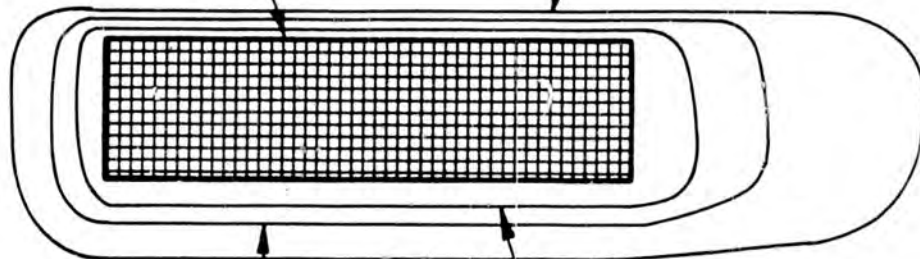
Run 3:
Clam Bay.
Round Pens

Net Pens
(280 m x 75 m)

2.0 kg/m²/yr
(0.9 kg C/m²/yr)

5.3 kg/m²/yr
(2.5 kg C/m²/yr)

10.8 kg/m²/yr
(5.2 kg C/m²/yr)



Scale in Meters
0 50 100

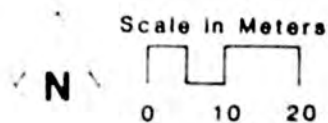
Run 4:
Clam Bay,
Double Wide Pens

Net Pens
(75 m x 17 m)

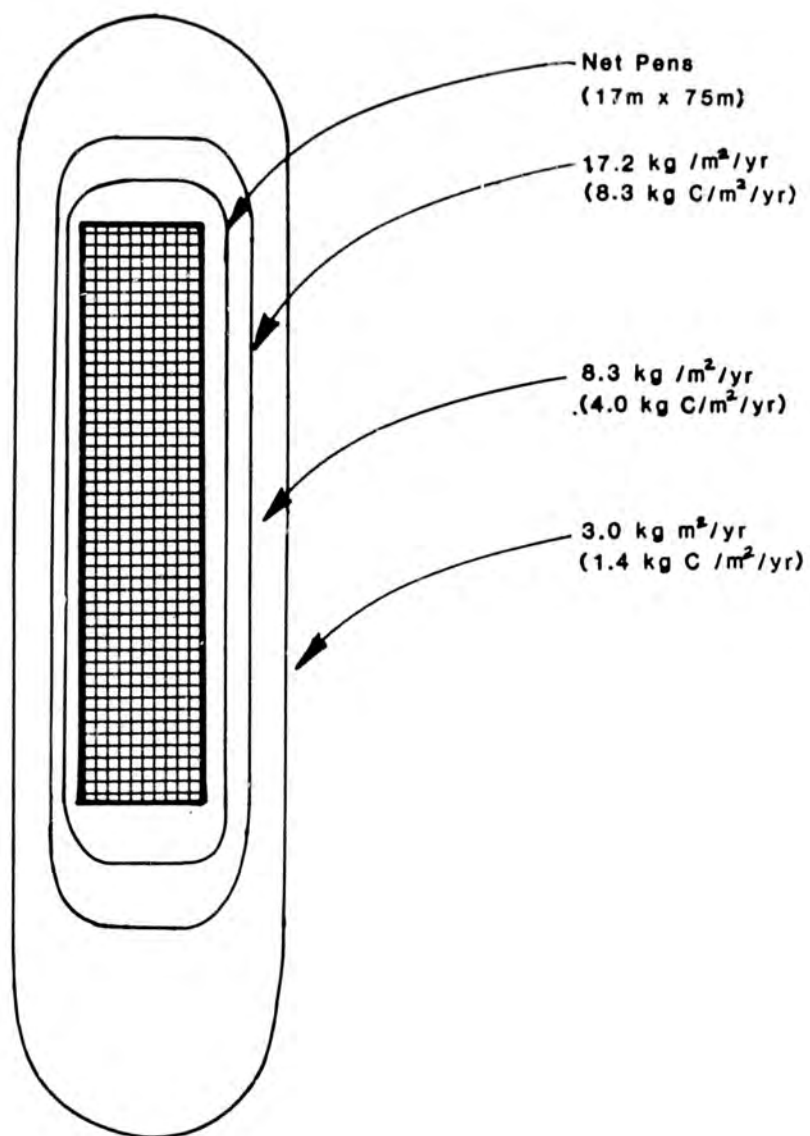
11.9 kg/m²/yr
(5.7 kg C/m²/yr)

5.2 kg/m²/yr
(2.5 kg C/m²/yr)

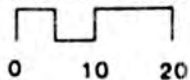
1.7 kg/m²/yr
(0.8 kg C/m²/yr)



Run 5:
Squaxin,
Existing Configuration



Scale in Meters



Run 6:
Squaxin Rotate 90°

APPENDIX C

Phytoplankton and Nutrient Studies Near Salmon Net-Pens

At Squaxin Island, Washington

PHYTOPLANKTON AND NUTRIENT STUDIES
NEAR SALMON NET-PENS
AT SQUAXIN ISLAND, WASHINGTON

by

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for

The Washington Department of Fisheries
and the
Technical Appendices of the
Programmatic Environmental Impact Statement:
Salmon Aquaculture in Puget Sound

January 6, 1989

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Abstract

The effect of a salmon net-pen farm on nutrient concentration, phytoplankton density and primary productivity was investigated in a shallow passage of southern Puget Sound, Washington. The farm was relatively large and situated in surface waters that are depleted of dissolved nitrogen for unknown periods during the summer. The assessment was conducted during a period of maximum net-pen fish biomass and one month later during similar tidal and weather condition, after release of 60% of the fish. Monitoring of reference stations at both ends of the passage, beyond the immediate effect of the net-pens, was conducted to assess source water conditions.

During the period of maximum fish biomass, minor increases in dissolved nitrogen ($\text{NO}_3 + \text{NO}_2 + \text{NH}_4^+$) were seen downstream of the pens during one tidal period, but not during the next. Total ammonia was significantly elevated within the pens compared to ambient concentrations, but concentrations were well below the chronic exposure concentration for salmonids and other sensitive coldwater fish. A distance of 30 m downstream approximately 80% of the ammonia had been oxidized to nitrate, presumably by microbial nitrification.

Before fish release, the rate of phytoplankton primary productivity (growth rate estimation by the C-14 method) was greater near the net-pens than at the reference stations during the morning tide, but not different during the following tide. After release of most of the fish, a similar trend was seen, but there were no significant differences of productivity between tidal periods or among stations. Phytoplankton density (chlorophyll a concentration) followed a similar trend before, but not after fish release.

The results indicate that phytoplankton density and growth rate fluctuated with tidal stage and time of day and were not directly related to nutrient discharge from the salmon farm. Surface waters throughout the passage were, at times, low in dissolved nitrogen content, but total nitrogen to phosphorus (N:P) ratios indicated that there was an adequate reserve of nitrogen in non-dissolved forms (e.g., plankton). The N:P ratio data suggest that nitrogen cycling processes (e.g., remineralization of organic matter in plankton) were adequate to prevent limitation of phytoplankton growth during the period of most likely impact by the net-pen farm.

Introduction

Salmon reared in marine net-pens produce solid and dissolved wastes including various forms of nitrogen. Dissolved nitrogen wastes from salmon are as much as 60 to 90% ammonia, with lesser amounts of urea and amino acids (Stickney 1979). Nitrogen is the nutrient most likely to be limiting to the growth of marine phytoplankton. Therefore, the potential for localized nutrient enrichment and increased algal abundance near salmon farms exists, and will depend mainly on the total size of the farms in the restricted water body and existing hydrographic conditions (Gowen et al. 1985, Gowen and Bradbury 1987).

Nutrient limitation of surface waters is a key consideration of the State of Washington's Recommended Interim Guidelines for the Management of Salmon Net-pen Culture in Puget Sound (SAIC 1986). That document conservatively, but somewhat arbitrarily, designated the nutrient limitation status of sub-areas of Puget Sound based on a threshold of 0.1 mg/l, two and one-half times greater than the literature value of 0.04 mg/l (URS 1986a). As discussed below, simple measurement of dissolved nutrient concentrations is inadequate to determine if nutrients are inadequate for algal growth.

There have been relatively few attempts to monitor nutrient enrichment near salmon net-pens and even fewer studies of the effects upon phytoplankton dynamics. Prior studies of nutrients from net-pens strongly suggest there is little measurable effect beyond the immediate area of the pens (near-field). While nutrient concentrations are relatively easy to monitor, phytoplankton studies (far-field second and third order effects) are more difficult to conduct and have typically relied on measurement of chlorophyll *a* concentrations, the primary photosynthetic pigment in phytoplankton.

In the only study conducted in the Pacific northwest on this topic, Pease (1977) surmised that no measurable impact on phytoplankton populations occurred under worst-case conditions. The study area at Henderson Inlet, Washington had limited circulation during summer months, exacerbated by the net-pen site location within a shallow log dumping and storage area. Intense dinoflagellates blooms occurred at the site during the summer of 1974 which killed farmed salmon and prawns (Rensel and Prentice 1980). The 1974 blooms, which appeared to be exceptional in abundance, occurred throughout large parts of Puget Sound and also killed salmon in net-pens at Squaxin Island. These conditions were not seen in the previous year at either Henderson Inlet (Snyder et al. 1974) or in several previous or one later year at Squaxin Island (Fraser 1976).

Pease (1977) found increased density of phytoplankton (chlorophyll *a*) during summer months with increasing distance

into the log rafting area. The net-pens were located near the outer, seaward edge of the log rafting area. Reference areas (controls) were located in the main channel of Henderson Inlet, outside the log rafting area, and further inside the log rafting area. From my analysis of his monthly dissolved nitrate data (Table 5 and Fig. 8 of Pease 1977), it appears that nitrogen-depleted conditions could have occurred only in July when some of the samples had less than 0.04 mg/l dissolved nitrogen. Since both total nitrogen and phosphorus concentrations were not monitored, there is no way to know for sure. Low concentrations of dissolved nitrogen coincided with chlorophyll *a* maxima, but that does not mean that nitrogen availability limited phytoplankton growth. A generalized, inverse correlation between dissolved nutrients (nitrate and orthophosphate) and phytoplankton density was apparent over the entire summer period.

Phytoplankton standing crop during Pease's study was consistently greater at a reference station inside the log rafting area and at the net-pen site, compared to an outside, midchannel reference area in the open water of Henderson Inlet. However, Pease (1977) concluded that there were no abnormally high concentrations of phytoplankton anywhere in the area, and that phytoplankton activity throughout the inlet was unrelated to the net-pen rearing.

The second conclusion is possible, but neither supported or refuted by his data, as the inside reference area was too close (a few hundred feet) to the net-pens to be considered as separate and unaffected. Since water currents are weak and often imperceptible at the Henderson Inlet site, the inside log-rafting reference areas can not be considered as separate from the net-pen site, with regard to phytoplankton populations. These criticisms do not invalidate Pease's conclusions regarding other water quality conditions, but suggests that a greater standing stock of phytoplankton existed near the net-pens and that the effect of location and nutrient impact of the net-pens could not be sorted out given the experimental design. Several years after removal of the Henderson Inlet facility Rensel (unpublished data, 1988) found that chlorophyll *a* concentrations in midchannel were about twice those found at the now vacant net-pen site, opposite the condition that prevailed throughout Pease's year long study (2.72 versus 1.71 ug Chl. *a*, SD = 0.273 and 0.412 respectively, *n* = 6). However, these samples were taken too late in the fall to be representative of optimum algal growing conditions and indicated relatively low phytoplankton density at both areas.

There are numerous difficulties in determining perturbations of phytoplankton from fish-farms or from other of man's activities. Foremost, as discussed above, once the net-pens are established, there is usually no adequate means to establish baseline conditions. Although nutrient uptake by phytoplankton may be rapid, there is a lag time of up to a day or so between the addition of nutrients and a measurable increase in phytoplankton biomass (Parsons et al. 1984). Knowledge of local hydrodynamic

processes of dispersion, such as distance of tidal excursion, are required for interpretation of these types of data. Simply monitoring upstream and downstream of a net-pen farm site may reveal near-field nutrient effects, but may not be adequate to monitor the relatively slow response of phytoplankton populations to the increased nutrient concentrations. Monitoring of phytoplankton abundance and dynamics in the field is also difficult due to natural variations in time and space of the phytoplankton. A number of discrete or loosely interacting measures of water column ecology must be assessed, as no single measure provides all the necessary information.

Nitrogenous wastes from net-pen reared fish or other sources are unlikely to increase phytoplankton abundance in most of the main channels of Puget Sound since nitrogen is already in abundance (Collias and Lincoln 1977, Anderson et al. 1984, SAIC 1986). Accordingly, this study focused on a worst-available-case of nutrient enrichment from net-pens in what appeared to be nutrient-depleted waters, at least during some tidal, seasonal and weather conditions. To establish baseline conditions, the present study was conducted before and after the release of large numbers of fish at a public benefit, salmon rearing and release net-pen site. In addition to having spatially separate reference areas, "before fish release" water quality samples were used as the experimental data, and "after fish release" monitoring served as a baseline.

Study Site: Description and Hydrography

The net-pen study site, located in Peale Passage east of Squaxin Island in southern Puget Sound (Fig. 1), is a cooperative Washington Department of Fisheries and Squaxin Island Indian Tribal sponsored program. Coho (*Oncorhynchus kisutch*) and other species of salmon have been reared at the site since the early 1970's (STOWW 1974) and the nearby beaches have abundant littleneck clam and planted oyster populations. The Squaxin Island net-pens are presently the largest public benefit facility in Washington state and produces substantial numbers of fish for commercial and sport fisheries (Rensel et al. 1988). There are three adjacent sets of net-pens, two for delayed release of salmon and, in recent years, a third rearing facility to the north operated by the tribe for normal commercial purposes (pen system 3 in Fig. 2). All of the fish reared at the first two facilities are destined for release into Puget Sound, and are held in the net-pens for only a few months of the year after attaining smolt condition.

Peale Passage is a shallow tidal channel connecting Dana Passage on the south and Pickering Passage to the north (Fig. 2). The Squaxin Island Indian reservation forms the west boundary of Peale Passage, Harstene Island the east boundary. The source waters for Peale Passage are relatively well-mixed by strong tidal currents, although only one year of sampling data were available for the Dana Passage sampling station (unpublished WDOE

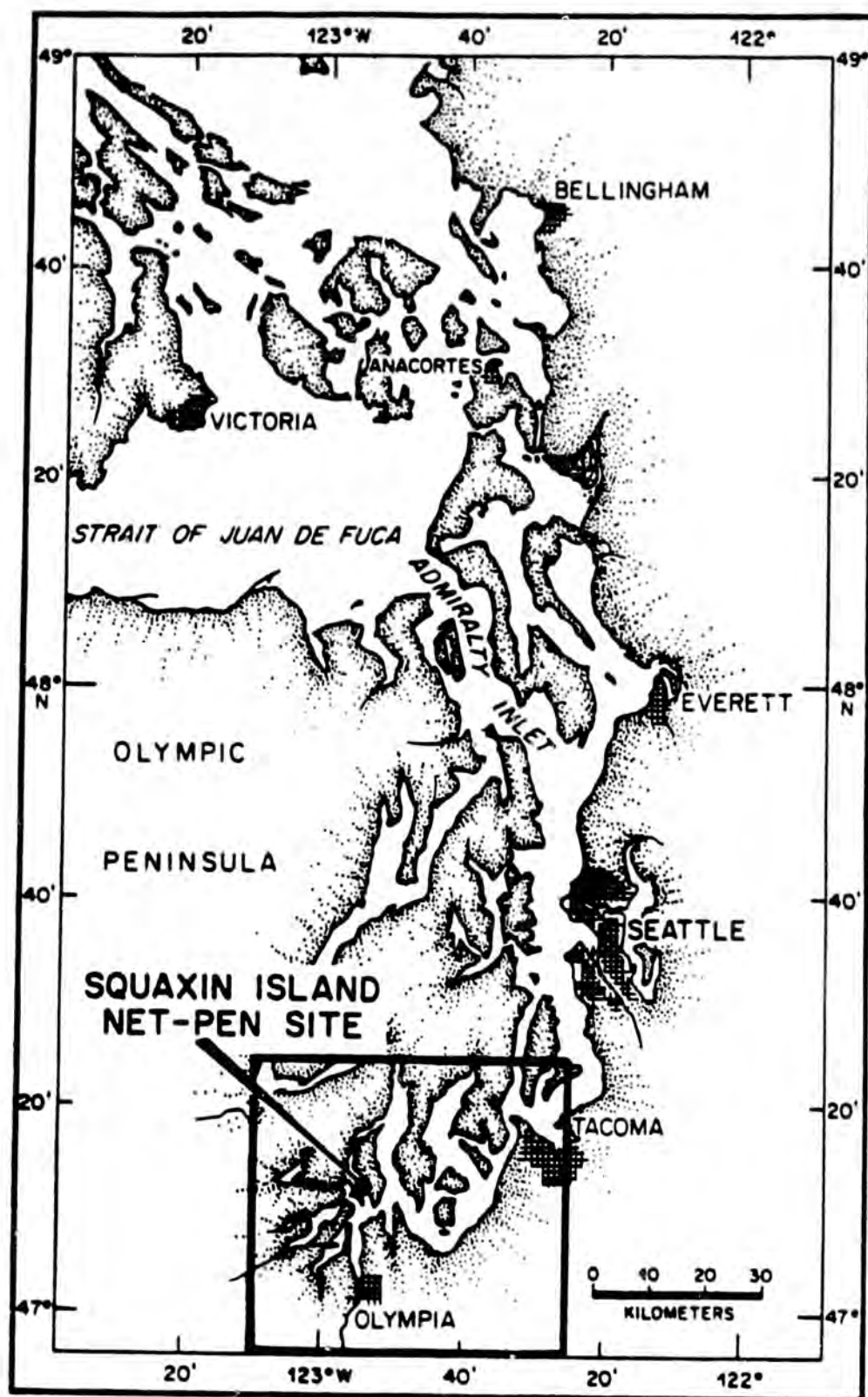


Figure 1. Map of the Puget Sound region with Squaxin Island net-pen site located in South Puget Sound within outlined box.

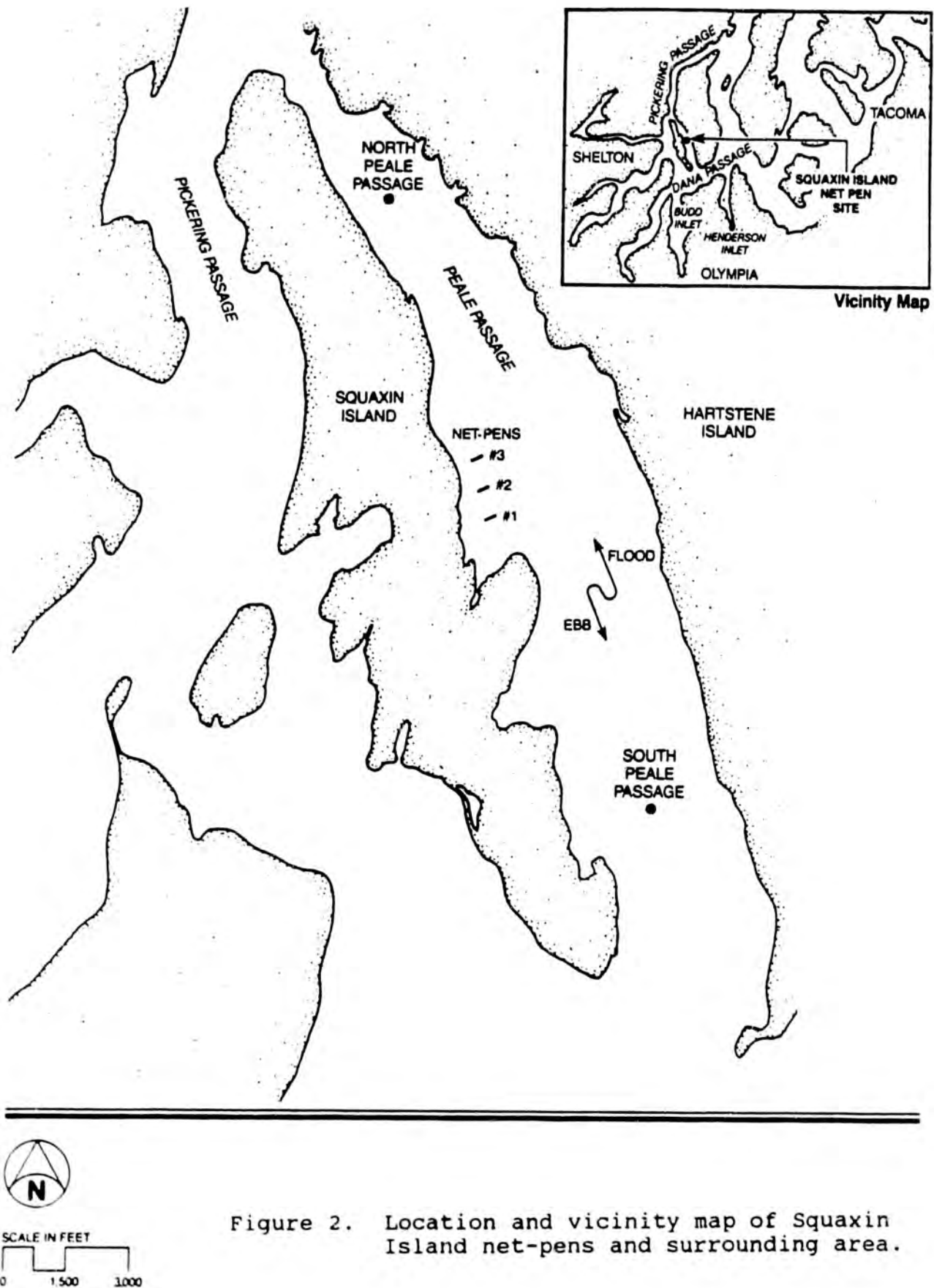


Figure 2. Location and vicinity map of Squaxin Island net-pens and surrounding area.

water quality data DNA001). These data indicate low dissolved nitrogen in surface waters occurred 15% of the period April to November. Pickering Passage data show low dissolved nitrogen in surface waters about 39% of the time (SAIC 1986).

Recent studies of circulation and nutrients in deep southern Puget Sound (URS 1986b) indicate that additional source waters for Peale Passage are the inlets at the west end of Dana Passage, especially Budd and Eld Inlets, due to clockwise circulation of surface and deeper waters in western Dana Passage. These inlets both exhibit strong vertical stratification and nutrient limitation during clement weather and undoubtedly influence Peale Passage surface waters at times during calm weather.

An early study of hydrographic conditions in southern Puget Sound measured vertical profiles of physicochemical parameters in Peale Passage on a few occasions (Oclay 1959). Moring (1973) noted that there was little background information concerning water quality in the Peale Passage area. His studies provide some basic information concerning conditions at the net-pen site. In subsequent years, fish culturists of the Squaxin Island Tribe collected additional information at the site that, combined with the earlier information, is adequate to characterize the vicinity. These data indicate that the area is well-mixed in the late fall to spring months but has a gradual thermal gradient and very minor salinity gradient in the clement weather periods of summer. There are no significant freshwater sources in Peale passage and no sharp discontinuities of water column characteristics.

Unpublished drogue (drift object) data collected for this study and recording current meter data collected for a related study (Weston and Gowen 1989) suggest that water passing through the net-pens does not exit Peale Passage on the same tide. This situation potentially could lead to an increased abundance of phytoplankton, since phytoplankton will rapidly assimilate dissolved nitrogen during growth-limiting, nitrogen depletion.

With an average depth of about 5.0 meters at mean lower low water (MLLW), depths in the vicinity of the net-pen site are shallow compared to other existing net-pens in Western Washington. Mean water current velocity near the most northern set of net-pens is about 6 to 7 cm sec⁻¹ with a net directional flow to the south (Weston and Gowen 1989). Currents diminish an undetermined amount in the vicinity of the other two net-pens and may be affected by the presence of a small cove that tends to slow water movement and form a gyre, particularly on the flood tide (unpublished survey data of B. Wood, Squaxin Island Tribe, 1982).

Although no historical nitrogen data were available from Peale Passage, two days prior to the first sampling date of this study I found dissolved nitrogen concentrations less than 0.04 mg/l, and a total molar nitrogen to phosphorus (N:P) ratio of 16.6 at 0 to 2 m depth in south Peale Passage. Use of a simple numerical

value of dissolved nitrogen may be misleading for representation of the actual threshold of nutrient depletion (Welch 1980); examination of the total N:P ratio is more useful in determining nitrogen depletion and the status of the complex nitrogen cycle. Recent studies in nearby Budd Inlet suggested that nutrient limitation in surface waters occurred during summer months when the concentration of dissolved nitrogen was less than 0.04 mg/l and N:P ratios were 5 to 1 or less (URS 1986a).

Experimental Design

Two types of experiments were conducted. The goal of experiment A was to see if rates of primary productivity, as measured by the uptake of radiocarbon isotope C-14, were enhanced in mid-Peale Passage near the net-pen site. Reference area stations were selected to be remote enough from the net-pens to avoid having waters that had passed through the net-pens on any single, moderate amplitude tide. Sampling was conducted during morning and early afternoon hours that coincided with the early and late portions of the flood tide, essentially low and high tide. The experiment was conducted before and after release of most of the delayed-release fish (experiments A-1 and A-2, respectively), about a month apart, during similar tidal exchange and timing. Both dates had relatively calm, warm weather and were during the peak algal growing season in Puget Sound (Winter et al. 1975, URS 1986a). Other direct measures of phytoplankton density (chlorophyll a and species cell counts for relative abundance) as well as indirect, surrogate measures (Secchi disk depth and dissolved oxygen concentration) were made as time allowed.

During sampling in late May 1988, the three sets of net-pens had a total of 118,600 kg of fish distributed 38% within system number 1, 45% in system number 2 and 17% in system number 3. Most of the fish in system one and two were released in early June. During the second sampling date in late June there was approximately 47,200 kg of fish in the net-pens, 55% within system number three and 45% in system two.

Experiment B was an assessment of water quality upstream and downstream of the net-pens, similar to nutrient monitoring described in the Interim Guidelines (SAIC 1986). The monitoring was conducted at low and high tide in late May, before release of the fish. The goal of experiment B was to monitor the near field effect of the net-pens on nutrient and ammonia concentrations. Table 1 summarizes the measurements and replication conducted for experiment A and B.

Worst-possible-case conditions were ensured by timing the experiments during a period with: the greatest amount of fish in the pens (experiment A-1) and with relatively small tidal

Table 1. Sampling parameters and number of replicates per depth.

	¹⁴ Carbon isotope -----	Chloro- phyll <u>a</u> -----	Dissolved nutrients -----	Dissolved oxygen -----	Secchi Disc -----	Temper.- Salinity -----	Phytop. counts -----	Total N & P -----
<u>Experiment A-1:</u> pens versus reference areas, May 25th, before fish release								
Low Tide	3	1	1	1	1	1	-	1
High Tide	3	1	1	1	1	1	1	1
<u>Experiment A-2:</u> pens versus reference areas, June 21st, after fish release								
Low Tide	3	3	3	1	1	1	1	1
High Tide	3	3	3	1	1	1	1	1
<u>Experiment B:</u> upstream and downstream of pens, May 25th								
mid-flood	-	-	3	1	1	-	-	3
early ebb	-	-	3	3	1	-	-	1

Codes: ¹⁴Carbon isotope = primary productivity assessment, phyto. counts = microscope identification and enumeration of phytoplankton, total N and P = total nitrogen and phosphorus (sum of dissolved and particulate) Total N and P from center of the net-pens only on ebb tide, experiment B. pH was sampled concurrent to collection of nutrient samples.

exchange. The mean tide for nearby Dofflemeyer Point is 10.4 feet, and the diurnal range is 14.4 feet. Sampling on May 25 and June 21st was conducted on the beginning and end of 6.3 and 4.9 foot flood tides, respectively.

Methods

Water velocity at the net-pen site was measured with a Scientific Instruments Price Meter, fitted with an Swoffer optical sensor and remote, digital readout unit. Surface drift sticks and 2 meter deep drogues were used to monitor current direction immediately downstream of the net-pens. Salinity and temperature were measured with a YSI SCT-33 meter carefully calibrated to standard seawater solution. All water samples were collected with a 2 liter Scott-Richards sampling bottle. Dissolved oxygen was measured by a modified Winkler titration method with an accuracy of 0.02 mg/l. pH was recorded in the field using a VWR model 55 probe. Chlorophyll *a* samples were collected by filtering 50 ml of water through Whatman GF/F filters. Filters were folded, packaged and iced for analysis the next day.

Nutrient samples were collected in acid washed and sample-water rinsed, polyethelene bottles, iced and frozen later the same day. No filtering or acidification was conducted to avoid introduction of broken cells and other artifacts, and to avoid destruction of nitrite (APHA 1985). This is standard research methodology used for dissolved nitrogen analysis of seawater samples at the University of Washington. Kjeldahl nitrogen, a measure of the concentration of combined organic nitrogen and ammonia, was not determined as it is a relatively useless measure in phytoplankton studies since it yields a combination of available and unavailable forms of nitrogen for cell growth. Separate determination of dissolved nitrogen ($\text{NO}_3 + \text{NO}_2 + \text{NH}_4^+$) and total nitrogen was conducted as well as determination of orthophosphate and total phosphate at the University of Washington Routine Chemistry Laboratory using a technicon autoanalyzer and a modification of the acid digestion method (APHA 1985), respectively. Dissolved nutrient and oxygen concentration were normally reported in mg/l (ppm), for ease of comparison to Weston (1986). Total nitrogen and phosphorus were reported as mg at./l, for comparison to other results of other studies using ratios. Identification and enumeration of larger phytoplankton (greater than 5-10 microns) was performed by an experienced phycologist using sedimentation chambers to concentrate samples and an inverted microscope (Unesco 1978).

Relative rates of phytoplankton production were estimated using a modification of the carbon 14 productivity method (Steemann Nielsen 1952), using water from the same water bottle cast that provided chlorophyll *a*, nutrients and other measures mentioned above. Samples were collected, during the morning and afternoon, from 2 m at three sites: directly next to the net-pens and at the north and south entrances to Peale Passage (Fig. 2). Triplicate

120 ml samples were put into acid-cleaned 125 ml BOD bottles and transported in the dark to the net-pens for incubation.

On May 25, 1988, 1.1 ml of the ^{14}C stock (20 $\mu\text{Ci/ml}$ NaHCO_3 solution) was added to each sample, and then 100 μl was immediately removed and placed into a liquid scintillation cocktail containing phenethylamine for total activity determination. The BOD bottles were incubated next to the pens at 2 m depth within 20 minutes of sample water collection. Care was taken to insure that the incubating samples were never shaded by the pens. At the end of the incubation period (5.67 hrs for the morning samples and 2.67 for the afternoon samples), duplicate 20 ml aliquots were removed from each BOD bottle and placed into a glass scintillation vial containing 1.8 ml of a 37% formalin. Upon return to the laboratory, the formalin-killed aliquots were filtered onto glass fiber filters (Whatman GF/F), fumed over 12 N HCL for 15 seconds, and placed in scintillation vials. Seven ml of liquid scintillation solution was added to the vial, and shaken overnight. The samples were counted in a Beckman LS1800 liquid scintillation counter for 15 minutes. Carbon uptake was calculated according to Strickland and Parsons, (1968). Reported values are not corrected for time-zero controls or dark bottles.

On June 21, 1988, the same initial procedures were followed. Additionally, single aliquots for time zero controls were removed and placed into glass liquid scintillation vials containing 1 ml 6 N HCL. At the end of sample bottle incubation, duplicate 5 ml aliquots were removed from each BOD bottle and placed into glass scintillation vials containing 1 ml of 6 N HCL. Upon returning to the laboratory, 8 ml of liquid scintillation solution was added to the vials, and they were shaken overnight. The samples were counted in a Beckman LS1800 liquid scintillation counter for 15 minutes. Reported values were corrected for time zero controls but not for dark bottles.

Statistical analysis of hydrographic data utilized one way and two-way analysis of variance and T-test procedures (Zar 1984).

Results

Experiment A

On sampling dates before and after the fish were released all stations had weak thermal stratification with little difference between the salinity at the surface and bottom (Tables 2 and 3). The highest water temperatures usually occurred at the southern entry to Peale Passage, not at the mid-channel areas near the net-pens. No trends in dissolved oxygen concentrations were seen on either sampling date. Secchi disk values (water transparency) were slightly lower at the net-pen site on both sampling dates.

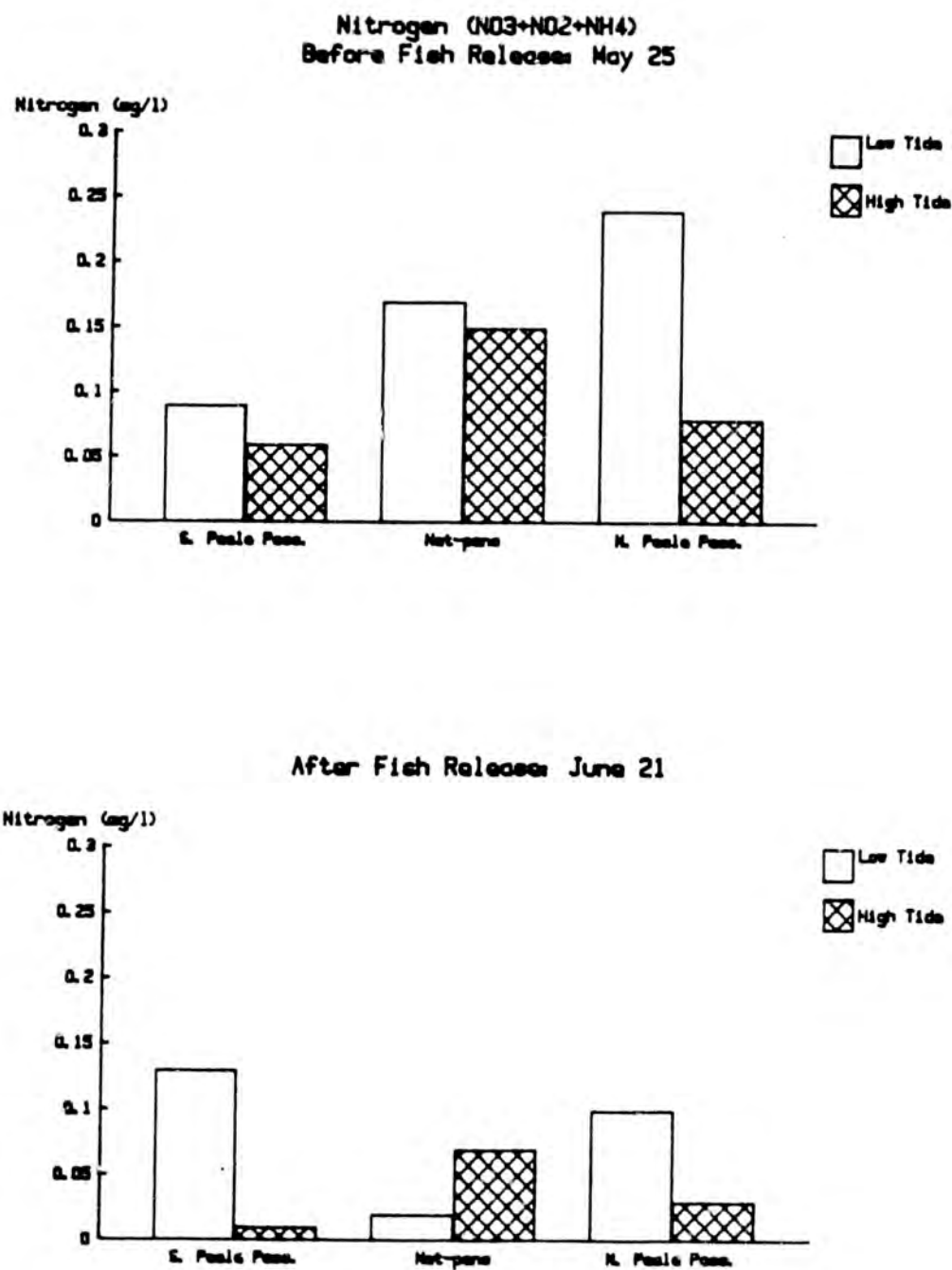


Figure 3. Dissolved nitrogen concentration before fish release (top, Fig. 3a) and after most of the fish were released (Fig. 3b). Standard deviation bars are omitted due to the very small amount of variance.

Table 2. Partial results of experiment A-1 from May 25, 1988.

Station	Depth (m)	Temp. (C)	Sal. PPT	Secchi Disk (m)	Dissolved Oxygen mg/l	Percent Oxygen Saturation	Chl. a ug/l	Dissolved Nitrogen* mg/l
<u>LOW TIDE</u>								
South	0	13.5	28.9	5.8				
Peale	2	13.5	29.0		10.8	124%	6.81	0.09
Passage	5	12.0	29.0					
	10	11.4	29.1					
Net-	0	13.1	29.0	3.6				
Pen	2	12.2	29.0		8.7	98%	23.91	0.17
Site	5	11.4	29.0					
North	0	12.1	28.9	4.0				
Peale	2	12.1	28.9		10.3	116%	6.52	0.24
Passage	5	11.9	29.1					
<u>HIGH TIDE</u>								
South	0	15.1	28.1	4.5				
Peale	2	13.5	28.4		13.7	158%	13.58	0.06
Passage	5	12.5	28.7					
	10	11.1	29.7		14.1	155%	15.25	0.70
Net-	0	13.1	29.0	3.5				
Pen	2	12.2	29.0		12.1	134%	15.56	0.15
Site	5	11.4	29.0					
North	0	13.6	29.0	3.9				
Peale	2	12.9	29.0		10.4	119%	9.76	0.08
Passage	5	12.1	29.0					

* Dissolved nitrogen values represent the total of nitrate, nitrite and ammonium. Nitrogen limitation for diatoms may occur below 0.04 mg/l.

Table 3. Partial results of experiment A-2 from June 21, 1988. Standard deviation shown in parenthesis.

Station	Depth (m)	Temp. (C)	Sal. (PPT)	Secchi Disk (m)	Dissolved Oxygen (mg/l)	Oxygen Saturation Percent	Chl. a (ug/l)	Dissolved Nitrogen*
<u>LOW TIDE</u>								
South	0	14.9	29.2	3.9				
Peale	2	13.8	29.1		9.6	116%	6.99	0.13
Passage	5	13.0	29.0				(0.082)	(0.019)
	10	12.6	29.0					
Net-	0	15.1	29.3	3.8				
Pen	2	14.9	29.0		12.0	143%	4.73	0.02
Site	5	14.1	28.8				(0.759)	(0.004)
North	0	15.0	29.0	3.4				
Peale	2	14.4	28.9		9.6	129%	6.84	0.10
Passage	5	13.8	28.7				(0.798)	(0.005)
<u>HIGH TIDE</u>								
South	0	15.3	29.0	3.7				
Peale	2	14.8	29.0		11.8	141%	3.95	0.01
Passage	5	13.5	29.0				(1.777)	(0.001)
	10	12.8	29.0					0.49 (---)
Net-	0	17.5	29.1	3.0				
Pen	2	15.0	28.8		12.1	144%	4.20	0.07
Site	5	14.1	29.0				(0.950)	(0.006)
	8	13.8	28.9					
North	0	16.4	28.5	3.5				
Peale	2	15.2	28.5		11.0	131%	5.47	0.03
Passage	5	14.0	28.7				(1.800)	(0.006)
	10	13.6	28.8					

* Dissolved nitrogen values represent the total of nitrate, nitrite and ammonium. Nitrogen limitation for diatoms may occur below 0.04 mg/l.

Table 4. Total nitrogen and phosphorus concentration, and T:N molar ratio. Mean and standard deviation of concentration when available from May 25, 1988 samples, expressed in ug-at/l.

<u>Site</u>	<u>Total N</u>	<u>Total P</u>	<u>N:P Ratio</u>
Experiment A-1: net-pen vicinity versus reference areas			
Low Tide			
south Peale	19.70	1.22	16.1
net-pen site	26.79	1.64	16.3
north Peale	31.06	1.91	16.3
High Tide			
south Peale	26.84	1.40	19.17
net-pen site	27.83	1.59	17.50
north Peale	26.83	1.58	16.98
Experiment B: upstream and downstream of pens			
Mid-flood			
upstream	24.95 (1.284)	1.50 (0.036)	16.63
downstream	30.83 (3.844)	1.87 (0.078)	16.49
Early ebb			
inside pens	47.35	1.93	24.53

Nutrients: Figure 3 shows dissolved nitrogen (defined as $\text{NO}_3 + \text{NO}_2 + \text{NH}_4^+$) at the three sampling stations on both sampling dates and tides. A gradient of increasing dissolved nitrogen from south to north was apparent at low tide. At high tide waters from central Peale Passage had moved toward the north Peale station to reduce dissolved nitrogen concentrations. Although dissolved nitrogen was relatively low at all stations on May 25th, it was not below the 0.04 mg/l threshold value for nitrogen limitation of diatoms (URS 1986a). Additionally, the total nitrogen to total phosphorus ratios (table 4) were not indicative of nitrogen limitation (Redfield 1958, Ryther and Dunstad 1971, McCarthy 1980, URS 1986a). Variation among replicates nitrogen samples was very small, thus statistical error bars were omitted in figure 3.

After release of most of the fish, dissolved nitrogen concentrations were lower at all stations than before the fish release, and not significantly different among stations ($p < 0.05$). Even on this later date, the dissolved nitrogen concentrations were not consistently lower than the growth limitation concentration. On both sampling dates the reference stations had lower dissolved nitrogen concentrations at low tide.

Chlorophyll a: The concentration of chlorophyll a was much greater at the net-pen station at low tide on May 25 but only slightly greater by high tide (Fig. 4a). Since replicates were not obtained, statistical significance is not known. However, the concentration at low tide near the net-pens was nearly four times greater than the reference areas and likely to be significantly greater. After most of the fish were released, on June 21 (Fig. 4b), there was significantly less chlorophyll a ($p < 0.05$) at the net pen site, compared to reference stations at low tide. Again, by high tide no differences were apparent as suggested by the overlapping standard deviation bars of that tide shown in figure 4b.

Primary Productivity: On May 25, primary productivity at the net-pen site was not significantly different at low tide versus high tide ($p < 0.05$). Compared to the reference stations, productivity was greater at low tide, but not at high tide (Fig. 5a). There were no statistical differences among stations on June 21, due to some of the replicate samples, possibly statistical outliers (see replicate values in appendix table A-2, pens). This data was not excluded from the analysis. Comparison of the trends of May 25 and June 21 data (Fig. 5a and 5b) suggests a similar trend with increased productivity during the morning low tide on both dates.

Due to methodological differences in processing the samples, the absolute values were considerably different on each sampling date, thus comparisons were not appropriate. Yet the

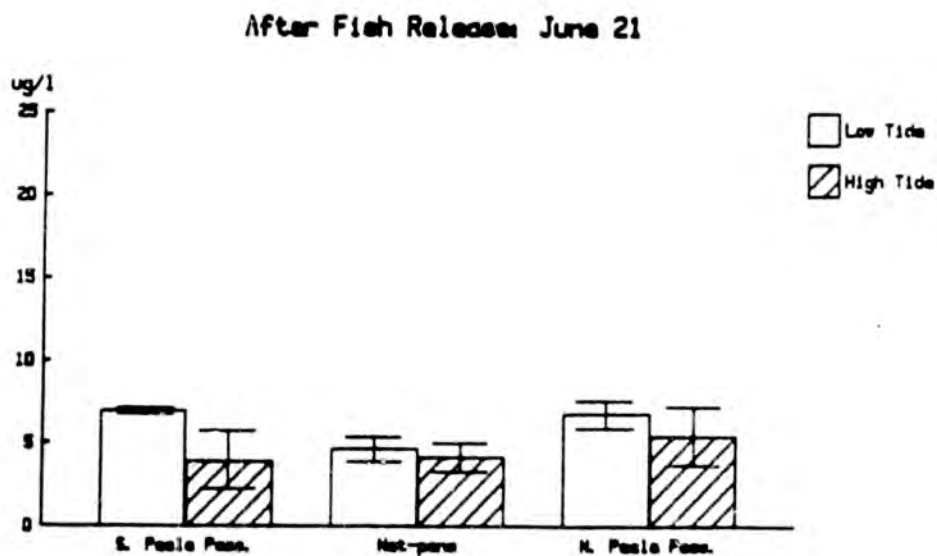
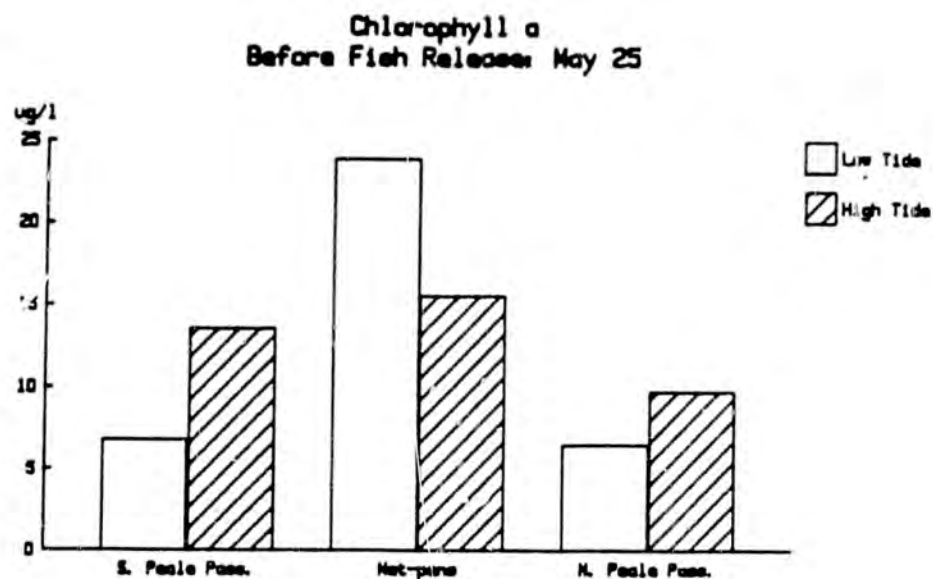


Figure 4. Chlorophyll a concentration before fish release (top, Fig. 4a) and after most of the fish were released (bottom, Fig. 4b). Standard deviation bars are shown where appropriate.

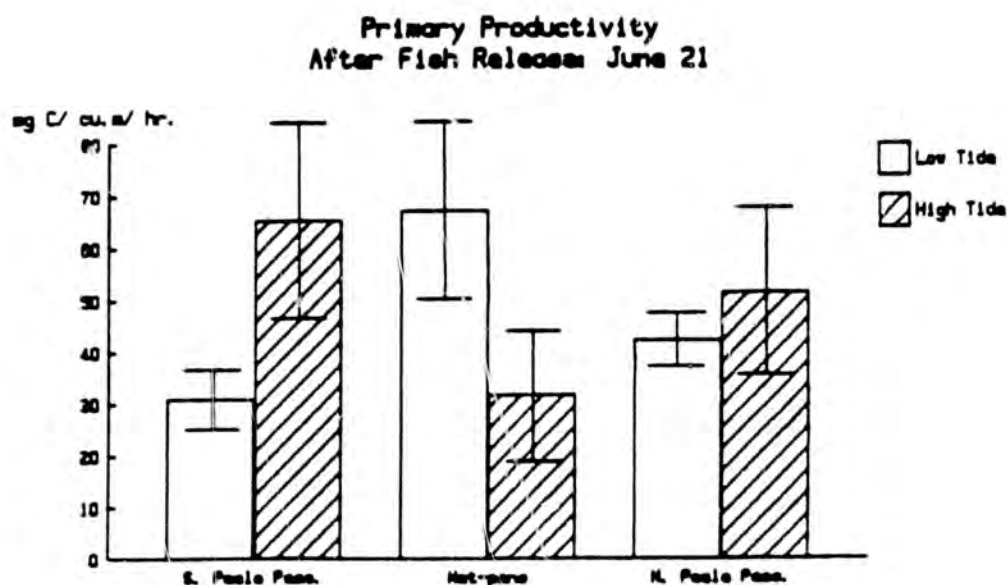
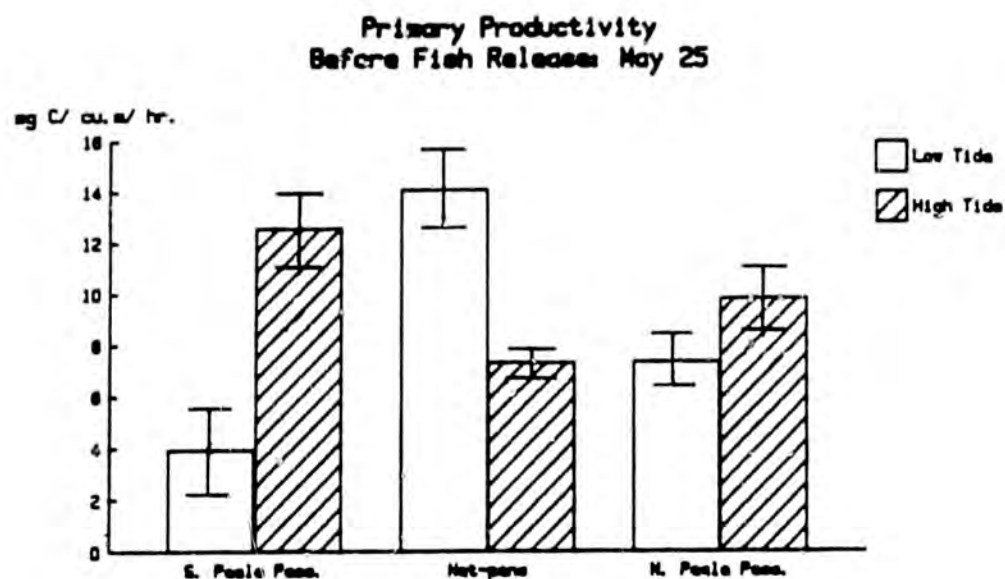


Figure 5. Primary productivity before fish release (top, Fig. 5a) and after most of the fish were released (bottom, Fig. 5b). Standard error bars are shown where appropriate. N = 6 for each station.

same relative trends on the two dates are apparent through inspection of figures 5a and 5b. Note that standard error bars were shown here, to save space, not standard deviation bars. Standard error is the standard deviation divided by the square root of the number of replicate measures. If standard deviation was shown on figure 5b, there would be greater overlap of bars.

Cell Counts: A summary of the species assemblage present during portions of the study is shown in table 5. On both sampling dates diatoms were by far the dominate phytoplankton. During the May sampling Coscinodiscus spp. and Thalassiosira spp., common chain forming species were prevalent. By late June Chaetoceros, also a very common diatom group, were most abundant. The Chaetoceros spp. present were members of the subgenus Hyalochaete, thought not to be directly responsible for fish kills in net-pens in the past as have been members of the subgenus Phaeoceros (Gaines and Taylor 1986). However, reports from Canada (Bell et al. 1974) and studies in Washington State (Rensel et al. in press), indicate that these species may contribute to mortality of net-pen salmon when abundant. There were not enough phytoplankton samples to make a rigorous comparison between tide stage or to other environmental factors. However, the slightly greater number of cells at the net-pens versus the reference station on May 25 appeared to correlate with nutrient and chlorophyll a values at high tide. The net-pen site had greater counts at high tide of June 21, which correlated with increased nutrient concentration, primary and specific productivity, but not with chlorophyll a concentration.

Table 5. Summary of cell counts from 2 m depth in cells per milliliter.

BEFORE FISH RELEASE: May 25, 1350-1420 hr.

	<u>S. Peale</u>	<u>Pen site</u>	<u>N. Peale</u>
<u>Chaetoceros Hyalochaete</u> spp.	51	0	not sampled
<u>Coscinodiscus onusta-lineata</u>	118	191	
<u>Thalassiosira</u> spp.	24	16	
total diatoms	231	278	
total dinoflagellates	22	131	
-----	----	----	
total phytoplankton (c/ml)	536	664	

AFTER FISH RELEASE: June 21, 1220-1310 hr.

<u>Chaetoceros Hyalochaete</u> spp.	536	1,639	740
<u>Skeletonema costatum</u>	6	25	80
Misc. pennate diatoms	2	59	22
total diatoms	645	1,825	952
total dinoflagellates	28	52	52
-----	----	----	----
total phytoplankton (c/ml)	806	2,069	1,109

Experiment B

During the morning flood tide, the concentration of dissolved nitrogen immediately upstream of the net-pens averaged 0.07 mg/l (table 6). The dissolved nitrogen (DN) was composed of nitrate (78%) and ammonia (22%). Just downstream of the net-pens, the concentration of dissolved nitrogen had doubled to 0.15 mg/l, which was significantly greater than upstream ($p < 0.005$). However, most of the dissolved nitrogen was in the form of nitrate ($\text{NO}_3^- = 86\%$ of DN), not ammonia ($\text{NH}_4^+ = 12\%$ of DN). A similar picture emerges if the data is viewed on a gram atom weight basis; the downstream nitrate was about 2.5 times greater than the ambient concentration. There was no statistical difference in the concentration of ammonia during this tide (on either unit basis) from upstream to downstream, but nitrate was significantly greater downstream ($p < 0.001$).

Total ammonia concentration in the plume of the net-pen during the morning flood averaged 0.0163 mg/l which is equivalent to an un-ionized ammonia concentration of 0.00037 mg/l at pH 8 and temperature 13 C. The EPA (1986) chronic exposure criteria (four day average concentration) for un-ionized ammonia under these conditions is 0.030 mg/l, about 80 times greater than the concentration observed downstream from the net-pens.

During the early portions of the ebb tide, the concentration of total dissolved nitrogen was significantly greater within the net-pens compared to upstream values ($p < 0.001$ for NH_4^+ and NO_3^- , $p < 0.005$ for NO_2^-). However, there was no significant difference in the upstream and downstream values of total dissolved nitrogen. Within that total, there was a significant increase in the concentration of ammonia (table 7). The proportion of toxic, un-ionized ammonia in the downstream area was about 90 times less than the EPA's (1986) chronic exposure criteria.

The concentration of un-ionized ammonia within the center of the net-pens during the ebb tide was 23 times greater than the upstream, ambient concentration. However, this amounted to only about 10% of the chronic exposure criteria mentioned above. The within-pen results were from the widest set of net-pens (three pens abreast), under maximum loading, and minimal current conditions. Ammonia loading within other net-pen systems at Squaxin Island was probably less due to the two abreast configuration which allows greater dilution with surrounding waters.

Table 6. Results of experiment B from May 25, 1988. All data collected from 2 meters depth where the water temperature was 12.2 C *. pH remained at 8.0 throughout this sample collection.

Tidal Stage & station	Dissolved Oxygen (mg/l)	Oxygen Saturation (%)	Dissolved Nitrogen** (Mean & SD) (mg/l)	Total Ammonia (mg/l)	Un-ionized Ammonia (mg/l)	Current Velocity (cm sec ⁻¹)
MID-FLOOD: 1200-1300 hours						
upstream:	11.7	132%	0.07 (0.020)	0.0155	0.00036	11.4
downstream	11.6	131%	0.15 (0.011)	0.0163	0.00037	5.2
EARLY EBB: 1500-1625 hours						
upstream:	12.2	137%	0.03 (0.006)	0.0069	0.00014	8.1
within pens***	10.4	117%	0.23 (0.006)	0.1606	0.00337	3.0
downstream	12.6	142%	0.03 (0.015)	0.0155	0.00033	7.9

* Total net-pen salmon biomass was 118,600 kg for the flood and 97,970 kg for the ebb, due to differing sampling location. Ebb tide samples were collected downstream (south) of the larger WDF pens (number 2).

** Dissolved nitrogen values represent the total of nitrate, nitrite and ammonium. Nitrogen limitation for diatoms may occur below 0.04 mg/l.

*** within pens site was in center of the pen system (number 2, WDF) that were 3 cages wide by 11 cages long with 52,640 kg of fish.

Table 7. Ammonia concentrations at the Squaxin Island net-pens during the upstream/downstream analyses (experiment B). Distance to downstream sampling station was 30 m from facility number 3. Percent change in concentration is relative to ambient, upstream concentration. Chronic exposure concentration is the four day average recommended by EPA (1986).

Tidal Stage	Influencing Fish Biomass (Kg)	Total Ammonia Concentration (mg/l) with standard deviation in parenthesis		
		Upstream	Within Pens	Downstream
Flood tide	118,600 kg	0.0155 (0.00686)	----	0.0163 (0.00202)
percent increase of total ammonia -->				5%
percent increase of un-ionized ammonia -->				2.3%
percent of chronic toxicity concentration ->				1.2%

Ebb tide	97,970 kg	0.0069 (0.00038)	0.1606 (0.00337)	0.0155 (0.00262)
percent increase of total ammonia -->			2,337%	224%
percent increase of un-ionized ammonia -->			2.1%	2.1%
percent of chronic exposure concentration ->			11.2%	1.1%

Discussion

Experiment A: Effects on Phytoplankton

Phytoplankton abundance and the growth rate at the net-pens varied significantly with the stage of the tidal cycle or the time of day. The most striking feature of this analysis was the very similar pattern of primary productivity seen before and after fish were release from the pens (Fig. 5). There was a general trend toward increased phytoplankton density (chlorophyll a) and C-14 productivity at the net-pens during the morning ebb tide, with no significant difference during the afternoon flood tide, regardless of the sampling date and amount of fish held in the net-pens (compare figs. 5a and 5b).

Total nitrogen to phosphorus ratios (table 4) indicated that growth was not limited due to nutrient depletion during the period before fish release, when greater phytoplankton density and significantly greater primary productivity was observed at the net-pens. Thus, the observed increased chlorophyll a during one tidal period of maximum fish biomass was not the result of

nutrient production from the net-pens, but may be related to the natural hydrodynamics of Peale Passage.

The reference areas used in experiment A were selected to be within the same passage, but as remote as possible from the net-pens. These areas were near the source waters of Pickering and Dana Passages, which are both subject to fairly intense horizontal and vertical mixing (URS 1986b) compared to the shallow Peale Passage area. It is likely that vertical mixing, and accordingly, light limitation for phytoplankton cells in both of the source areas is much greater than in Peale Passage. By the time source waters bearing nutrients and phytoplankton seed stock reach the middle portions of Peale Passage, a day or longer has passed, allowing for significant growth to occur in the water column, which is entirely within the euphotic zone.

Although similar trends in C-14 primary productivity were apparent on both sampling dates, there was no statistical difference among sites on the later sampling date, due to one possible outlier, a replicate sample that was not discarded. Further, the absolute values were different between sampling dates due to methodological differences and thus no comparison of primary production rates is possible between sampling dates.

Dissolved nutrient concentrations appeared to be roughly correlated with chlorophyll *a* values and were lower at all stations after most of the salmon were released. As discussed previously, Pease (1977) found an inverse relationship between the two throughout his study of Henderson Inlet. No causal relationship between these factors at the Squaxin Island net-pens is likely, due to the remoteness of the unperturbed reference areas, the relatively small amount of dissolved nitrogen contributed by the net-pens (theoretically about 33 kg/day total dissolved nitrogen) and results of nutrient sampling over the tidal cycle discussed below.

Some of the dissolved nitrogen concentrations during this study were below the threshold of limitation for diatom growth (0.04 mg/l; URS 1986). To show maximum effects this study should have been conducted when surface waters were nearly depleted of all forms of nitrogen (dissolved and total), if it ever occurs, to test the possibility that the pens could cause or sustain a phytoplankton bloom. These results and pre-experiment nutrient sampling indicated that dissolved nitrogen values at the pens fluctuated regularly, above and below the 0.04 mg/l growth limitation threshold. This value obtained for nutrient limitation of diatoms is not absolute and should be used with caution because growth limitation also depends upon the concentration of phytoplankton cells and organic matter in the water, rates of remineralization of the organic matter to dissolved inorganic nitrogen (Harris 1986), and the type and size of phytoplankton (Redfield 1958, Ryther and Dunstad 1971, Eppley 1972, McCarthy 1980, URS 1986a).

On May 25, during the period of maximum fish biomass, increasing concentrations of dissolved nitrogen were seen at low tide on a south to north, long-channel axis (Fig. 3a). This observation suggests that nutrient-rich waters were entering from the north end of the passage at that time. Due to the location of the net-pens relative to the ebb tide flow (Fig. 2), it also indicates that nutrients from the net-pens were not the major source of the higher concentrations of dissolved nitrogen seen at the north end of the passage. Later that day during the flood tide, a similar concentration of dissolved nitrogen, about 0.07 mg/l, previously seen at the south end of the passage was observed immediately upstream of the net-pens in the results of the upstream/downstream analyses (experiment B).

The elevated level of chlorophyll *a* at the net-pens prior to fish release and during the morning low tide (Fig. 4a; 24 ug/l), was nearly 4 times that of the reference stations. This non-replicated value was near the maximum values seen in two years of sampling in central Puget Sound (e.g., Anderson et al. 1984), but was much lower than summer values seen in nearby Henderson Inlet at control and experiment stations by Pease (1977). By high tide, the concentration of chlorophyll *a* had diminished at the Squaxin Island net-pen site.

After the fish release, there was significantly less chlorophyll *a* at the net pens on the morning low tide, but no difference by the afternoon. Compared to the period prior to fish release, and if one disregarded other data collected in this study, this suggests an effect due to the pens. However, the fact that dissolved nutrients were not limiting to phytoplankton growth prior to fish release is a more important factor and discounts any possible effect suggested by the increased chlorophyll *a*.

Another factor to be accounted for is the biomass of fish stock on hand before and after fish release. As previously mentioned, about 40% of the initial biomass (47,200 kg, both delayed release and fish for commercial purposes) was still on hand during the June 21 sampling date. However, this amount of biomass is small relative to the maximum amount of biomass that a typical two acre net-pen farm could maintain (up to 250,000 kg, J. Lindberg, pers. comm. in Weston 1986). I would have preferred that more of the fish had been released for the later sampling date, to provide a more representative experimental control, but that was not possible.

The results indicate that tidal stage, time of day and ambient nitrogen conditions were more important determinants of phytoplankton conditions at the net-pens and that nutrients from the net-pens did not produce a significant, measurable effect on the phytoplankton production. If time and materials allowed, several sampling stations midway between the pens and the reference areas would have been useful to search for a gradient of effects. Nevertheless, given the natural excess of total and dissolved nitrogen that existed throughout the study area at the

time of the study, no effects from the pens were possible. Nitrogen may be limiting in the study area later in the summer, but most of the salmon have generally been released by that time.

Recent studies in Scotland (Gowen et al. 1988) focused on phytoplankton density and growth rates in a restricted, fjordic sea-loch that had slow water movement (maximum flow of 16 cm sec^{-1}) and a single, large salmon net-pen farm. Additionally, water exchange into the 50 meter deep Loch Spelve is restricted by a 4 meter deep shallow sill. Study results indicate no measurable effect of the farm on phytoplankton density, although localized hypernitrification (elevated ammonia) was seasonally observed immediately around the net-pen farm. 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 net-pens, the residency time of water was too brief to allow measurable increases in phytoplankton density or growth rates.

Experiment B: Effects on Near Field Water Quality: Ammonia

This experiment involved measurement of nutrient levels upstream and downstream of the net-pen cages on May 25, when the maximum amount of salmon was present in pens. Divergent dissolved nitrogen results were seen between the two tidal stages monitored; the morning flood showed significantly elevated levels of dissolved nitrogen downstream, but only a very small, statistically insignificant increase in ammonia concentration. Monitoring during the afternoon ebb showed no significant difference in dissolved nitrogen concentration, but within that measure, the total ammonia concentration increased greatly as a percentage of upstream, ambient levels. However, the maximum concentration of un-ionized ammonia was only about 10 % of the EPA (1986) chronic exposure level for "salmonids and other sensitive coldwater species" and far below acute toxicity criteria.

The results of the flood tide analyses suggest that very rapid nitrification of ammonia occurred in the plume of the net-pen, consistent with general concepts of marine chemistry (Harris 1986). Most of the dissolved nitrogen was in the form of nitrate ($\text{NO}_3^- = 86\%$ of dissolved N), not ammonia ($\text{NH}_4^+ = 12\%$ of dissolved N) a distance of 30 m downstream of the third net-pen system.

The concentration of dissolved nitrogen was the same at the upstream and downstream stations on the afternoon ebb (0.03 mg/l). Total ammonia was about 52% of the dissolved nitrogen in the downstream samples, compared with 70% inside the pens. In addition to nitrification, reduced ammonia downstream was apparently due to dilution during the ebb tide measurements.

The rate of ammonia nitrification can be approximated as follows, using the flood tide data. Assuming that 70% of the dissolved nitrogen within the pens was ammonia, as it was on the ebb, and

given the average current velocity of 8.3 cm sec^{-1} , the mean distance from the center of all three net-pen systems to the downstream sampling location was 290 m. Accordingly, ammonia within the cages was converted from 70% to 12% of the total dissolved nitrogen concentration within about 1 hour. By then, the concentration of un-ionized ammonia was far below the exposure criteria for sensitive species such as salmonids (EPA 1986).

It has previously been conservatively assumed that all dissolved nitrogen produced by the net-pen fish was in the form of ammonia or urea, not nitrate (Weston 1986). While this is apparently true within the pens, the results presented here substantiate that nitrification converts the ammonia to nitrate over very short time periods, rapid compared to the doubling time of phytoplankton populations (minutes versus hours or days, respectively). The dominant dissolved nitrogen compound measured immediately downstream of the net-pens is nitrate. Nitrate is less preferred by phytoplankton cells, and its uptake rate is slower than that of ammonia.

The calculated production rate of dissolved nitrogen from the net-pen should be at least $0.22 \text{ to } 0.28 \text{ g kg}^{-1} \text{ fish day}^{-1}$ greater than the ambient concentration. These values represent the sum of nitrate and ammonia produced by salmon (SAIC, 1986 and Weston 1986, respectively), multiplied by 0.87, the soluble fraction. Using the greater figure to be conservative, on the flood tide there should have been a net increase of 33.2 kg/day or $0.384 \text{ gram sec}^{-1}$ nitrate and ammonia in the plume of the net-pen ($118,600 \text{ kg} \times 0.28 \text{ g divided by } 86,400 \text{ seconds per day}$). When spread over the average cross sectional area of all the pens ($93.6 \text{ m long} \times 4 \text{ m deep} = 374 \text{ m}^2$), and dispersed with the current (0.083 m sec^{-1}), this is equivalent to 0.012 mg/l greater than the upstream, ambient concentrations ($37.9 \text{ kg divided by } 31.04 \text{ m}^3 \text{ sec}^{-1}$). The observed downstream concentration was 0.08 mg/l , about six times greater than ambient dissolved nitrogen, but less than an order of magnitude different. Variation among sample replicates was very little, lending credibility to the results. Using similar calculations for the ebb tide results, there should have been a similar predicted increase of dissolved nitrogen concentration downstream, but none was observed.

The lack of any measurable increase in dissolved nitrogen on one tidal phase and the increase on the other could be due to tidal hydrodynamics of the site and fish physiology. I have conducted similar studies at several other locations and have found increased concentrations of ammonia within or immediately downstream of the every net-pen system monitored (appendix B), but total nitrogen values have been more variable, sometimes even less than the upstream values.

Measured increase of nutrients that exceed predicted concentrations can be explained by several factors. The predicted increase was based on literature from freshwater

hatcheries, not from marine net-pens. The Squaxin Island net-pen systems is mostly used for delayed release of relatively small (<40 g) coho salmon that require more rearing space per pound of fish than larger fish typically held in a commercial grow out facility. Accordingly, there is more netting and floats for growth of fouling organism, that may contribute nutrients. In addition, the net-pens are not removed and cleaned at the delayed release facility during the rearing period. The nets in a delayed release facility are installed in late winter and left in place until late spring to early summer. By the initial sampling time of this study (late spring), there was a considerable accumulation of invertebrate and algal fouling organisms on the nets. This condition is tolerated since the nets are removed in early summer for the remainder of the year. To determine the contribution of nutrients from floats and invertebrates growing on the nets, it would be useful to measure nitrogen concentrations at the Squaxin Island net-pens after the salmon were released, but before the nets are removed.

Finally, there is a inverse relationship between fish size and rate of metabolite production. Clark et al. (1985) found rapidly decreasing rate of ammonia production with increased fish size, about a 50% reduction from the 10 gram to 200 gram mean weight. The dominance of small fish at the Squaxin Island delayed release net-pens would therefore result in proportionately greater nitrogen discharge than a grow out facility with fish ranging in size from 20 grams to 10 kg or larger.

The lack of increased dissolved nitrogen downstream of the net-pens on the ebb tide could be due to dilution or unknown and irregular water motion. A one m deep drift stick placed immediately downstream of the net-pens moved very little for 20 minutes prior to the ebb tidal sample. From this observation, and numerous other observations by the author at some other facilities during low velocity periods of water movement, there appears to be an area immediately downstream of some net-pen facilities that may temporarily exhibit lack of water movement or anomalous patterns of water flow.

Other recent data collected to more accurately predict expected dissolved nitrogen concentrations downstream of net-pen facilities (appendix B) are insufficient in quantity at this time for regression analyses. The following narrative describes some of the recent studies.

Studies conducted near the world's largest net-pen facility, Domsea Farms, Inc., found no measurable effect on downstream water quality (D. Damkaer, NMFS, unpublished data cited in Weston 1986). Tidal flows in that area are greater than at the Squaxin Island net-pen site and annual production was approximately 8 times greater than at Squaxin Island.

Milner-Rensel Associates (1986) found similar results for ammonia production in a study of water quality near a relatively small

net-pen system in Port Angeles Harbor (see appendix B). The pens contained 27,000 kg of fish and there was mean current velocity of 7 cm sec^{-1} during sampling. The concentration of ammonia increased within the net-pens, but immediately downstream the ammonia was converted to nitrate and diluted. The concentration of total ammonia inside the net-pens at Port Angeles was 0.020 mg/l, compared to 0.007 mg/l in the ambient, upstream water. The total ammonia concentration had diminished 30 m downstream of the net-pens to 0.011 mg/l, or 0.004 mg/l greater than the ambient, upstream value. Downstream nitrate increased 0.049 mg/l over ambient, although there was a fairly high variance within replicates. As the site was so near the Strait of Juan de Fuca, total dissolved nitrogen was much higher than at Squaxin Island and was 97% nitrate, the remainder being mostly ammonia.

Two years later in Port Angeles Harbor there were 192,000 kg of fish on hand with a current velocity of about 8 cm sec^{-1} (Rensel, unpublished data). In spite of the relatively large size and minimal currents during sampling, the concentration of toxic un-ionized ammonia was less than 6% of the EPA (1986) four day chronic exposure level for "salmonids and other sensitive coldwater species".

Another upstream/downstream analysis was conducted at a very small facility in the first year of operation at north Skagit Bay. The results indicate extremely minor increases of ammonia (0.001 mg/l increase in total ammonia downstream), and total dissolved nitrogen levels actually decreased downstream (Rensel 1988).

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Appendix A

Appendix Table A-1. Productivity data from Squaxin Island on May 25, 1988.

SAMPLE	Total Activity		DPM				
	CPM	H#					
LA1	45322	126.3	48385				
LA2	40302	107.3	42667				
LA3	41287	105.7	43688				
LA4	41640	105.3	44056				
LA5	43032	105	45525				
LA6	37755	104.3	39934				
LA7	44236	105.3	46803				
LA8	41820	104.3	44234				
LA9	40342	104	42667				
LA10	34420	105	36414				
LA11	30763	105.7	32552				
LA12	29903	104.7	31632				
LB4	34385	105	36377				
LB5	45706	103.3	48331				
DA10	37593	104.7	39768				
LB10	42070	104.3	44499				
L-	40516	107	42890				
DA12	39540	103.7	41816				
mean & sd =			41791	4877			

Sample	cpm	H#	dpm	mgC/m ³	mgC/m ³ /h	site mean	st dev
N. Peale	11117	152.3	12098	35.09	6.19	7.37	2.36
1100 h	14557	141.7	15701	45.53	8.04		
	6355	144.3	6869	19.92	3.52		
	12779	144.7	13816	40.07	7.07		
	16809	149.3	18244	52.91	9.34		
	18191	143.7	19651	56.99	10.06	2.49	0.13
NP dark	4681	144.3	5059	14.67	2.59		
	4350	140.3	4687	13.59	2.40		
S. Peale	6411	146.3	6940	20.13	3.55	3.96	0.64
1100 h	8969	140.0	9661	28.02	4.94		
	5904	144.0	6379	18.50	3.26		
	6374	141.7	6875	19.94	3.52		
	7269	144.7	7858	22.79	4.02		
	8044	142.3	8680	25.17	4.44	2.77	0.21
SP dark	5286	143.3	5709	16.56	2.92		
	4740	143.7	5121	14.85	2.62	14.10	3.40
Pens	24502	142.7	26448	76.70	13.54		
1100 h	34093	143.3	36819	106.78	18.84		
	19775	143.0	21350	61.92	10.93		
	25980	155.3	28352	82.22	14.51		
	30384	146.7	32904	95.42	16.84	2.74	0.82
	18019	144.3	19475	56.48	9.97		
Pens dark	6009	141.0	6478	18.79	3.32		
	3918	139.7	4220	12.24	2.16		

Appendix Table A-1 Continued

Pens	7065	140.7	7615	22.08	8.28	7.33	0.83
1420 h	5805	141.3	6259	18.15	6.81		
	5461	144.3	5902	17.12	6.42		
	6984	138.7	7516	21.80	8.17		
	5574	146.7	6036	17.50	6.56		
	6585	143.0	7110	20.62	7.73		
Pens dark	5023	143.0	5423	15.73	5.90	5.98	0.11
	5151	144.7	5569	16.15	6.06		
N. Peale	8788	143.0	9488	27.52	10.32	9.83	2.35
1420 h	7746	141.3	8353	24.22	9.08		
	10884	142.7	11748	34.07	12.78		
	6095	142.7	6579	19.08	7.15		
NP dark	5074	142.7	5477	15.88	5.96	7.57	2.29
	7823	143.7	8451	24.51	9.19		
S. Peale	9809	142.7	10588	30.71	11.52	12.59	3.90
1420 h	10953	144.0	11835	34.32	12.97		
	15027	145.0	16250	47.13	17.67		
	7061	142.7	7622	22.10	8.29		
SP dark	8513	142.7	9189	26.65	9.99	10.63	0.90
	9567	147.3	10366	30.06	11.27		

Appendix Table A-2. Productivity data from Squaxin Island
on June 21, 1988.

Total Activity				Time Zero			
SAMPLE	CPM	H#	DPM	SAMPLE	CPM	H#	DPM
LA1	30709	97.7	32431	LA1	12914	187.3	14640
LA2	32320	97.3	34130	LA2	17286	188.0	19615
LA3	40114	96.7	42355	LA3	23496	191.3	26792
DA2	31354	97.7	33112	DA2	15559	190.0	17707
LA4	42788	100.0	45209	LA4	14053	191.3	16025
LA5	33342	98.0	35213	LA5	15352	191.0	17497
LA6	32321	97.7	34134	LA6	19196	191.3	21888
DA4	57645	97.3	60872	DA4	15914	190.0	18111
LA7	35327	96.7	37300	LA7	23220	190.7	26454
LA8	41635	97.3	43966	LA8	18071	189.7	20558
LA9	56040	92.3	59131	LA9	20634	189.0	23449
DA6	46998	97.0	49626	DA6	28962	188.7	32899
LA10	34203	98.3	36125	LA10	13760	189.7	15653
LA11	32854	97.0	34691	LA11	17595	189.7	20015
LA12	30044	97.0	31725	LA12	20718	190.7	23604
DA8	36880	99.3	38961	DA8	16791	190.3	19118
LB1	33806	98.7	35709	LB1	15999	190.7	18227
LB2	44646	98.0	47152	LB2	23215	190.0	26420
LB3	55483	96.7	58582	LB3	31380	191.0	35766
DA10	35420	97.0	37401	DA10	38891	187.7	44114
LB4	31400	96.7	33154	LB4	45703	187.0	51788
LB5	41051	95.7	43337	LB5	26202	188.3	29746
LB6	38103	90.3	40196	LB6	35817	190.7	40805
DA12	47776	111.0	50643	DA12	20863	189.7	23733
mean & sd =			41465 8848	mean & sd =			25193 9650
				Inc Time 1 =	6.42		
				Inc Time 2 =	3.00		
SAMPLE	CPM	H#	DPM	mg C/m ³	mg C/m ³ /h	site means	st err
N. Peale	39926	190.7	45486	240.17	37.41	42.42	4.96
1020 h	35680	190.7	40649	182.93	28.49		
	40080	189.0	45547	240.91	37.52		
	42000	188.7	47709	266.48	41.51		
	43650	189.3	49626	289.18	45.04		
	52944	189.3	60193	414.24	64.52		
dark	24044	189.5	27344	25.46	3.97	-6.09	10.06
	14498	187.3	16435	-103.65	-16.14		
S. Peale	47033	189.0	53449	334.43	52.09	31.07	5.86
1020 h	44343	189.3	50414	298.51	46.50		
	31438	190.0	35778	125.29	19.51		
	33980	188.3	38576	158.40	24.67		
	31870	190.0	36271	131.11	20.42		
	33273	188.7	37795	149.15	23.23		
dark	31688	190.0	36063	128.65	20.04	10.94	9.10

Appendix Table A-2. Continued

	23020	189.7	26187	11.77	1.83		
Pens	30478	189.7	34671	112.18	17.47	67.39	16.82
1020 h	29487	189.3	33524	98.60	15.36		
	59108	190.0	67270	497.99	77.57		
	76650	187.3	86893	730.24	113.74		
	65200	189.0	74094	578.77	90.15		
	65085	189.7	74039	578.12	90.05		
dark	31450	189.3	35756	125.02	19.47	22.09	2.62
	33914	190.0	38597	158.65	24.71		
N. Peale	29780	190.7	33927	103.37	34.46	51.66	16.51
1330 h	43497	191.3	49598	288.95	96.28		
	44550	188.7	50605	300.77	100.26		
	35031	188.7	39793	172.80	57.60		
	22695	189.7	25817	7.39	2.46		
	26412	188.3	29985	56.71	18.90		
dark	25720	190.0	29271	48.27	16.09	0.40	15.69
	18724	190.3	21319	-45.84	-15.28		
S. Peale	25636	194.7	29384	49.60	16.53	65.47	18.93
1330 h	22595	188.3	25651	5.43	1.81		
	48384	191.7	55204	355.19	118.40		
	41857	189.7	47615	265.38	88.46		
	43607	188.7	49534	288.08	96.03		
	38120	189.3	43339	214.77	71.59		
dark	12257	190.0	13950	-133.07	-44.36	-22.69	21.67
	21942	189.0	24935	-3.05	-1.02		
Pens	25096	189.3	28532	39.52	13.17	31.80	12.34
1330 h	25007	189.0	28419	38.18	12.73		
	28747	190.0	32716	89.04	29.68		
	22293	187.7	25287	1.12	0.37		
	40063	189.0	45528	240.68	80.23		
	34303	190.0	39039	163.88	54.63		
dark	21967	190.3	25011	-2.15	-0.72	15.55	16.26
	29307	188.0	33256	95.44	31.81		

Appendix B

A number of studies have been conducted in Washington state to assess the nearfield effects of net-pen operation on nutrient and dissolved oxygen concentration in marine waters. Several of these studies have been conducted in accordance with methods outlined in the State of Washington's Recommended Interim Guidelines for the Management of Salmon Net-pen Culture in Puget Sound (SAIC 1986). Other studies, conducted prior to the guidelines, were essentially the same, although within net-pens sampling stations were utilized instead of the the first downstream sampling station.

All of the near field studies (Appendix Table B-1) have shown increased concentrations of ammonia immediately downstream or within the net-pens. Total ammonia values have increased from 3 to 2,327%. However, the amount of un-ionized ammonia increased only a few percent of the four-day maximum chronic exposure level recommended by EPA (1986), ranging from 0.9 to 11.2%. The maximum increase (11.2% of the recommended chronic exposure value) was found within, not downstream, of the largest of three net-pen systems at Squaxin Island. These pens were configured to have three pens wide by 10 pens long, causing significantly reduced water flow within the center pens, where samples were collected. As the concentration of any waste nutrient is greatly dependent on tidal flow rate, and the samples were collected in a worst case area at only a few cm per second flow, this appears to be a worst-available-case analysis. To compensate for reduced flows and possible reduced growth, fish culturists at that site have reduced fish loading within the center pens.

Studies of nutrients in "upstream" and "downstream" waters immediately adjacent to net-pens in Washington state have also indicated that relatively rapid rates of nitrification occur, i.e., ammonia (NH_4^+) is oxidized by microbial action to nitrate (NO_3). A typical scenario involves elevated concentrations of ammonia within the net-pens but a short distance downstream, the ammonia has been converted to nitrate.

The data has been included here to illustrate the amount of ammonia produced by a wide variety of pens, of differing size. The results show that adverse effects are minimal, even at relatively large facilities. The continued collection of this data will eventually allow more precise calculation of the total dissolved nitrogen produced from marine net-pen reared salmon, the fouling organisms on the nets and floats and the fish associated with the net-pen facility. Such data will allow more precise calibration of numerical models that are designed to assess the possible cumulative effect of salmon net-pens in restricted embayments. Presently the only data available for this purpose is from freshwater hatchery culture of relatively small fish.

Appendix Table B-1. Summary of dissolved nitrogen, total and un-ionized ammonia production from marine net-pen farms in Washington state compared to maximum recommended four day exposure concentration (EPA 1986). Percent change in concentration is relative to upstream concentration.

Site - Data Source & Instantaneous loading (Kg)	Concentration (mg/l) & Percent Change		
	Upstream	Within Pens	30 meters Downstream
PORT ANGELES HARBOR ^{1/} 27,000 kg			
Total dissolved nitrogen-->	0.832	0.882	0.887
Total Ammonia -->	0.0074	0.0201	0.0119
NH ₄ ⁺ percent increase relative to ambient ->	272%		62%
percent of ammonia that is toxic (NH ₃) -->	1.8%		1.8%
percent of chronic toxicity concentration ->	1.5%		0.9%

	Upstream	6 meters Downstream	30 meters Downstream
SKAGIT BAY ^{2/} (Lone Tree Pt.) 4,300 kg			
Total dissolved nitrogen-->	1.067	1.131	1.139
Total Ammonia -->	0.0277	0.0303	0.0287
NH ₄ ⁺ percent increase relative to ambient ->	9%		3%
percent of ammonia that is toxic (NH ₃) -->	0.3%		0.3%
percent of chronic toxicity concentration ->	1.9%		1.8%

SQUAXIN ISLAND ^{3/} (Peale Passage) 118,600 kg			
	Upstream	6 meters Downstream	30 meters Downstream
Total dissolved nitrogen-->	0.07	----	0.15
Total Ammonia -->	0.0155	----	0.0163
NH ₄ ⁺ percent increase relative to ambient ->			5%
percent of ammonia that is toxic (NH ₃) -->			2.3%
percent of chronic toxicity concentration ->			1.2%

Appendix Table B-1, continued

SQUAXIN ISLAND ^{4/} (Peale Passage) 97,970 kg

Concentration (mg/l) & Percent Change

	<u>Upstream</u>	<u>Within pens</u>	<u>30 meters Downstream</u>
Total dissolved nitrogen-->	0.03	0.23	0.03
Total Ammonia -->	0.0069	0.1606	0.0155
NH ₄ ⁺ percent increase relative to ambient ->	2,327%		225%
percent of ammonia that is toxic NH ₃ -->	2.1%		2.1%
percent of chronic toxicity concentration ->	11.2%		1.1%

PORT ANGELES HARBOR ^{5/} 192,500 kg

	<u>Upstream</u>	<u>6 meters Downstream</u>	<u>30 meters Downstream</u>
Total dissolved nitrogen-->	1.4869	1.6688	1.6207
Total Ammonia -->	0.0343	0.0873	0.0516
NH ₄ ⁺ percent increase relative to ambient ->	254%		150%
percent of ammonia that is toxic (NH ₃) -->	1.5%		1.5%
percent of chronic toxicity concentration ->	6.4%		3.8%

PORT ANGELFS HARBOR ^{6/} 192,500 kg

	<u>Upstream</u>	<u>6 meters Downstream</u>	<u>30 meters Downstream</u>
Total dissolved nitrogen-->	1.5862	1.5771	1.4992
Total Ammonia -->	0.0122	0.0642	0.0336
NH ₄ ⁺ percent increase relative to ambient ->	526%		275%
percent of ammonia that is toxic (NH ₃) -->	1.5%		1.5%
percent of chronic toxicity concentration ->	4.7%		2.4%

Data sources and downstream velocity: 1) Milner-Rensel Associates 1986, 8.0 cm sec⁻¹ @ 30m downstream; 2) Rensel 1988, 38.8 cm sec⁻¹ @ 6m; 3) See main text, flood tide, 5.2 cm sec⁻¹; 4) See main text, ebb tide, 7.9 cm sec⁻¹. 5) Rensel unpublished on flood tide, 8.2 cm sec⁻¹; 6) Rensel unpublished on ebb tide, 8.4 cm sec⁻¹.

APPENDIX D

Infectious Diseases of Salmon in the Pacific Northwest

FISH DISEASES

Metazoan Parasites. External copepods (*Lepeophtheirus salmonis* and *Caligus* sp.) and monogenean gill flukes *Laminiscus sterkorli* are the only metazoan parasites that have been observed in sufficient intensities to be considered significant pathogens of net-pen reared fish in Washington (Kent and Elston, 1987b; L. W. Harrell, NMFS, Manchester, WA, pers. comm).

Protozoans. Diseases due to marine protozoan parasites are common in net-pen reared salmon. These include *Parvicapsula* sp. (Myxosporea: Myxozoa) which causes kidney disease in pen-reared coho salmon (Hoffman 1984; Johnstone 1984, Kent and Elston 1987b) for which cod is the likely reservoir for infection (Johnstone, 1984); *Paramoeba pemaquidensis*, a ubiquitous, normally free-living amoeba which infects gills (Kent et al. 1988b); an unidentified protozoan (rose tte agent) which infects inflammatory cells of maturing chinook salmon in net-pens (Elston et al. 1986; Harrell et al. 1986); and a microsporidan protozoan which infects blood-forming cells of chinook and causes severe anemia (Elston et al. 1987).

Freshwater protozoan pathogens may also be transmitted with fish when they are introduced to net-pens. Kent and Elston (1987b) observed infections by a microsporidan similar to *Loma salmonae* (Microspora) in the gills of coho salmon held in net-pens. These infections were apparently contracted in freshwater. *Ichthyobodo* (*Costia*) is a common flagellate protozoan pathogen in freshwater which can apparently survive and cause disease in fish after seawater transfer (Ellis and Wooten 1978) and it has occasionally been associated with gill disease in pen-reared salmon in Washington.

Bacteria. *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease of salmonids, is widespread in net-pen reared salmon in Washington State, as well as British Columbia, and is a serious threat to the industry (Evelyn 1988). Salmonid fishes are the primary hosts for this obligate pathogen but herring (*Clupea harengus*) and black cod (*Anoplooma fimbria*) can be infected experimentally by injection of the bacterium (Traxler and Bell in press). It is believed that the organism is not part of the normal bacterial aquatic microflora (Austin and Austin 1987) and salmon are the likely reservoir for infection (Fryer and Sanders 1981). The disease can be transmitted either horizontally (from fish to fish) or vertically within eggs (Evelyn et al. 1984), and it is often exacerbated after infected fish are transferred to seawater (Banner et al. 1983). The bacterium can be detected in pen-reared salmon several months after transfer to seawater and the disease can be transmitted to other salmon in adjacent net-pens (Evelyn 1988). The bacteria persist in wild fish in seawater (Banner et al. 1986) and it is probable that wild brood stocks are a source of infections in some fish farms (Evelyn 1988).

It is difficult to treat fish with clinical disease so prevention is the most common control method. Prevention strategies include screening brood stock and discarding eggs from positive females and screening smolts prior to seawater introduction. Erythromycin injection of females prior to spawning appears to induce high enough levels of the antibiotic in eggs to reduce vertical transmission to the fry (Evelyn et al. 1986) and this practice has been initiated at several fish farms.

Furunculosis, caused by the Gram-negative bacterium Aeromonas salmonicida, often causes severe disease in freshwater fishes. Although the bacterium often originates in freshwater, it can apparently survive and spread in seawater (Scott 1968), and it has been recognized as a pathogen in seawater in Washington (Novotny 1978). As with Renibacterium, epizootic disease in salmon with latent infections occurs after transfer to seawater (Cox et al. 1986; Smith et al. 1982). Though the disease is most often observed in salmonid fishes, it has also been reported in several non-salmonid marine and freshwater species (Elliot and Shotts 1980; McCarthy 1975; Morrison et al. 1984). Furunculosis is usually treated with oxytetracycline or Romet 30. There is active research on an effective bath immersion vaccine, but this is not routinely used in production facilities.

Vibriosis, caused by marine bacteria of the genus Vibrio, is a cosmopolitan disease infecting many fish species. It frequently occurs in net-pen reared fish in Washington State (Novotny 1978) and British Columbia (Evelyn 1971). Though several Vibrio spp. have been incriminated as agents of disease in cultured fishes, only three species are well documented pathogens of salmonid fishes; V. anguillarum, V. ordalii and V. salmonicida (Egidius 1987). Only the former two species have been reported in fish from Washington (Novotny 1978). Vibrio anguillarum is ubiquitous in the marine environment (Muroga et al. 1986) and can survive without a fish host for several months (Toranzo et al. 1982). Therefore, V. anguillarum is considered a facultative pathogen and does not require a fish host to survive in the marine environment (Muroga et al. 1986). Whereas V. anguillarum infects over 40 fish species and has been isolated from wild as well as cultured fishes, V. ordalii has only been isolated from pen-reared salmon.

A newly identified Vibrio sp., V. salmonicida is the causative agent of Hitra disease in net-pen reared Atlantic salmon in Europe (Egidius et al. 1986; Wiik and Egidius 1986). Vibrio salmonicida has not been detected in salmon reared in North America. No Vibrio spp. pathogenic to man have been associated with disease in salmon and human health concerns with Vibrio spp. have been restricted to warm water aquaculture (Egidius 1987). Unlike R. salmoninarum, Vibrio infections usually occur only after seawater transfer. Vibriosis is usually an acute systemic disease and fish which recover show strong immunological protection against reinfection. Effective vaccines are commercially available which protect fish from V. anguillarum and V. ordalii infections and the disease is prevented by vaccinating fish prior to seawater introduction.

Viruses. Though several viral diseases are important in salmon during their freshwater phase of development, none have been reported from salmon in seawater. Infectious hematopoietic necrosis (IHN) is of most concern in the Pacific Northwest. This virus is a persistent problem in fry and fingerling chinook salmon at several hatcheries. Apparently only fingerlings and returning salmon in freshwater are infected with IHN and it has not been isolated from fish in seawater. In vitro studies by Pietsch et al. (1977) and Toranzo et al. (1982) indicate that the virus survives poorly in seawater.

Idiopathic Diseases. Kent and Elston (1987a) observed a condition similar to pancreas disease in Atlantic salmon reared in Washington. This disease has previously been described in Atlantic salmon reared in Europe during their first year in seawater (Munro et al. 1984; McVicar 1987). Fish become emaciated and histological

examination reveals diffuse necrosis and atrophy of the exocrine pancreas. The cause is unknown. Researchers in Scotland have proposed various etiologies; Ferguson et al. (1986) suggested that the condition may be related to vitamin E and selenium deficiencies, whereas Munro et al. (1984) reported epizootiological evidence consistent with an infectious etiology. If the cause of this disease is an infectious agent, it is of marine origin with no link to freshwater or stock origin (McVicar 1987). An infectious etiology is also indicated in a study by Ferguson (1986). Fish from the same egg lot were transferred to two sites. Fish at the site where the disease was enzootic developed the disease while fish transferred to a site with no history of the disease remained unaffected.

APPENDIX E

The Economics of Salmon Farming

THE ECONOMICS OF SALMON FARMING:

ROBERT L. STOKES

REPORT TO THE WASHINGTON STATE
DEPARTMENT OF FISHERIES

OCTOBER 1988

EXECUTIVE SUMMARY

This report examines three economic issues arising from recent growth in Washington's salmon farming industry. The first issue is potential gains in output, income and employment to the economies of the state and of selected counties. The second is impact on revenues and expenditures of state government. The third is implications for real estate values of various (externally provided) assumptions concerning visual impacts of salmon farming facilities. The report concludes with a benefit - cost analysis of hypothetical siting decisions that demonstrates positive statewide economic gains under all assumptions and substantial gains under assumptions favorable to the industry.

Washington's salmon farming industry is a segment of the world's rapidly growing mariculture industry. After some years of concentration on Pacific salmon (pan size coho), industry interest has shifted to production of mature Atlantic salmon. Several sites have been established in the past 2 years and many more are in various stages of planning or application for permits.

The combination of favorable water temperatures, sheltered waters and infrastructure make Washington's Puget Sound one of the prime sites in the US for salmon farming. Current operators compete favorably with Norwegian and Scottish producers for US markets, and industry leaders feel that the combination of

domestic and Japanese demand provides a market base for extensive future growth. The following are this authors general conclusions concerning the economic consequences for Washington State (and selected counties) of permitting or encouraging expansion of the fish farming industry.

*** The economic impacts of such growth were determined by assuming that a representative Atlantic salmon facility (1,000,000 lbs production, \$5,000,000 revenue) was sited in each of Clallam, Jefferson, Kitsap, San Juan and Skagit Counties. Conclusions of that analysis were that the state economy would gain (from all 5 sites) \$38 - \$48 million in output, \$11 - \$21 million in household income and 257 - 303 jobs. Average County impacts for a single site were output \$5.8 - \$6.8 million, household income \$1.1 - 2.1 million and 40 - 51 jobs.

*** These economic impact results provided the basis for estimates of state fiscal (revenue and expenditure) consequences. Depending on the economic impact values used and method of relating economic impacts to fiscal consequences, salmon farming would contribute \$.36 - \$2.26 million to state revenues and \$1.08 - \$1.48 to state expenditures.

*** Property values were examined by collecting and statistically analyzing 335 current real estate listings and assessed property valuations. The average front footage price of \$409 had a standard deviation of \$290, approximately half of which could be accounted for by general location (County), land type (high/low

bank) and improvements (water, sewer, etc). The remaining or "residual" price variation was presumed to result, at least in part, from variations in visual aesthetic quality.

*** Finally, benefit - cost and sensitivity analyses were used to relate gross economic gains (household income) to potential losses (adverse property consequences). Sixty-four benefit cost ratios were calculated to reflect all combinations of data input ranges and necessary subjective judgments, the latter including opportunity costs of labor, interest rates, degree and geographic extent of adverse visual impact, and interest rates. All ratios, (including those most unfavorable to the fish farming industry) exceed unity, suggesting net statewide economic gains from salmon farming. Average results for all sensitivity calculations and results calculated under assumptions favorable to the industry indicated substantial net economic gains.

Thus it is concluded that, within the overall framework of this analysis, Washington's economy would, in any event, benefit from further growth in fish farming, and that it may benefit substantially.

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INTRODUCTION

This report, prepared under contract with the Washington State Department of Fisheries, examines selected economic aspects of the Washington salmon farming industry. The stimulus for this study is a general review of siting policy currently being conducted by the Washington Department of Fisheries and other state agencies.

Several of the issues referred to in recent salmon farm siting decisions have been economic in nature. These include potential gains in state and county income and employment, fiscal impacts on state and local governments, and adverse consequences for waterfront land values in the vicinity of proposed sites.

Each of these issues is addressed below. A brief history and description of the salmon farming industry is provided in Section I, followed by a discussion of regional input-output theory (Section II) and discussion of the economic data used to characterize salmon farming in input-output terms (Section III). Section IV reports input-output results (state/county employment, income, etc.) which are applied to the calculation of state fiscal impacts in Section V. Section VI deals property values and Section VII uses sensitivity analysis to express the preceding economic data in the form of benefit-cost ratios.

I. THE SALMON FARMING INDUSTRY

Salmon farming is emerging in Washington State as part of a rapidly growing world mariculture industry. Mariculture is the cultivation of marine organisms for harvest, as distinguished from capture fisheries (the harvest of naturally occurring fish) and aquaculture (the cultivation of freshwater organisms). Historically, mariculture has been a major world producer of shellfish and finfish. Washington State has long participated in mariculture as one of the primary US oyster producers.

Much of the science and technology which now underpins private salmon mariculture was initially developed to support Pacific Northwest public hatchery programs. In the past several decades research supporting those hatchery programs has focused on all five species of Pacific salmon, as well as on Atlantic salmon. Early research on the hatchery production of Atlantic salmon was done at the University of Washington by US and Norwegian biologists working in cooperation.

Transfer of Pacific salmon production technology to the private sector was initiated by, among others, the Weyerhaeuser

Corporation in Oregon and Domsea Farms (Cambell Soup Co.) in Washington. The first private production of Atlantic salmon began in Norway in 1971, leading to a booming Atlantic salmon farming industry in that nation, and later in Scotland as well.

In the Pacific Northwest, British Columbia has seen the greatest growth in salmon farming. The first major British Columbia site was licensed in 1973, with major production beginning in about 1985. Today (1988) 128 sites produce 900 metric tons of chinook, coho, and Atlantic salmon, as well as rainbow trout and Arctic char.¹

After many years of relatively stable production (1.5 to 2.0 million lbs from 1979 to 1986) Washington State has become the scene of increasing interest in Atlantic salmon pen culture. There are now 15 sites operating in Puget Sound and North Puget Sound Counties, as well as 17 in the permit cycle. Total 1987 production of 3.4 million pounds consisted primarily of coho, but included 400 thousand pounds of Atlantic salmon.²

Puget Sound is the largest potential salmon farming site in the United States because of its desirable water temperature, sheltered waters, and good economic infrastructure. Salmon farms currently in production compete successfully with Norwegian and Scottish imports on the US West Coast and in the Midwest. Industry spokesmen suggest that production could expand significantly without saturating potential markets, particularly

if, for Japanese markets, Washington's geographic advantage over Europe can be exploited.

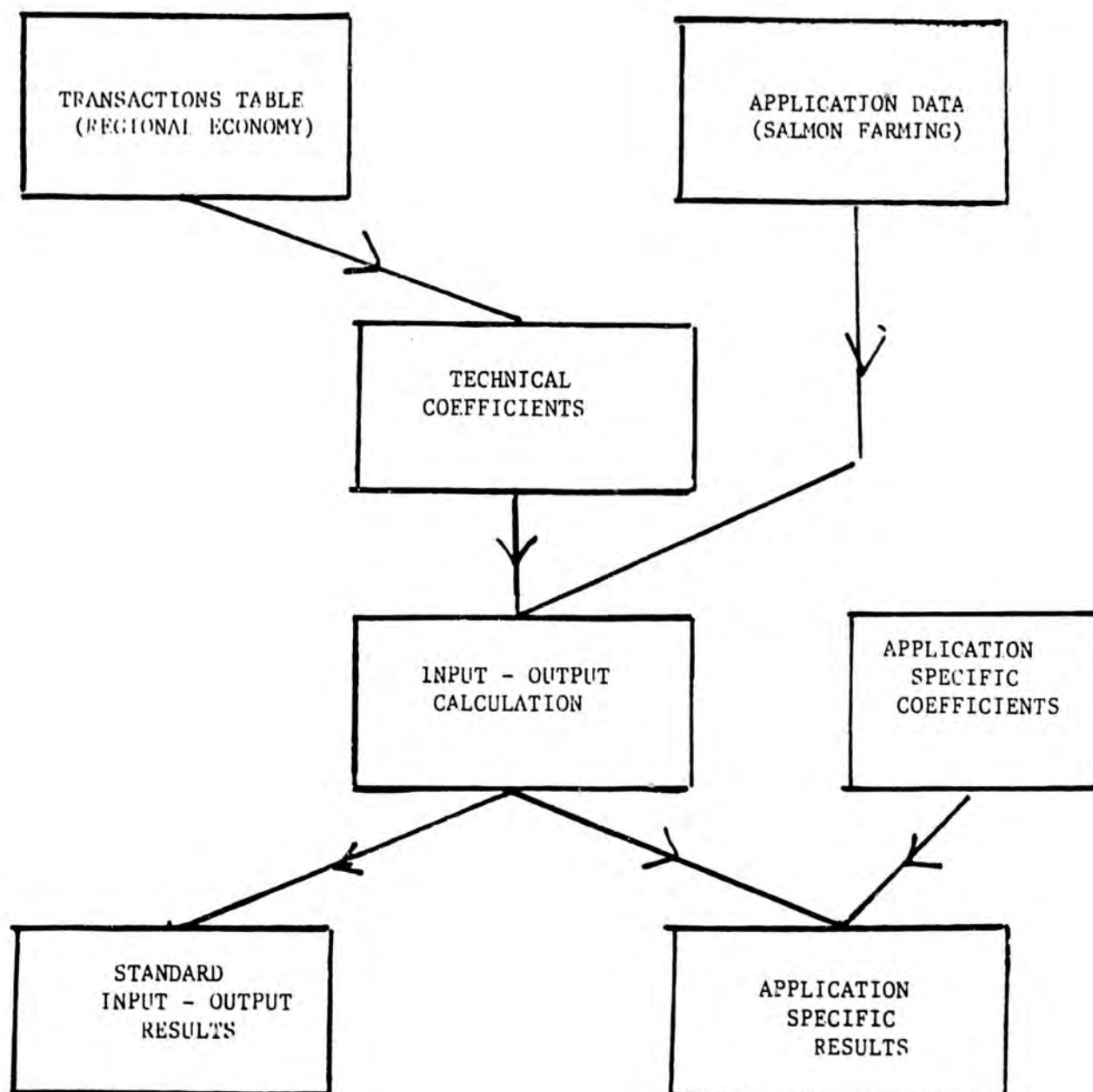
II. INPUT - OUTPUT THEORY

Input-output theory is a widely used method of regional economic analysis, appropriate to the issues addressed in this report. Developed as a post World War II extension of Keynesian national income analysis, input-output theory shares the Keynesian assumption of an economy with slack producing capacity. In such an economy output is, over moderate variations, determined by aggregate demand. This characterization fits the situation of "open" regional economies, such as states and counties. In such open economies, labor and other inputs are available at relatively constant prices, and are employed in relatively fixed proportions to produce goods and services demanded by regional and external consumers (Richardson, 1972).

Typical evaluation applications of input-output theory include determinations of the regional output, income and employment implications of specific industrial facilities siting decisions. Planning applications have included studies anticipating the public infrastructure requirements of economic growth, and more recently, studies assessing regional energy requirements and environmental waste loads.

The general procedures by which input-output analysis extracts estimates of regional output, income and employment from externally provided estimates of final demand are traced in figure 2.1. Economic information on the entire regional economy

Figure 2.1 Schematic Representation of Input - Output Analysis



(usually obtained from background studies) is recorded in a transactions table, from which a table of technical coefficients is computed. Data on the industry or facility under analysis is then collected (as part of the specific application) and introduced as a column vector of final demands. These final demands are aggregated into the same categories as those used in the transactions table. Matrix multiplication of the final demand vector and the technical coefficients table (and side calculations as necessary), produce the desired results.

These procedures conform to specific accounting principles and technological assumptions, which are illustrated with the Clallam County input-output model. That model and structurally identical ones for Washington State, and for Jefferson, Kitsap, San Juan and Skagit Counties were developed for this study from data found in the US Forest Service IMPLAN system. These models necessarily reflect 1982 economic conditions. This is because 1982 is the effective year of IMPLAN, and is also the effective year of the most recent complete census of manufactures. The reader interested in the detailed mechanics of the input-output procedures employed here is invited to trace the calculations reported in tables 2.1 to 2.4 (U.S. Forest Service, 1988).

For the more general reader, we offer the following observations on the appropriateness of input-output analysis to the task at hand. An assumption crucial to the application of input-output analysis is that the inputs and outputs of regional industries can be varied in constant proportions, without altering prices, encountering physical resource constraints, or

Table 2.1 Clallam County Transaction Table
(thousand dollars)

1 Agriculture, Fisheries, Fisheries	7 Retail Trade									VA Value Added				
2 Mining	8 Finance, Insurance, Real Estate									IMP Imports				
3 Construction	9 Services									PCE Personal Consumption				
4 Manufacturing	10 Federal Government									FD Final Demand				
5 Transport, Comm, Public Utilities	11 State and Local Government									T Total				
6 Wholesale Trade														
	1	2	3	4	5	6	7	8	9	10	11 PCE	FD	T	
1	461	0	61	776	1	1	1	239	344	1	2	795	5974	8660
2	0	0	4	7	0	0	0	0	0	0	0	0	52	62
3	89	0	64	4403	1619	8	441	4604	1663	1	1782	0	29650	44322
4	56	0	2003	57097	212	15	1478	396	1692	2	44	1639	311085	375719
5	224	2	993	8511	7988	48	1789	586	3996	4	480	8132	24614	57371
6	1	0	9	49	3	0	1	0	15	0	0	35	1067	1181
7	23	0	1830	641	145	2	73	113	291	1	21	21423	34803	59365
8	187	1	216	1340	555	18	1501	3554	2945	3	31	35603	58217	104172
9	114	2	1431	5690	1720	77	1763	1512	6276	27	115	37753	82031	138511
10	0	0	6	13	17	0	3	190	11	12	1	145	357	756
11	11	0	27	1012	255	2	110	131	341	1	48	1589	64494	68022
VA	3050	34	16646	122780	24727	786	43037	81322	73261	458	63892	0	7917	438110
IMP	4245	22	21033	173399	20130	224	9169	11525	47672	241	1608	330995	0	620261
T	8660	62	44322	375719	57371	1181	59365	104172	138511	756	68022	438110	620261	1916511

Table 2.2 Clallam County Technical Coefficients
(thousand dollars)

1 Agriculture, Fisheries, Fisheries
2 Mining
3 Construction
4 Manufacturing
5 Transport, Comm, Public Utilities
6 Wholesale Trade

7 Retail Trade
8 Finance, Insurance, Real Estate
9 Services
10 Federal Government
11 State and Local Government

VA Value Added
PCE Personal Cons
r Total

	1	2	3	4	5	6	7	8	9	10	11	PCE
1	0.0532	0.0000	0.0014	0.0021	.0000	0.0009	.0000	0.0023	0.0025	0.0019	.0000	0.0018
2	0.0000	0.0021	0.0001	.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0102	0.0076	0.0014	0.0117	0.0282	0.0071	0.0074	0.0442	0.0120	0.0012	0.0262	0.0000
4	0.0065	0.0042	0.0452	0.1520	0.0037	0.0131	0.0249	0.0038	0.0122	0.0027	0.0006	0.0037
5	0.0258	0.0322	0.0224	0.0227	0.1392	0.0404	0.0301	0.0056	0.0288	0.0116	0.0070	0.0186
6	0.0001	0.0000	0.0002	0.0001	0.0001	0.0001	.0000	.0000	0.0001	0.0001	.0000	0.0001
7	0.0026	0.0003	0.0413	0.0017	0.0025	0.0015	0.0012	0.0011	0.0021	0.0015	0.0003	0.0489
8	0.0216	0.0180	0.0049	0.0036	0.0097	0.0148	0.0253	0.0341	0.0213	0.0045	0.0005	0.0013
9	0.0132	0.0319	0.0323	0.0151	0.0300	0.0652	0.0297	0.0145	0.0453	0.0355	0.0017	0.0862
10	.0000	0.0000	0.0001	.0000	0.0003	0.0002	0.0001	0.0018	0.0001	0.0161	.0000	0.0003
11	0.0013	0.0021	0.0006	0.0027	0.0044	0.0016	0.0018	0.0013	0.0025	0.0010	0.0007	0.0036
VA	0.3753	0.5511	0.3756	0.3268	0.4310	0.6659	0.7250	0.7807	0.5289	0.6058	0.9393	0.0000
r	0.5099	0.6494	0.5255	0.5385	0.6491	0.8108	0.8455	0.8894	0.6558	0.6818	0.9764	0.2445

Table 2.3 Clallam County Economic Impact Illustration
(thousand dollars)

1 Agriculture, Fisheries, Fisheries
2 Mining
3 Construction
4 Manufacturing
5 Transport, Comm, Public Utilities
6 Wholesale Trade

7 Retail Trade
8 Finance, Insurance, Real Estate
9 Services
10 Federal Government
11 State and Local Government
VA Value Added
T Total

ROUND	SECTOR												
	1	2	3	4	5	6	7	8	9	10	11	VA	T
1	\$20.16	\$0.00	\$14.53	\$49.31	\$86.17	\$0.25	\$92.58	\$162.77	\$180.33	\$0.72	\$9.19	\$368.15	\$984.15
2	\$2.69	\$0.00	\$13.52	\$15.11	\$29.79	\$0.07	\$19.63	\$43.17	\$49.13	\$0.48	\$2.71	\$365.07	\$541.38
3	\$1.08	\$0.00	\$3.78	\$5.66	\$13.92	\$0.04	\$18.69	\$33.15	\$36.51	\$0.22	\$1.72	\$100.67	\$215.46
4	\$0.43	\$0.00	\$2.56	\$2.50	\$5.87	\$0.01	\$5.26	\$10.76	\$12.02	\$0.11	\$0.61	\$70.20	\$110.34
5	\$0.21	\$0.00	\$0.88	\$1.10	\$2.82	\$0.01	\$3.60	\$6.55	\$7.21	\$0.05	\$0.34	\$23.69	\$46.47
6	\$0.09	\$0.00	\$0.51	\$0.51	\$1.24	\$0.00	\$1.23	\$2.43	\$2.71	\$0.02	\$0.14	\$13.88	\$22.76
7	\$0.04	\$0.00	\$0.20	\$0.23	\$0.59	\$0.00	\$0.71	\$1.32	\$1.45	\$0.01	\$0.07	\$5.29	\$9.92
8	\$0.02	\$0.00	\$0.10	\$0.11	\$0.26	\$0.00	\$0.27	\$0.53	\$0.59	\$0.00	\$0.03	\$2.81	\$4.73
9	\$0.01	\$0.00	\$0.04	\$0.05	\$0.12	\$0.00	\$0.14	\$0.27	\$0.30	\$0.00	\$0.01	\$1.15	\$2.10
10	\$0.00	\$0.00	\$0.02	\$0.02	\$0.06	\$0.00	\$0.06	\$0.11	\$0.13	\$0.00	\$0.01	\$0.58	\$0.99
T	\$24.75	\$0.01	\$36.14	\$74.60	\$140.82	\$0.39	\$142.19	\$261.08	\$290.38	\$1.62	\$14.84	\$951.49	\$1,938.30

Table 2.4 Clallam County Economic Impact Illustration
First Round Calculation

Sector	1	2	3	4	5	6
First Round Input	300	0	0	250	250	0
1	300 X 0.0532 + 0 X 0.0000 + 0 X 0.0014 + 250 X 0.0021 + 250 X 0.0000 + 0 X 0.0009					
2	300 X 0.0000 + 0 X 0.0021 + 0 X 0.0001 + 250 X 0.0000 + 250 X 0.0000 + 0 X 0.0000					
3	300 X 0.0102 + 0 X 0.0076 + 0 X 0.0014 + 250 X 0.0117 + 250 X 0.0202 + 0 X 0.0071					
4	300 X 0.0065 + 0 X 0.0042 + 0 X 0.0042 + 250 X 0.1520 + 250 X 0.0037 + 0 X 0.0131					
5	300 X 0.0250 + 0 X 0.0322 + 0 X 0.0024 + 250 X 0.0227 + 250 X 0.1392 + 0 X 0.0404					
6	300 X 0.0001 + 0 X 0.0000 + 0 X 0.0002 + 250 X 0.0001 + 250 X 0.0001 + 0 X 0.0001					
7	300 X 0.0026 + 0 X 0.0003 + 0 X 0.0043 + 250 X 0.0017 + 250 X 0.0025 + 0 X 0.0015					
8	300 X 0.0216 + 0 X 0.0180 + 0 X 0.0049 + 250 X 0.0036 + 250 X 0.0097 + 0 X 0.0140					
9	300 X 0.0132 + 0 X 0.0319 + 0 X 0.0023 + 250 X 0.0151 + 250 X 0.0300 + 0 X 0.0652					
10	300 X 0.0000 + 0 X 0.0000 + 0 X 0.0001 + 250 X 0.0000 + 250 X 0.0003 + 0 X 0.0002					
11	300 X 0.0013 + 0 X 0.0021 + 0 X 0.0006 + 250 X 0.0027 + 250 X 0.0044 + 0 X 0.0016					
VA	300 X 0.3753 + 0 X 0.5511 + 0 X 0.3756 + 250 X 0.3268 + 250 X 0.4310 + 0 X 0.6659					

Sector	7	8	9	10	11	PCE	First Round On Second Round I
First Round Input	0	0	125	0	0	1850.	
1: +	0 X 0.0000 + 0 X 0.0023 + 125X 0.0025 + 0 X 0.0019 + 0 X 0.0000 + 185X 0.0018 =						20.16
2: +	0 X 0.0000 + 0 X 0.0000 + 125X 0.0000 + 0 X 0.0000 + 0 X 0.0000 + 185X 0.0000 =						.00
3: +	0 X 0.0074 + 0 X 0.0442 + 125X 0.0120 + 0 X 0.0012 + 0 X 0.0262 + 185X 0.0000 =						14.53
4: +	0 X 0.0249 + 0 X 0.0038 + 125X 0.0122 + 0 X 0.0027 + 0 X 0.0006 + 185X 0.0037 =						49.31
5: +	0 X 0.0301 + 0 X 0.0056 + 125X 0.0208 + 0 X 0.0116 + 0 X 0.0070 + 185X 0.0186 =						86.17
6: +	0 X 0.0000 + 0 X 0.0000 + 125X 0.0001 + 0 X 0.0001 + 0 X 0.0000 + 185X 0.0001 =						0.25
7: +	0 X 0.0012 + 0 X 0.0011 + 125X 0.0021 + 0 X 0.0015 + 0 X 0.0003 + 185X 0.0189 =						92.58
8: +	0 X 0.0250 + 0 X 0.0341 + 125X 0.0213 + 0 X 0.0045 + 0 X 0.0005 + 185X 0.0013 =						162.77
9: +	0 X 0.0297 + 0 X 0.0145 + 125X 0.0453 + 0 X 0.0355 + 0 X 0.0017 + 185X 0.0662 =						180.33
10: +	0 X 0.0001 + 0 X 0.0018 + 125X 0.0001 + 0 X 0.0181 + 0 X 0.0000 + 185X 0.0003 =						0.72
11: +	0 X 0.0010 + 0 X 0.0013 + 125X 0.0025 + 0 X 0.0010 + 0 X 0.0007 + 185X 0.0036 =						9.19
VA: +	0 X 0.7250 + 0 X 0.7807 + 125X 0.5289 + 0 X 0.6058 + 0 X 0.9393 + 185X 0.0000 =						360.15

otherwise changing base period economic and technological conditions. These conditions are reasonably well satisfied in this application because the current and proposed salmon farming industry is small in relation to the economies of Washington State and its coastal counties. One exception to this expectation of constant technical coefficients is the possibility that a growing salmon farming industry might lead to import substitution. That is, instate suppliers may avail themselves of opportunities to provide specialized inputs that are now imported. This possibility is addressed by means of sensitivity analysis (maximum and minimum impact calculations) described in sections III and IV.

Another important assumption is that the accounting stance of relevant decisionmakers coincides with the scope of the input-output model. Such a coincidence would seem to exist for this evaluation of state and county siting policy. Even within a regional accounting stance, though, input-output results cannot, without modification, be interpreted as net benefits in the benefit-cost sense. This qualification is addressed in section VII, where input-output results are given a net benefits interpretation, but only after subtraction of opportunity costs.

III. THE REPRESENTATIVE SALMON FARM

To analyze the regional economic impacts of an activity like salmon farming requires that it first be described in terms of total revenue/expenditure and the allocation of each among sectors of the regional economy. Of greatest importance to accurate impact assessment is the division of revenues between export and local sales, and of expenditures and net incomes between regional and non-regional recipients.

This step in the analysis was accomplished by interviews with several salmon farming industry participants. These individuals provided information on their own operations, as well as a general overview of what, in their view, the future salmon farming industry would look like.

Production and financial profiles of several salmon farms were obtained from their owners or managers. In some cases interviewees provided exact revenues or expenditures, and in other cases general planning factors, "Feed is \$.90 per finished pound," "Sales cost is 5% of gross revenue," etc. Confidentiality commitments preclude identifying the firms supplying this data or, given the small number of firms, publication of specific data in even masked form. Instead, the revenue/cost profile of a representative operation (table 3.1) was built from the data provided. By design, this profile describes the industry in general, but no firm in particular. In addition, while estimates of profit are sufficiently accurate for regional economic

Table 3.2 Representative Atlantic Salmon Farm
Regional Distribution of Expenditures

	In County		In State	
	Max	Min	Max	Min
Hatchery: Eggs	100%	0%	100%	50%
Hatchery: Labor	100%	100%	100%	100%
Hatchery: Other	50%	25%	75%	50%
Fish Farm: Labor	100%	100%	100%	100%
Fish Farm: Other	50%	25%	75%	50%
Feed	0%	0%	100%	50%
Processing	100%	100%	100%	100%
Packaging	0%	0%	100%	100%
Freight	0%	0%	100%	100%
Brokerage	0%	0%	100%	100%
General Administration	50%	25%	75%	50%
Debt Service	0%	0%	100%	0%
Equity Return	100%	0%	100%	0%

analysis, they should not be considered reliable for investment planning or other purposes.

Industry interviews also suggested that production will include pan size and mature coho, chinook and Atlantic salmon, but that mature (about 9 lb round weight) Atlantic salmon will gain in significance over time. Hence, the profile described in table 3.1 describes the production, revenues and expenditures of a 1,000,000 finished pound Atlantic salmon production facility. This production is assumed to sell entirely out of state at \$5.00 per pound. The disbursement of the resulting \$5,000,000 in annual revenue is allocated among phases of production (hatchery, fish farm, administration) and among input types (feed, labor, etc).

The extent to which these inputs are supplied locally or from outside the region is the primary determinant of the facilities' indirect and induced regional economic impact. The local/import supply factors used here are reported in table 3.2. For some inputs the pattern of regional/import supply was either obvious, or could be reliably determined by interview. Labor is necessarily supplied from within the state and, for the most part, within the subject county. Processing of fresh round fish is most conveniently done nearby, certainly in Washington and most likely in the subject county. Packaging materials, freight, and brokerage services for fish shipped out of Seattle will most likely be supplied by in-state, but not in-county firms.

Table 3.1 Representative Atlantic Salmon Farm
Revenues and Costs (thousand dollars)

Production and Revenue

Finished pounds	1,000,000
Price	\$5.00
Gross revenue	\$5,000,000

Expenditures

Item	Amount	\$/lb
Hatchery: Eggs	\$300,000	\$0.30
Hatchery: Labor	\$250,000	\$0.25
Hatchery: Other	\$50,000	\$0.05
Hatchery: Employment	8	
Fish Farm: Labor	\$500,000	\$0.50
Fish Farm: Other	\$450,000	\$0.45
Fish Farm Employment	20	
Feed	\$900,000	\$0.90
Processing	\$250,000	\$0.25
Packaging	\$100,000	\$0.10
Freight	\$250,000	\$0.25
Brokerage	\$250,000	\$0.25
General Administration	\$250,000	\$0.25
Administrative Employment	5	
Debt Service	\$350,000	\$0.35
Equity Return	\$1,100,000	\$1.10
TOTAL	\$5,000,000	\$5.00

Sources of other inputs are less certain, and may vary over time with the size of the industry, and with other factors. The following maximum and minimum local input factors were adopted for these inputs. Currently, the preponderance of feed is provided by Moore Clark of LaConner (Skagit County) Washington, with some feed imported from Oregon. Washington feed supply is set at 100 % to 50 %, a factor which will depend, among other things, on the future competitive position of Washington suppliers. Egg costs are set at either 100 % Washington and 100 % county (local production) or 50 % Washington (external purchase). Other expenditures and administrative costs are set at 75% to 50% Washington and 50 % to 25 % county supply. Debt service is set at 100 % and 0 % Washington (in or out of state financing), and equity return is set at 100 % Washington 100 % county (local ownership) or 0 % Washington 0 % county (out of state ownership).

IV. REGIONAL ECONOMIC IMPACTS

Regional economic impacts are computed by allocating the expenditures of the representative salmon farm to appropriate model categories, and then performing the calculations described in tables 2.3 and 2.4. All results vary depending on whether minimum or maximum state/local supply assumptions are used. County results vary further (although only slightly) as a result of each county's different economic structure. Results are reported in summary form in table 4.1, and in more detail in tables 4.2 (statewide), table 4.3 (Clallam Co.), table 4.4 (Jefferson Co.), table 4.5 (Kitsap Co.), Table 4.6 (San Juan Co.) and table 4.7 (Skagit Co.).

Statewide impacts were based on an industry expansion equal to 5 of the representative salmon farms discussed in the preceding section. County impacts were based on one such facility in each county. Because of the linear nature of input-output analysis, the computation of impacts for other industry sizes (combination of facilities) can be accomplished by simple multiplication of these results. That is, two operations in a county would have exactly twice the county impact of one, and 10 facilities would have twice the state impact of 5.

As described in table 4.1, a 5 million pound Atlantic salmon farming industry (5 representative facilities) would contribute between \$38 and \$48 million to state output, between \$11 and

Table 4.1: Summary of Impacts: 5,000,000 lb Atlantic Salmon Industry in Washington, and Average Results for a 1,000,000 lb Facility in Clallam, Jefferson, Kitsap, San Juan or Skagit County (\$ thousands)

	OUTPUT	INCOME	EMPLOYMENT
Maximum			
State	\$48,395	\$21,412	303
County	\$6,812	\$2,748	51
Minimum			
State	\$38,227	\$10,615	257
County	\$5,775	\$1,132	40

Table 4.2: Detailed Impacts: 5,000,000 lb Atlantic
Salmon Production: Washington State (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$1,500	\$750	\$2,362	\$1,255
Mining	\$0	\$0	\$42	\$30
Construction	\$0	\$0	\$476	\$274
Manufacturing	\$6,250	\$4,000	\$9,011	\$5,682
Transport, Comm, Utilities	\$3,125	\$2,500	\$4,897	\$3,616
Wholesale Trade	\$1,250	\$1,250	\$1,299	\$1,278
Retail Trade	\$0	\$0	\$682	\$342
Finance, Insurance, Real Estate	\$1,750	\$0	\$3,968	\$1,083
Services	\$938	\$625	\$3,202	\$1,869
Federal Government	\$0	\$0	\$22	\$10
State and Local Government	\$0	\$0	\$86	\$48
Housholds	\$9,250	\$3,750	\$21,412	\$10,615
Total Output	\$25,000	\$25,000	\$48,395	\$38,227
Employment	161	161	303	257

Table 4.3: Detailed Results: 1,000,000 lb Atlantic
Salmon Farm: Clallam County (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$300	\$0	\$325	\$4
Mining			\$0	\$0
Construction			\$36	\$17
Manufacturing	\$250	\$250	\$325	\$307
Transport, Comm, Utilities	\$250	\$125	\$391	\$188
Wholesale Trade	\$0	\$0	\$0	\$0
Retail Trade			\$142	\$59
Finance, Insurance, Real Estate	\$0	\$0	\$261	\$107
Services	\$125	\$63	\$415	\$186
Federal Government			\$2	\$1
State and Local Government			\$15	\$7
Housholds	\$1,850	\$750	\$2,801	\$1,171
Total Output	\$5,000	\$5,000	\$6,937	\$5,858
Employment	32	32	52	41

Table 4.4: Detailed Results: 1,000,000 lb Atlantic
Salmon Farm: Jefferson County (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$300	\$0	\$321	\$6
Mining			\$0	\$0
Construction			\$45	\$16
Manufacturing	\$250	\$250	\$291	\$281
Transport, Comm, Utilities	\$250	\$125	\$348	\$172
Wholesale Trade	\$0	\$0	\$3	\$1
Retail Trade			\$140	\$58
Finance, Insurance, Real Estate	\$0	\$0	\$230	\$95
Services	\$125	\$63	\$369	\$166
Federal Government			\$1	\$1
State and Local Government			\$16	\$7
Housholds	\$1,850	\$750	\$2,786	\$1,155
Total Output	\$5,000	\$5,000	\$6,776	\$5,770
Employment	32	32	51	40

Table 4.5: Detailed Results: 1,000,000 lb Atlantic
Salmon Farm: Kitsap County (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$300	\$0	\$310	\$5
Mining			\$0	\$0
Construction			\$14	\$3
Manufacturing	\$250	\$250	\$286	\$280
Transport, Comm, Utilities	\$250	\$125	\$309	\$154
Wholesale Trade	\$0	\$0	\$1	\$0
Retail Trade			\$84	\$35
Finance, Insurance, Real Estate	\$0	\$0	\$188	\$79
Services	\$125	\$63	\$304	\$139
Federal Government			\$16	\$7
State and Local Government			\$9	\$4
Housholds	\$1,850	\$750	\$2,615	\$1,080
Total Output	\$5,000	\$5,000	\$6,361	\$5,598
Employment	32	32	42	36

Table 4.6: Detailed Results: 1,000,000 lb Atlantic
Salmon Farm: San Juan County (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$300	\$0	\$343	\$8
Mining			\$2	\$2
Construction			\$45	\$19
Manufacturing	\$250	\$250	\$313	\$284
Transport, Comm, Utilities	\$250	\$125	\$459	\$218
Wholesale Trade	\$0	\$0	\$29	\$12
Retail Trade			\$544	\$225
Finance, Insurance, Real Estate	\$0	\$0	\$310	\$127
Services	\$125	\$63	\$254	\$119
Federal Government			\$1	\$1
State and Local Government			\$35	\$14
Housholds	\$1,850	\$750	\$2,957	\$1,225
Total Output	\$5,000	\$5,000	\$7,518	\$6,068
Employment	32	32	67	46

Table 4.7: Detailed Results: 1,000,000 lb Atlantic
Salmon Farm: Skagit County (thousand dollars)

Local Supply Sector	Direct		Total	
	Maximum	Minimum	Maximum	Minimum
Agriculture, Forestry, Fisheries	\$300	\$0	\$345	\$10
Mining			\$0	\$0
Construction			\$24	\$10
Manufacturing	\$250	\$250	\$403	\$325
Transport, Comm, Utilities	\$250	\$125	\$353	\$172
Wholesale Trade	\$0	\$0	\$3	\$1
Retail Trade			\$76	\$30
Finance, Insurance, Real Estate	\$0	\$0	\$155	\$60
Services	\$125	\$63	\$292	\$130
Federal Government			\$0	\$0
State and Local Government			\$7	\$3
Housholds	\$17,850	\$750	\$2,581	\$1,027
Total Output	\$5,000	\$5,000	\$6,466	\$5,581
Employment	32	32	44	37

\$21 million to household incomes, and would create between 257 and 303 jobs statewide. Averaging results obtained from individual county models suggests that a single 1 million pound facility would contribute between \$5.8 and \$6.8 million to county output, between \$1.1 and \$2.7 million to county household income, and would create 40 to 51 jobs within the county (Table 4.8).

**Table 4.8: 1,000,000 lb Atlantic Salmon Farm, Average
County Results (thousand dollars)**

County	Total Output		Housholds		Employment	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Clallam	\$6,937	\$5,858	\$2,801	\$1,171	52	41
Jefferson	\$6,361	\$5,598	\$2,615	\$1,080	42	36
Kitsap	\$6,776	\$5,770	\$2,786	\$1,155	51	40
San Juan	\$7,518	\$6,068	\$2,957	\$1,225	67	46
Skagit	\$6,466	\$5,581	\$2,581	\$1,027	44	37
Average	\$6,812	\$5,775	\$2,748	\$1,132	\$51	\$40

V. STATE AND LOCAL FISCAL IMPACTS

The foregoing input-output analysis results provide a basis for the comprehensive assessment of how an expanded salmon farming industry would affect state revenues and expenditures. The required extensions to the input-output model can be identified by examining the major items of revenue and expenditure reported in table 5.1.

There, we see that 71 % of state revenue arises from 4 sources, sales taxes, gross receipts taxes, property taxes, and federal grants, with the remaining 29 % consisting of miscellaneous taxes and revenues. Similarly, 71 % of expenditures are for education (all levels) and human resources (including welfare), with the remaining 29 percent going to other categories including general government. The general government category, however, includes debt service and pension expenditures, many of which could properly be allocated by function to education and human services as well.

Thus, obtaining a fiscal analysis from input-output results involves relating 5 revenue types and 3 functional expenditure categories to the economic changes described by the above input-output analysis. Figure 5.1 illustrates, in general, what must be done to accomplish this. The first steps, input-output analysis to produce impacts on output, household income and employment, have already been accomplished. This section is

Table 5.1 Distribution of 1982 Washington State
Revenues and Expenditures

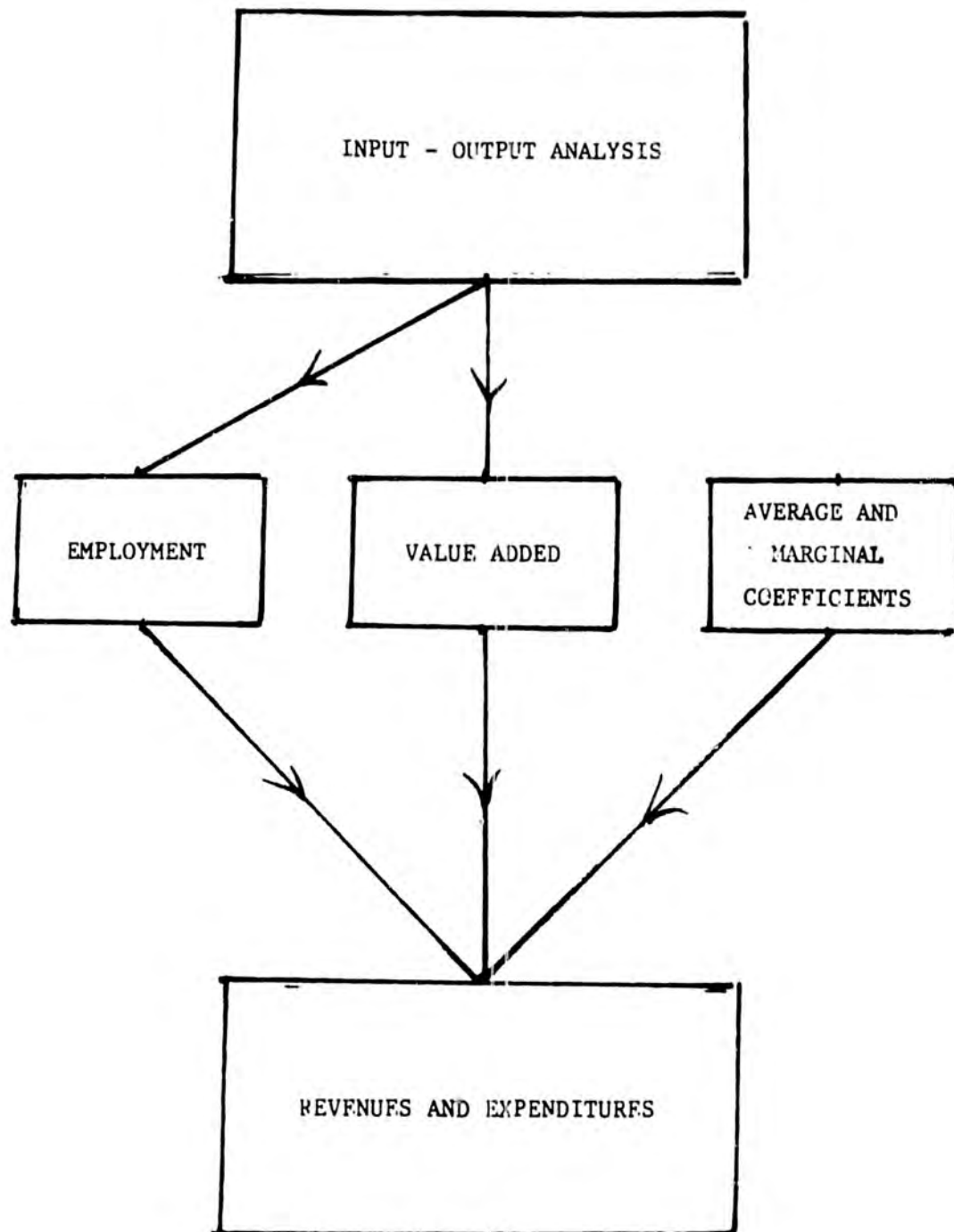
REVENUE

Item	1982 \$000	% Revenue or Expenditure
General and Selective Sales Taxes	\$1,901	30%
Gross Receipts Taxes	\$635	10%
Property and In Lieu Taxes	\$628	10%
Other Taxes	\$319	5%
Federal Grants	\$1,356	21%
Other Revenue	\$1,550	24%
Total Revenue	\$6,389	

EXPENDITURE

Education	\$2,751	44%
Human Resources	\$1,647	27%
Other Expenditures	\$1,796	29%
Total Expenditures	\$6,194	

Figure 5.1 Schematic Description of Fiscal Impact Calculation



devoted to the remaining steps; examining possible relationships between those economic variables and revenues/expenditures, choosing coefficients for calculation from among the examined possibilities, and, finally, using sets of chosen coefficients to calculate ranges of fiscal impacts.

The underlying (though not readily observable) economic processes that relate economic expansion (or contraction) to state revenue and cost are postulated to be as follows. Increases in gross output (with household income as a proxy variable) increase gross receipts taxes. Increases in household income increase consumption which, in turn, increases sales tax revenue. To the extent that both induce increases in taxable assets held by business and consumers, they increase property taxes as well. Depending on the their basis of application, other taxes and revenues also rise.

Expenditures and federal grants are assumed to respond to economic change in a somewhat more complex way. Input-output estimated increases in employment represent jobs filled by some combination of immigrants and unemployed current residents. Increased labor force participation has little, if any, effect on educational and general state expenditures, and may actually reduce human resource expenditures. By contrast, increased population will increase all three expenditure categories; education due to the children accompanying new immigrants, human resources due to increased welfare and other case loads, and general expenditures for similar reasons. Federal grants will

also increase, to the extent that federal funding formulas include general or target populations.

Figure 5.1 describes the calculations required to implement the above theory of fiscal effect. Included among the standard input-output results are estimates of employment and household income (value added) resulting from the siting of salmon farms. The relationship between personal income and revenue is direct; changes in household income affect sales taxes, gross receipts taxes, property taxes, and other taxes and revenues. The degree of effect is determined by the estimates reported in tables 5.2 (as estimated from table 5.3 data). The algorithm used to make those calculations is reported in table 5.4. The relationship of employment to expenditures and federal grants has two links; employment to population, and population to enrollment. Each of these is also estimated in table 5.2 and reflected in the algorithm in table 5.4.

Two methods of relating economic change to fiscal magnitudes are reported in table 5.2. In both cases estimates are based on 1970-1985 data, with financial magnitudes expressed in 1982 prices. The first method is that of average ratios. For example, sales tax revenue averaged \$.0078 per dollar of personal income, population averaged 2.43 persons per employee, school enrollment per school child. The second method is that of marginal change, based on regression analysis. For example, the marginal change in sales tax revenue with respect to personal income was \$.0014, the

Table 5.2 Statistics Used to Relate Regional Economic Impacts to Washington State Revenue and Expenditure:

Independent Variable (X)	Dependent Variable (Y)	Average Ratio (Y/X)	Coefficient (B) (Y = A + BxX)	T Statistic	R ²
Personal Income	Gross Receipts Taxes	\$0.0078	\$0.0014	3.14	0.92
Personal Income	Gen & Sel Sales Tax	\$0.0331	\$0.0062	5.38	0.67
Personal Income	Prop & In Lieu Tax	\$0.0071	\$0.0006	10.38	0.88
Personal Income	Other Taxes	\$0.0048	\$0.0010	3.58	0.48
Personal Income	Other Revenue	\$0.0164	\$0.0052	2.73	0.35
Employment	Population	2.43	1.52	14.96	0.94
Population	Federal Grants	\$317	\$408	5.26	0.66
Population	Human Resources Exp	\$355	\$751	11.32	0.9
Population	Other Expenditures	\$419	\$774	5.42	0.68
Population	Enrollment	0.42			
Enrollment	Education Exp	\$2,945			

Table 5.3 Washington State Economic and Fiscal Data: 1970 - 1985 (1982 \$)

1 Population (000)					7 General and Selective Sales Tax (millions)					13 Education (millions)					15 Total Expenditures (millions)				
2 Employment (000)					8 Gross Receipts Tax (millions)					14 Human Resources (millions)					16 CPI				
3 Unemployment (000)					9 Property and In-lieu Excises (millions)					17 Other Taxes 10-9-8-7 (millions)					18 Other Revenue 12-11-10 (millions)				
4 Children (000)					10 Total Tax (millions)					19 Other Expenditure 15-14-13 (millions)									
5 DSHS caseload (000)					11 Federal Grants (millions)														
6 Personal Income (billions)					12 Total Revenue (millions)														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
70	3413	1285	130	817	166.0	28.5	1815.0	258.3	251.7	2291.6	896.4	4070.8	1910.7	937.7	4284.8	0.925	166.2	890.8	1376.4
71	3436	1259	142	805	200.4	29.8	1633.1	294.6	249.8	2403.7	859.2	3909.7	1831.5	956.4	4107.2	0.965	226.3	646.8	1319.4
72	3430	1297	137	791	202.4	32.1	1584.1	276.0	271.9	2418.4	1157.7	4523.8	1832.1	1103.0	4434.2	1.000	286.3	947.6	1469.0
73	3444	1367	117	788	207.9	36.5	1686.2	307.6	255.1	2505.9	1094.3	4275.8	1731.7	1070.9	4191.1	1.058	257.0	675.6	1388.5
74	3509	1420	109	785	206.3	41.1	1565.3	329.2	161.0	2403.3	1124.7	4545.6	1857.1	1170.5	4412.0	1.164	247.8	1017.6	1384.4
75	3568	1412	149	784	214.5	46.3	1688.4	335.4	256.5	2551.6	1044.8	4222.8	1725.2	1087.4	4098.6	1.253	271.3	626.4	1286.1
76	3635	1481	140	780	253.2	51.9	1816.0	345.7	423.9	2889.0	1284.2	5263.4	2248.5	1351.4	5030.3	1.317	303.4	1090.2	1430.4
77	3715	1544	148	776	245.0	57.7	1787.9	545.7	507.2	3098.1	1214.1	4976.2	2125.8	1277.7	4755.9	1.393	257.3	664.0	1352.4
78	3836	1684	124	769	241.1	67.8	1981.2	597.3	537.8	3383.1	1328.6	5752.1	2337.3	1495.2	5548.9	1.490	266.8	1040.4	1656.3
79	3979	1806	131	764	240.1	78.0	1938.3	649.1	594.5	3444.3	1218.3	5274.2	2198.2	1371.0	5087.9	1.625	262.4	611.7	1518.7
80	4132	1826	156	757	269.1	87.8	1850.5	645.6	608.8	3354.7	1531.2	6113.3	2729.8	1715.9	6247.3	1.790	249.7	1227.4	1801.6
81	4227	1806	190	749	299.6	98.1	1777.2	669.4	631.2	3320.4	1409.2	5626.1	2512.2	1579.2	5749.5	1.945	242.5	896.6	1658.1
82	4264	1773	245	739	254.8	102.9	1901.0	635.0	679.0	3535.0	1355.5	6375.0	2751.5	1646.5	6194.0	2.060	320.0	1484.5	1796.0
83	4285	1838	231	736	249.4	107.7	2232.6	768.6	724.3	4060.2	1307.3	6148.2	2653.6	1587.9	5973.6	2.136	334.7	780.7	1732.1
84	4328	1859	194	741	272.0	113.9	2470.3	756.1	706.6	4273.3	1409.9	7097.8	2868.3	1864.2	7194.6	2.208	340.2	1414.6	2462.1
85	4384	1917	170	749	297.9	126.0	2275.2	780.2	686.3	4081.3	1348.1	6786.4	2742.4	1782.4	6878.9	2.305	339.6	1357.0	2354.1

Table 5.4 Algorithm for Calculating State Revenues and Expenditures From Regional Economic Impacts

PERSONAL INCOME DRIVEN VARIABLES

ITEM	AVERAGE	MARGINAL
1. Gross Receipts Taxes	\$0.0078	\$0.0078
2. Gen & Selective Sales Tax	\$0.0331	\$0.0331
3. Property & In Lieu Tax	\$0.0071	\$0.0071
4. Other Taxes	\$0.0048	\$0.0048
5. Other Revenue	\$0.0164	\$0.0164
	0.0692	0.0692
6. Employment >> Population	2.43	2.43

POPULATION DRIVEN VARIABLES

7. Federal Grants	\$317	\$317
8. Human Resources Expenditure	\$355	\$355
9. Other Expenditures	\$419	\$419
10. Population >> Enrollment	0.42	0.42

ENROLLMENT DRIVEN VARIABLES

11. Education Expenditure	\$2,945	\$2,945
---------------------------	---------	---------

$$\text{Revenue} = \text{VA} * (1 + 2 + 3 + 4 + 5) + \text{E} * 6 * 7$$

$$\text{Expenditure} = \text{E} * 8 * ((8 + 9) + 10 * 11)$$

$$\text{Net} = \text{Revenue} - \text{Expenditure}$$

E = Employment

VA = Value Added = Personal Income

change in population with respect to employment was 1.52 persons per employee, and the change in human resource expenditure with respect to population was \$751.

Both the average ratio and marginal change method are subject to error. For example, there is considerable evidence that households maintain a reasonably stable standard of living over the medium term, adjusting their savings (or dissavings) rate as well as their consumption expenditures in the face of short-term income changes. We would thus expect (as is observed in table 5.2) that marginal changes in consumption based taxes will be less than average ratios. On the expenditure side fixed program costs will not vary in direct proportion to population or caseload. Thus we again expect marginal effects to be less than average ratios.

That this is not the case in table 5.2 points up the principal defect of the marginal approach. Estimates of marginal change based on regression analysis can be (as these estimates undoubtedly are) biased by neglected changes occurring during the period of estimation. Changes affecting revenue would include alteration of tax rates and the basis of their application, both of which have occurred in the 1970 -1985 period -- most notably the removal of the sales tax from food. On the expenditure side, bias can result from legislated changes in the scale of state programs and entitlement formulas, as well as changes in population structure. Increased state level school funding, and declines in fecundity between 1970 - 1985 illustrate sources of potential bias in the marginal values reported in table 5.2.

The removal of these and other biases, if possible at all, would require data gathering and statistical analysis beyond the scope of this project. Hence, to give a range of possible fiscal effects we use both average ratios and marginal values to compute fiscal effects. An exception is the exclusive use of average ratios to calculate changes in educational expenditure. Estimated marginal values (regression coefficients) relating children to population, and educational expenditures to children, were both illogical negative values. The first undoubtedly reflects declines in fecundity, and the second changes in the state funding formula.

Table 5.4 describes the algorithm used to calculate fiscal effects. To calculate taxes and other revenues, average and marginal rates were multiplied by maximum and minimum estimates of the statewide value added resulting from a 5,000,000 pound salmon farming industry. Federal grant revenue, human resource expenditures, and other expenditures were similarly calculated by multiplying maximum and minimum employment estimates by the product of population per employee and category expenditures per capita. Education expenditures were calculated in a similar manner, with the insertion of enrollment per capita.

Results, reported in table 5.5, indicate that annual state revenues from a 5,000,000 pound industry could range from a high of \$2.26 million (maximum impact, average ratio) to a low of \$.36 million (minimum impact, marginal value). Expenditures could

Table 5.5 Impacts of a \$25,000,000 Salmon Farming Industry on Washington State Revenues and Expenditures

Case	Revenues	Expenditures	Net
Maximum Economic Impact			
Average Calculation	\$2,257,105	\$1,482,468	\$774,637
Marginal Calculation	\$598,608	\$1,273,621	(\$675,013)
Minimum Economic Impact			
Average Calculation	\$1,201,216	\$1,256,711	(\$55,494)
Marginal Calculation	\$362,981	\$1,079,668	(\$716,687)

range from a high of \$1.48 million (maximum impact average ratio) to a low of \$1.08 million (minimum impact, marginal value).

VI. PROPERTY VALUES

The last empirical research task undertaken in this report is to investigate the economic implications of assertions that salmon farms will, due to negative visual aesthetics effects, reduce adjacent waterfront property values.

It must be emphasized that it is the economic implications of assertions about aesthetic loss and price decline that are being examined, not the assertions themselves. Where the existence of markets, or other circumstances, permits the observation of human behavior toward aesthetic resources, the measurement of aesthetic values is theoretically possible and occasionally attempted. However, employment here of the methods used in such empirical inquiries, such as consumer surveys and hedonic pricing, would require far more time and resources than are currently available.

A simpler method is offered instead, which relies only on publicly available property value data and simple regression analysis. The results of this analysis are, by means discussed below and in the next section, combined with essentially arbitrary judgments about the aesthetic effect of salmon farms. The purpose of this exercise is to provide an analytical framework within which the results of other research into (or personal opinion concerning) aesthetic effects can be integrated with other economic data to inform siting decisions.

The first step in implementing this approach was to collect

the types of data on waterfront property which are available from real estate firms, multiple listing services, and county assessors. Summary statistics on the 335 properties surveyed on this basis are reported in tables 6.1 to 6.7. As indicated in table 6.1, the average value of the 335 properties surveyed was \$409 per front foot, with a standard deviation of \$209. The lowest average value was in Clallam County \$271, and the highest was in San Juan County \$506. This pattern, which coincides with views of consulted realtors and assessors, results partly from locational preference for the San Juan Islands, and partly from the proportion of lower valued "high bank" waterfront in Clallam County.

Among the classes of values obtained, market values (asked or sold as reported by realtors and multiple listing services) were on average \$223 per front foot higher than assessed values, \$531 versus \$303. This difference was also supported by the experience of realtors and assessors. Current, full market value is the legal standard for property assessment in Washington State. However, because there are so few transactions in rural waterfront areas it is often difficult for assessors to keep values current in times of inflation.

Over the entire sample, values of low bank and no bank property were, as expected, the highest of the three categories, \$534 per front foot, versus \$396 for medium bank and \$312 for high bank.

Finally, an index, called SCORE, was tabulated, as the sum of listed property improvements (other than buildings) and other

Table 6.1 Puget Sound Waterfront Property Front Footage Values

	Assessed	Market	All
	-----	-----	-----
	AVERAGE PRICE PER FRONT FOOT		
Puget Sound	\$303	\$531	\$417
Clallam Co	\$223	\$619	\$271
Jefferson Co	\$300	\$451	\$428
Kitsap Co	\$437	\$364	\$425
San Juan Co	375	\$614	\$506
Skagit Co	\$305	\$489	\$381

	N	AVERAGE PRICE PER FRONT FOOT
	-----	-----
All	335	\$409
High Bank	116	\$312
Medium Bank	50	\$396
Low or No Bank	100	\$534

Score	N	AVERAGE PRICE PER FRONT FOOT
	-----	-----
0	110	\$324
1+	205	\$464
2+	153	\$476
3+	101	\$462
4+	89	\$458
5+	31	\$541

Table 6.2 Puget Sound Waterfront Property

Item	Assessed	Market	All
Number	183	142	325
Front Footage			
Maximum	3000	5348	5348
Average	408	198	316
Minimum	50	40	40
Acreage			
Maximum	206.00	264.00	264.00
Average	8.83	3.94	6.69
Minimum	0.33	0.17	0.17
Price			
Maximum	\$2,110,000	\$3,000,000	\$3,000,000
Average	\$73,064	\$140,223	\$102,407
Minimum	\$1,700	\$10,000	\$1,700
Price per Front Foot			
Maximum	\$1,665	\$1,525	\$1,665
Average	\$315	\$531	\$409
Minimum	\$9	\$72	\$9

Table 6.3 Clallam County Waterfront Property

Item	Assessed	Market	All
-----	-----	-----	-----
Number of Prop	36	5	41
Front Footage			
Maximum	1320	209	1320
Average	223	118	210
Minimum	62	80	62
Acreage			
Maximum	11.71	2.00	11.71
Average	2.49	0.82	2.29
Minimum	0.50	0.17	0.17
Price			
Maximum	\$72,600	\$100,000	\$100,000
Average	\$34,722	\$60,800	\$37,903
Minimum	\$9,340	\$30,000	\$9,340
Price per Front Foot			
Maximum	\$450	\$1,050	\$1,050
Average	\$223	\$619	\$271
Minimum	\$55	\$144	\$55

Table 6.4 Jefferson County Waterfront Property

Item	Assessed	Market	All
-----	-----	-----	-----
Number of Prop	10	35	45
Front Footage			
Maximum	320	400	400
Average	147	146	152
Minimum	70	60	60
Acreage			
Maximum	20.00	7.11	20.00
Average	4.48	2.55	3.35
Minimum	0.89	0.17	0.17
Price			
Maximum	\$77,440	\$105,000	\$105,000
Average	\$41,429	\$58,794	\$56,024
Minimum	\$17,850	\$17,500	\$17,500
Price per Front Foot			
Maximum	\$360	\$907	\$907
Average	\$300	\$451	\$428
Minimum	\$142	\$175	\$142

Table 6.5 Kitsap County Waterfront Property

Item	Assessed	Market	All
-----	-----	-----	-----
Number of Prop	40	8	48
Front Footage			
Maximum	540	330	540
Average	179	250	191
Minimum	50	80	50
Acreage			
Maximum	11.14	5.03	11.14
Average	2.74	3.38	2.84
Minimum	0.44	0.30	0.30
Price			
Maximum	\$156,500	\$150,000	\$156,500
Average	\$67,960	\$73,000	\$68,800
Minimum	\$7,600	\$29,000	\$7,600
Price per Front Foot			
Maximum	\$802	\$900	\$900
Average	\$437	\$364	\$425
Minimum	\$91	\$150	\$91

Table 6.6 San Juan County Waterfront Property

Item	Assessed	Market	All
-----	-----	-----	-----
Number of Prop	50	61	111
Front Footage			
Maximum	950	4500	4500
Average	304	339	323
Minimum	100	80	80
Acreage			
Maximum	13.28	264.00	264.00
Average	3.75	10.38	7.39
Minimum	0.36	0.50	0.36
Price			
Maximum	\$304,890	\$2,000,000	\$2,000,000
Average	\$97,711	\$164,268	\$94,648
Minimum	\$27,500	\$28,500	\$27,500
Price per Front Foot			
Maximum	\$650	\$1,525	\$1,525
Average	\$375	\$614	\$506
Minimum	\$120	\$72	\$72

Table 6.7 Skagit County Waterfront Property

Item	Assessed	Market	All
-----	-----	-----	-----
Number of Prop	47	33	80
Front Footage			
Maximum	3000	5348	5348
Average	910	558	765
Minimum	60	40	40
Acreage			
Maximum	206.00	114.00	206.00
Average	25.21	13.00	20.17
Minimum	0.33	0.21	0.21
Price			
Maximum	\$2,110,000	\$3,000,000	\$3,000,000
Average	\$165,883	\$210,470	\$184,275
Minimum	\$1,700	\$10,000	\$1,700
Price per Front Foot			
Maximum	\$1,665	\$1,500	\$1,665
Average	\$305	\$489	\$381
Minimum	\$9	\$121	\$9

positive features. For example, SCORE 3 might be availability of water, telephone and sewer. SCORE 2 might be an access road and included tidelands. No effort was made to assign relative value to the items that were added up to obtain the variable SCORE. Also, of importance to subsequent discussion, computation of SCORE was based entirely on features of the property itself. Comments on the general area (near the golf course, mountain view, etc.) were not counted. Average value increased with the value of SCORE, from \$324 for properties with SCORE = 0, to \$541 for those with SCORE ≥ 5 .

The above summary statistics suggest a method of "backing into" an estimate of the value of visual aesthetics. As mentioned, the average value of sampled properties was \$417 per front foot, with a standard deviation of \$290. This standard deviation estimate suggest that, among all properties from which the sample was drawn, about 68 out of any 100 should fall within a price range of \$417 $\pm$ \$290, or between \$127 and \$707.

The sample was drawn from areas throughout Puget Sound, presumably including parcels overlooking a wide variety of visual amenities, and disamenities. Thus, perceived differences in the quality of nearby visual amenities must have given rise to at least part of the reported variance in market value. Note, however, that part of the variance in value can also be explained by factors unrelated to view of the immediate area. Data in table 6.1 suggests that such non-aesthetic factors include county, source of price information (assessor or realty firm), bank type (high, low, medium) and SCORE (which by design reflected only the

degree of land improvement and/or positive features confined within the parcel itself).

Multiple regression analysis is a statistical procedure in which overall variance in a dependent variable (here price per front foot) is either explained by a computed regression equation, or assigned to the category of unexplained residual variance. The summary statistic R^2 measures the proportion of variance explained by the regression equation, the statistic $(1 - R^2)$ then measures unexplained residual variance.

Multiple regression analysis was performed on the property value data set reported in Appendix 1, with the results reported in table 6.8. The regression equation R^2 of .52 suggests that 48 percent of the overall variance in price per front foot remains unexplained.

To express this result in terms of price ranges, consider the previously mentioned one - standard deviation range around the overall average price per front foot, \$417 +/- \$290, or \$127 to \$707. If 76 percent of variance remains unexplained, then the unexplained, one - standard deviation range is \$417 +/- variance results from differences in visual amenities adjacent to the surveyed properties. In the next section we discuss how this

Table 6.8 Regression Analysis of Puget Sound Waterfront Property Values

Dependant Variable: PFF = Price Per Front Foot, R Square .52
Standard Deviation of PFF \$290

Independent Variables	Definitions	Coefficient	T Statistic

STEPWISE INCLUDED			
Constant:		453.05	17.24
DPT1	Dummy Variable for Asking Price	174.63	6.38
FF	Front Footage Per Property	-0.38	-12.00
PRICE	Price Per Property	0.00	11.37
DCO1	Dummy Variable for Clallam County	120.55	3.60
DBNK1	Dummy Variable for High Bank	-167.61	-5.61
DBNK2	Dummy Variable for Medium Bank	-177.81	-5.75
DPT2	Dummy Variable for Assesed Price	152.9	2.66
DCO2	Dummy Variable for Jefferson County	64.78	2.21
		453.05	17.24
STEPWISE EXCLUDED			
DCO3	Dummy Variable for Kitsap County	0.07	1.53
DCO4	Dummy Variable for San Juan County	-0.05	-0.94
ACRES	Acres Per Property	0.04	0.52
SCORE	Index of Property Improvements	0.08	1.72

variance range can be combined with the results of regional input-output analysis to perform an overall benefit cost analysis of salmon farm siting decisions.

VII. BENEFIT - COST ANALYSIS OF SALMON FARM SITING DECISIONS

In this concluding section we organize the foregoing results into a framework for evaluation (from a state economic standpoint) of salmon farm siting decisions. Two steps precede development of an evaluation algorithm. The first is to convert previously developed economic information into comparable economic values. The second is to relate changes in these values to the specific circumstances of salmon farm siting. Each of these steps is accomplished by use of the parameter ranges reported in table 7.1.

Regional economic benefits of salmon farming will accrue to state or county residents during each year of the facilities' operation. Adverse visual effects, on the other hand, will cause a one time reduction in property values when the facilities are sited. However, any such reduction in capital value can be expressed as the loss of an annual-income equivalent by use of an appropriate interest rate. The economic logic behind making such a conversion derives from the observation that a property owner always has the option of selling his property and earning an annual income from it, as determined by earnings on investments available to him. That he does not sell, suggests that he places at least this annual value on the utility or satisfaction derived from the use of the land in recreational or residential use.

Table 7.1 Input Parameters to Sensitivity Analysis

PARAMETER NAMES	DESCRIPTIONS	High	Low

RANGES			
A =	HOUSHOLD INCOME	\$21,412,000	\$10,615,000
B =	OPPORTUNITY COST OF CURRENT EARNINGS	50%	75%
C =	VISUALLY EFFECTED MILES OF WATERFRONT	25	50
D =	SAMPLE STANDARD DEVIATION	\$285	\$285
F =	% CHANGE IN AESTHETIC INDEX	10%	20%
G =	INTEREST RATE	3%	8%
CONSTANTS			
D =	SAMPLE STANDARD DEVIATION		\$285.
G =	EXPLAINED VARIANCE (R^2)		0.24

What interest rate should be chosen to reflect this actual or implicit annual income is a matter of considerable discussion among economists. One point upon which they agree, though, is that a "real" interest rate (i.e. financial rate less expected inflation) should be used. Deduction of expected inflation is necessary because the inflation premium in financial rates, which only maintains initial capital value, provides no estimate of actual net earnings. As reported in table 7.1, we adopt a real interest rate range of 3% to 8% to convert property values into annual equivalents comparable to regional economic benefits.

The different alternatives facing waterfront property owners and individuals benefiting from regional economic expansion point up the need for another conversion. Feasible non-recreational/residential uses of rural waterfront property consist primarily of agriculture and forestry, activities that would support only a small fraction of prevailing market prices. Thus, the waterfront property owner has no realistic alternative to simply accepting any loss in value that results from diminished visual aesthetics.

By contrast, the household incomes earned due to local economic expansion represent payments for labor and other factors of production that have reasonably attractive alternatives. Most workers employed on salmon farms, or in industries supporting them, could find employment elsewhere. For these otherwise employable workers, incomes, working conditions or other values achievable in alternative employment comprise a significant share of the value they place on their chosen employment. Alternative

value is not, however, likely to exceed value in the chosen occupation, as in that case the rational worker would change jobs.

Alternative value will also fall short of the value of current employment, to the extent that there are costs (and delays) in finding alternative employment, and to the extent that some workers (such as the elderly or unskilled) lack viable alternatives. We adopt an opportunity cost range of 50% to 75% (ie an implicit net value of gross income of 25% to 50%) to reflect the sum of all these differences between gross regional income and opportunity cost.

We now address the task of interpreting the preceding section's statistical analysis of property values in terms of lost net economic value. For previously stated reasons, we begin by restating our inability to determine, what, if any, negative aesthetic effects can be attributed to salmon farms. The purpose of this report is to work out the economic implications of independently provided assessments of visual impact, not to directly estimate these in economic or other terms.³

Recall the conclusion of section IV, which suggests that the front footage price of 68% (one standard deviation) of the properties from which the sample was drawn should fall within a range computed as follows:

Actual price = regression calculated price +/- unexplained variance (.48) * standard deviation (\$290)

For the purposes of this section's benefit cost analysis we posit an aesthetics index, ranging from zero to one, which

explains all of that otherwise unexplained variation. By this formulation a property with a zero aesthetics index would fall at the bottom of the one standard deviation range, ie its price would be the regression calculated value less $(.48 * \$290 = \$139)$. A property with an index of 1.0, would fall at the top of that range (within which 68% of properties now fall), ie. as calculated from the regression equation, plus \$139. Were some event to change a property's aesthetics index from one (best) to zero (worst) the result would be a loss of \$278 per front foot.

We assume that less than a 1 to 0 change in this aesthetics index would result from siting salmon farming facilities. Specifically our benefit cost calculations are based on a 10 % to 20 % range of reductions. These values are, as previously mentioned, posited for illustration, rather than being offered either as the results of this research, or as the judgments of the author.

In addition to a judgment concerning the degree of aesthetic loss (per affected front foot), we need a similar judgment concerning the geographic extent (feet or miles of coastline) over which that adverse effect will extend. Here we assume, subject to the same qualifications as above, a range of 5 to 10 miles per site, or 25 to 50 miles of coastline for a 5 site industry.

The final variable required by the benefit-cost algorithm is gross benefit to the state from economic expansion. For this purpose we enter the statewide maximum and minimum value-added estimates of \$21.4 and \$10.6 million.

The benefit-cost algorithm used to perform sensitivity analysis over the above ranges is reported in table 7.2. Each calculation compares maximum beneficiary willingness to pay (numerator), with the minimum required to compensate losers (denominator). Maximum beneficiary willingness to pay in this case is the statewide value-added contributions of 5 salmon farms, adjusted by an opportunity cost factor. Minimum compensation of losers is the loss of waterfront property value, calculated as discussed above.

A six variable, 64 case, sensitivity model was used to calculate benefit cost ratios for all combinations of the input parameters listed in table 7.1. Results are reported in table 7.3. For the input values and ranges adopted, all cases yield benefit cost ratios in excess of unity. This suggests that, under all circumstances and judgments represented by table 7.1 parameters, beneficiaries from salmon farm siting could more than fully compensate losers. The maximum ratio, resulting from the most favorable combination of range variables, is 97.11. The least favorable is 2.26. Finally, high and low range results are calculated as the mean value of \$21.06 +/- the standard deviation of \$19.34. These results range from 40.41 to 1.72.

Thus, under all parameters and parameter combinations examined, siting 5 salmon farms would be in the state's economic interest, as this was defined above in terms of beneficiary willingness to pay and amounts required to compensate losers.

Table 7.2 Sensitivity Analysis Algorithm, and
Illustrative Calculation

BCR = ANNUAL BENEFITS/ ANNUAL COSTS =	2.26
ANNUAL BENEFITS = $A*(1-B)$ =	\$2,653,750
ANNUAL COSTS = $5280*C*2*D*(1-G)*E*F$ =	\$1,175,962

WHERE:

WHERE:

A =	HOUSHOLD INCOME	\$10,615,000
B =	OPPORTUNITY COST OF CURRENT EARNINGS	75%
C =	VISUALLY EFFECTED MILES OF WATERFRONT	50
D =	SAMPLE STANDARD DEVIATION	\$290
E =	% CHANGE IN AESTHETIC INDEX	20%
F =	INTEREST RATE	8%
G =	EXPLAINED VARIANCE (R^2)	0.52

Parameter values and ranges are reported in table 7.2.
Full sensitivity results in table 7.3.

Table 7.3 Sensitivity Analysis Results

F >>			3%	3%	3%	3%
A (millions)			\$21	\$21	\$11	\$11
B >>			50%	75%	50%	75%
C	E	D	----- BCR -----			
25	10%	\$290	97.11	48.55	48.14	24.07
25	10%	\$290	97.11	48.55	48.14	24.07
25	20%	\$290	48.55	24.28	24.07	12.04
25	20%	\$290	48.55	24.28	24.07	12.04
50	10%	\$290	48.55	24.28	24.07	12.04
50	10%	\$290	48.55	24.28	24.07	12.04
50	20%	\$290	24.28	12.14	12.04	6.02
50	20%	\$290	24.28	12.14	12.04	6.02

F >>			8%	8%	8%	8%
A (millions)			\$21	\$21	\$11	\$11
B >>			50%	75%	50%	75%
C	E	D	----- BCR -----			
25	10%	\$290	36.42	18.21	18.05	9.03
25	10%	\$290	36.42	18.21	18.05	9.03
25	20%	\$290	18.21	9.10	9.03	4.51
25	20%	\$290	18.21	9.10	9.03	4.51
50	10%	\$290	18.21	9.10	9.03	4.51
50	10%	\$290	18.21	9.10	9.03	4.51
50	20%	\$290	9.10	4.55	4.51	2.26
50	20%	\$290	9.10	4.55	4.51	2.26
Average		21.06	High range		40.41	
Standard		19.34	Low range		1.72	
Maximum		97.11				
Minimum		2.26				

Notes

1. British Columbia data was provided by Jim Fraylick, British Columbia Ministry of Agriculture and Fisheries.
2. Washington data was provided by Robert Hoyser, Washington State Department of Natural Resources; and Eric Hurlburt, Washington State Department of Fisheries.
3. Some data and an appraiser's judgment concerning the degree and geographic extent of adverse visual and market effect are provided in Alpine Appraisers, 1988. The author of that document concludes that "floating net pens have no effect on upland property values in the areas studied (Peal Passage, Mason County, and Rich Passage, Kitsap County). Additionally, the appraiser concludes that "the pens will have minimal, if any, visual impact at distances over 2400 lineal feet".

References

Alpine Appraisal Service. "Influence of Floating Salmon Net Pens on Residential Property Values." Report to the Jamestown Clallam tribe, Sequim, Washington, August 30, 1988.

Richardson, Harry W. Input Output and Regional Economics. (New York: John Wiley and Sons, 1972).

U.S. Forest Service (Portland Oregon). IMPLAN Data, (Reports provided to the Author).

Washington State, Office of Program Planning and Fiscal Management. Pocket Data Guide. Olympia, WA 1983.

A.1 Puget Sound Waterfront Property Survey.

COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PRICE TYPE	BAFF. FEATURES	BUILDINGS	SCORE	SOURCE
Clallam	Port Angeles	1.50	100	\$45,000	\$450	assessed h	water, pave	57950	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	136	\$27,200	\$200	assessed			0	Clallam Co Assessor
Clallam	Port Angeles	0.96	100	\$35,000	\$350	assessed h	elec, water, ph, pave		4	Clallam Co Assessor
Clallam	Discovery Bay	1.13	136	\$27,200	\$200	assessed			0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	102	\$9,340	\$32	assessed l	tdl, elec, wat, sew, ph, road		6	Clallam Co Assessor
Clallam	W. of Port Angeles	11.26	1320	\$72,600	\$55	assessed	erosion		0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.09	105	\$13,650	\$130	assessed h	elec, ph, access	295	3	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	295	\$60,670	\$206	assessed h		1375	0	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	\$63,670	\$250	assessed h	elec, ph	1375	2	Clallam Co Assessor
Clallam	Clallam Bay	0.50	121	\$24,320	\$201	assessed l	tdl, elec, wat, sew, ph, road	48710	6	Clallam Co Assessor
Clallam	Port Angeles	1.16	100	\$45,000	\$450	assessed h	elec, pave		2	Clallam Co Assessor
Clallam	Clallam Bay	0.50	150	\$30,150	\$201	assessed l	tdl, elec, wat, sew, ph, road		6	Clallam Co Assessor
Clallam	Port Angeles	1.16	104	\$46,800	\$450	assessed h	elec, water, septic, ph, pave	69700	5	Clallam Co Assessor
Clallam	Clallam Bay	0.50	62	\$12,660	\$204	assessed l	tdl, elec, wat, sew, ph, road	11820	6	Clallam Co Assessor
Clallam	Clallam Bay	0.50	63	\$12,660	\$201	assessed l	tdl, elec, wat, sew, ph, road	30890	5	Clallam Co Assessor
Clallam	W. of Port Angeles	9.05	560	\$56,025	\$100	assessed h			0	Clallam Co Assessor
Clallam	Discovery Bay	1.22	200	\$27,335	\$137	assessed h			0	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	\$31,835	\$125	assessed h	elec, no perk		0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.75	175	\$22,750	\$130	assessed h	elec, ph	475	2	Clallam Co Assessor
Clallam	W. of Disc Bay	1.10	100	\$13,000	\$130	assessed h	elec, ph, access		3	Clallam Co Assessor
Clallam	W. of Disc Bay	5.03	255	\$61,640	\$242	assessed	elec, ph, access	61630	4	Clallam Co Assessor
Clallam	W. of Port Angeles	4.40	215	\$21,500	\$100	assessed h			0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	63	\$12,660	\$201	assessed l	elec, water, sewer, road	36270	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	136	\$22,000	\$162	assessed			0	Clallam Co Assessor
Clallam	Discovery Bay	1.09	136	\$27,200	\$200	assessed			0	Clallam Co Assessor
Clallam	Discovery Bay	2.05	150	\$52,500	\$350	assessed			0	Clallam Co Assessor
Clallam	W. of Port Angeles	11.71	1320	\$72,600	\$55	assessed	poor terrain		0	Clallam Co Assessor
Clallam	Port Angeles	1.18	90	\$40,500	\$450	assessed h	elec, water, septic, ph, pave		5	Clallam Co Assessor
Clallam	Port Angeles	1.44	100	\$45,000	\$450	assessed h	elec, water, septic, ph, pave	51920	5	Clallam Co Assessor
Clallam	W. of Port Angeles	4.50	335	\$33,535	\$100	assessed h			0	Clallam Co Assessor
Clallam	Port Angeles	1.50	110	\$46,750	\$425	assessed h	elec, water, septic, ph, pave	71350	5	Clallam Co Assessor
Clallam	Discovery Bay	1.09	136	\$27,200	\$200	assessed			0	Clallam Co Assessor
Clallam	W. of Disc Bay	1.23	100	\$13,000	\$130	assessed	access, easement		2	Clallam Co Assessor
Clallam	Port Angeles	1.37	134	\$50,000	\$373	assessed h	elec, water, sep, ph, pave	67990	4	Clallam Co Assessor
Clallam	Discovery Bay	1.00	200	\$27,135	\$136	assessed			0	Clallam Co Assessor
Clallam	Clallam Bay	0.50	99	\$19,920	\$201	assessed l	elec, water, sewer, road	66780	4	Clallam Co Assessor
Clallam	W. Ediz Hook	0.17	100	\$50,000	\$500	market h	Buildable		1	See Ridge Realty
Clallam	The Place Beech	0.75	100	\$100,000	\$1,000	market l	lagoon		2	See Ridge Realty
Clallam	Freshwater Bay	2.00	209	\$30,000	\$144	market h			0	See Ridge Realty
Clallam	4 Seasons Ranch	1.00	90	\$84,000	\$1,050	market l	Drain field, planned dev, tdlnds		4	See Ridge Realty
Clallam	Straits		100	\$40,000	\$400	market h	Building int		1	See Ridge Realty
Jefferson	Ft. Flagler	0.89	100	\$36,000	\$360	assessed h	easement	33045	4	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.34	200	\$67,500	\$338	assessed h		42125	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	3.00	70	\$17,850	\$255	assessed l			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.13	100	\$36,000	\$360	assessed	water, dirt road	9780	2	Jefferson Co Assessor
Jefferson	Ft. Flagler	1.93	240	\$77,440	\$323	assessed h	poor access	21285	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	5.00	110	\$28,050	\$255	assessed l			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	0.92	100	\$35,000	\$350	assessed h			0	Jefferson Co Assessor
Jefferson	Ft. Flagler	5.04	120	\$43,000	\$358	assessed h		27030	4	Jefferson Co Assessor
Jefferson	Squamish Harbor	20.00	320	\$45,395	\$142	assessed l			0	Jefferson Co Assessor
Jefferson	Squamish Harbor	5.00	110	\$28,050	\$255	assessed h			0	Jefferson Co Assessor
Jefferson	E. Hood Canal	0.61	100	\$58,000	\$580	market h	septic, water, road		3	Jefferson Co Realtor
Jefferson	North Beach	0.26	90	\$45,000	\$500	market h	water, road, sewer		4	Realty World
Jefferson	Middle Pt.	5.02	121	\$46,000	\$380	market h	power, road, need septic, need well		2	Realty World
Jefferson	Squamish Harbor	1.41	105	\$45,000	\$429	market h	sandy beach		1	Jefferson Co Realtor
Jefferson	Nats Nats Bay	1.62	170	\$42,500	\$250	market h	tidelands, power, well		3	Realty World

A.1 Puget Sound Waterfront Property Survey

COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PRICE TYPE	MARK FEATURES	BUILDINGS	SCORE	SOURCE
Jefferson	Oak Bay	2.07	105	\$59,500	\$567	market	n easment		1	Jefferson Co Realtor
Jefferson	Narrowstone I.	2.32	148	\$45,000	\$304	market	power		1	Jefferson Co Realtor
Jefferson	Pt. Ludlow	0.17	60	\$43,500	\$725	market	n water, no rights		2	Jefferson Co Realtor
Jefferson	Mats Mats Bay	1.61	100	\$74,000	\$740	market	septic		1	Jefferson Co Realtor
Jefferson	Narrowstone I.	4.96	300	\$65,000	\$217	market			0	Jefferson Co Realtor
Jefferson	Islands Pen.	2.63	185	\$49,500	\$268	market	n power, fruit trees		2	Jefferson Co Realtor
Jefferson	Narrowstone I.	3.03	150	\$49,000	\$327	market	power, septic		2	Jefferson Co Realtor
Jefferson	Bulawa	2.70	100	\$82,500	\$825	market	n water, timber, beach		3	Jefferson Co Realtor
Jefferson	Narrowstone I.	3.26	290	\$105,000	\$362	market			0	Jefferson Co Realtor
Jefferson	Cape George	0.57	149	\$48,000	\$322	market	h water, power, tel, drain field		4	Realty World
Jefferson	Oak Bay	0.95	100	\$39,500	\$395	market			0	Jefferson Co Realtor
Jefferson	E. Hood Canal	1.00	100	\$56,000	\$560	market	l water, power		2	Jefferson Co Realtor
Jefferson	Middle Point	5.20	121	\$52,000	\$430	market	h road, need well, need septic		2	Realty World
Jefferson	Admiralty Inlet	0.96	100	\$40,000	\$400	market	h		0	Jefferson Co Realtor
Jefferson	Madlock	5.01	400	\$92,500	\$231	market	tidelands, water, power		3	Jefferson Co Realtor
Jefferson	E. Hood Canal	0.53	75	\$68,000	\$907	market	h easment		1	Jefferson Co Realtor
Jefferson	E. Hood Canal	2.05	118	\$51,000	\$432	market	n perk problem,		0	Jefferson Co Realtor
Jefferson	Hood Canal	2.63	185	\$45,000	\$243	market	n tidelands, road, power, perks,		4	Realty World
Jefferson	Straits	3.00	136	\$49,500	\$364	market	well		1	Jefferson Co Realtor
Jefferson	Narrowstone I.	0.86	100	\$75,000	\$750	market	l septic		1	Jefferson Co Realtor
Jefferson	Narrowstone I.	3.36	200	\$99,500	\$498	market	power		1	Jefferson Co Realtor
Jefferson	Oak Head	7.11	200	\$69,800	\$349	market	h power		1	Jefferson Co Realtor
Jefferson	Narrowstone I.	3.36	200	\$99,500	\$498	market	n tidelands, well, power, tel		4	Realty World
Jefferson	Middle Pt.	5.30	121	\$52,500	\$434	market	h power, road, need well, need septic		2	Realty World
Jefferson	Tarbo Bay	1.23	100	\$17,500	\$175	market	n spring		1	Jefferson Co Realtor
Jefferson	E. Hood Canal	3.47	200	\$48,000	\$240	market	h power		1	Jefferson Co Realtor
Jefferson	Gardiner	3.20	171	\$79,000	\$462	market	h power, water, timber		4	Realty World
Jefferson	Discovery Bay	2.52	100	\$75,000	\$750	market	l		0	Jefferson Co Realtor
Jefferson	Middle Pt.	5.02	121	\$46,000	\$380	market	h power, road, need well, need septic		2	Realty World
Jefferson	Cape George	0.40	90	\$45,000	\$500	market	h power, well		2	Jefferson Co Realtor
Kitsap	Poulsbo	2.70	175	\$52,500	\$300	assessed	le BQPMF6X	62540	3	Kitsap Co Assessor
Kitsap	Fletcher Bay	4.67	220	\$107,350	\$488	assessed	h BQPMF6X		4	Kitsap Co Assessor
Kitsap	Fletcher Bay	0.88	70	\$40,390	\$577	assessed	le BQPMF6X		0	Kitsap Co Assessor
Kitsap	Eglon	0.46	50	\$7,600	\$152	assessed	h BQPMF6X		0	Kitsap Co Assessor
Kitsap	Eglon	0.56	60	\$9,120	\$152	assessed	h BQPMF6X		0	Kitsap Co Assessor
Kitsap	Colvos Passage	2.50	210	\$42,000	\$200	assessed	h BQPMF6X		2	Kitsap Co Assessor
Kitsap	Poulsbo	0.53	100	\$30,000	\$300	assessed	le BQPMF6X		2	Kitsap Co Assessor
Kitsap	Vinland	1.38	155	\$109,810	\$702	assessed	le BQ(CPC)CAGX	90860	5	Kitsap Co Assessor
Kitsap	Vinland	0.79	120	\$96,240	\$802	assessed	le BQ(CPC)CAGX	65360	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	1.97	160	\$92,090	\$576	assessed	le BQ(CPC)CFGE	39220	5	Kitsap Co Assessor
Kitsap	Colvos Passage	5.07	330	\$50,160	\$152	assessed	h BQ(CPC)PMF6X		3	Kitsap Co Assessor
Kitsap	Toku Pt.	5.97	425	\$97,150	\$221	assessed	h BQ(CPC)PMF6X		2	Kitsap Co Assessor
Kitsap	Vinland	2.36		\$110,400		assessed	le BQ(CPC)CAGX	41430	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.77	205	\$138,780	\$677	assessed	le BQ(CPC)CAGX	34280	5	Kitsap Co Assessor
Kitsap	Colvos Passage	5.08	142	\$46,434	\$327	assessed	le BQ(CPC)CAGX		2	Kitsap Co Assessor
Kitsap	Vinland	3.94	200	\$100,400	\$502	assessed	le BQ(CPC)CAGX	44810	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	1.47	73	\$53,020	\$726	assessed	le BQ(CPC)CFGE	95230	6	Kitsap Co Assessor
Kitsap	Eglon	1.88	100	\$9,100	\$91	assessed	h BQPMF6X		0	Kitsap Co Assessor
Kitsap	Eglon	2.02	170	\$21,250	\$125	assessed	le BQPMF6X		1	Kitsap Co Assessor
Kitsap	Fletcher Bay	3.80	210	\$156,500	\$745	assessed	h BQ(CPC)PMF6X	146150	5	Kitsap Co Assessor
Kitsap	Fletcher Bay	2.61	150	\$101,050	\$674	assessed	le BQ(CPC)PMF6X		4	Kitsap Co Assessor
Kitsap	Vinland	0.86	100	\$80,200	\$802	assessed	le BQ(CPC)CAGX	113380	4	Kitsap Co Assessor
Kitsap	Toku Pt.	8.49	300	\$101,980	\$340	assessed	le BQ(CPC)CAGX	182700	4	Kitsap Co Assessor
Kitsap	Colvos Passage	3.26	200	\$40,000	\$200	assessed	h BQPMF6X		1	Kitsap Co Assessor
Kitsap	Colvos Passage	8.18	220	\$77,440	\$352	assessed	le BQ(CPC)CFGE		4	Kitsap Co Assessor
Kitsap	Eglon	2.38	260	\$21,200	\$120	assessed	h BQPMF6X		0	Kitsap Co Assessor

A.1 Puget Sound Waterfront Property Survey

FRONT	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PRICE TYPE	BBW FEATURES	BUILDING	SCORE	SOURCE
Kitsap	Fletcher Bay	1.61	39	\$59,260	\$666	assessed h	GS(CPC)MFE	69530	4	Kitsap Co Assessor
Kitsap	Toku Pt.	11.14	540	\$102,310	\$189	assessed le	GNBMBGN		1	Kitsap Co Assessor
Kitsap	Colvos Passage	6.09	285	\$86,070	\$302	assessed h	USMBNGE		1	Kitsap Co Assessor
Kitsap	Winland	0.66	100	\$80,200	\$802	assessed le	BN(CPC)CAGX	134780	5	Kitsap Co Assessor
Kitsap	Poulsbo	0.60	116	\$37,450	\$323	assessed le	GN(CPC)CFRE	59100	5	Kitsap Co Assessor
Kitsap	Winland	0.59	110	\$89,220	\$802	assessed le	BN(CPC)CAGX	72370	5	Kitsap Co Assessor
Kitsap	Colvos Passage	1.27	100	\$20,200	\$202	assessed h	USMBNGE		1	Kitsap Co Assessor
Kitsap	Egion	5.30	510	\$73,500	\$144	assessed h	XSNMBGN		0	Kitsap Co Assessor
Kitsap	Poulsbo	0.50	97	\$63,240	\$652	assessed le	BN(CPC)CAGX		5	Kitsap Co Assessor
Kitsap	Poulsbo	0.60	130	\$91,260	\$702	assessed le	B(CPC)CAGX	25280	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.30	100	\$35,000	\$350	assessed le	BN(CPC)CFRE	30350	5	Kitsap Co Assessor
Kitsap	Poulsbo	1.11	115	\$80,530	\$700	assessed le	BN(CPC)CAGX	102990	5	Kitsap Co Assessor
Kitsap	Poulsbo	0.44	90	\$36,000	\$400	assessed le	GNPCFBN		2	Kitsap Co Assessor
Kitsap	Poulsbo	0.68	160	\$64,000	\$400	assessed le	GN(CPC)CFRE	114510	4	Kitsap Co Assessor
Kitsap	Stavris Bay Road	5.00	330	\$49,500	\$150	market he	phone, no elec		1	Coldwell Banker
Kitsap	Stavris Bay Road	5.03	330	\$62,500	\$189	market he	power, phone		2	Coldwell Banker
Kitsap	Stavris Bay Road	5.00	330	\$65,000	\$197	market he	elec, phone, no water		2	Coldwell Banker
Kitsap	Stavris Bay Road	5.00	330	\$150,000	\$455	market l	power, phone, septic, well		4	Coldwell Banker
Kitsap	Stavris Bay Road	5.00	330	\$70,000	\$212	market he	elec, phone, no water		2	Coldwell Banker
Kitsap	Big Beef Harbor	0.50	104	\$29,000	\$279	market n	elec, phone, needs well		2	Coldwell Banker
Kitsap	Rich Passage	0.30	80	\$72,000	\$900	market l	elec, phone, water		3	Coldwell Banker
Kitsap	Olympic View Road	1.23	163	\$86,000	\$528	market he	elec, phone, no water		2	Coldwell Banker
San Juan	San Juan W.	9.54	770	\$304,890	\$396	assessed n		59400	4	San Juan Co Assessor
San Juan	Shaw S	1.38	310	\$118,050	\$381	assessed l	tidelands	16500	4	San Juan Co Assessor
San Juan	Orcas	1.56	210	\$90,510	\$431	assessed n	tidelands		1	San Juan Co Assessor
San Juan	Shaw M	4.37	315	\$94,500	\$300	assessed l		69720	4	San Juan Co Assessor
San Juan	Lopez M	2.81	315	\$94,500	\$300	assessed h			4	San Juan Co Assessor
San Juan	Shaw M	0.57	157	\$54,950	\$350	assessed n		24200	4	San Juan Co Assessor
San Juan	Lopez E	0.43	270	\$33,750	\$125	assessed n			0	San Juan Co Assessor
San Juan	Shaw S	4.9	740	\$155,500	\$210	assessed h		214690	4	San Juan Co Assessor
San Juan	Orcas	3.02	310	\$62,000	\$200	assessed n			0	San Juan Co Assessor
San Juan	Lopez M	12.7	400	\$90,010	\$225	assessed n			0	San Juan Co Assessor
San Juan	San Juan SW	1.91	213	\$128,850	\$605	assessed n	tidelands	7220	5	San Juan Co Assessor
San Juan	Shaw SE	1.18	100	\$60,000	\$600	assessed n		25040	4	San Juan Co Assessor
San Juan	Orcas E	5.71	290	\$96,450	\$333	assessed h		1670	0	San Juan Co Assessor
San Juan	Shaw M	2.83	300	\$90,000	\$300	assessed n		76940	4	San Juan Co Assessor
San Juan	Shaw SE	1.84	150	\$83,400	\$556	assessed n	tidelands	13780	5	San Juan Co Assessor
San Juan	Shaw M	6.44	665	\$160,290	\$241	assessed l		1880	0	San Juan Co Assessor
San Juan	Lopez M	0.38	110	\$41,250	\$375	assessed n	tidelands	16750	5	San Juan Co Assessor
San Juan	Orcas E	5.09	360	\$112,050	\$311	assessed n		121970	4	San Juan Co Assessor
San Juan	Lopez M	12.29	590	\$154,990	\$263	assessed h			0	San Juan Co Assessor
San Juan	San Juan W.	2.05	200	\$110,000	\$550	assessed h			0	San Juan Co Assessor
San Juan	Lopez E	0.68	120	\$66,720	\$556	assessed n	tidelands	42410	5	San Juan Co Assessor
San Juan	Lopez E	2.5	140	\$84,000	\$600	assessed n		133790	4	San Juan Co Assessor
San Juan	Lopez E	0.36	100	\$27,500	\$275	assessed n			0	San Juan Co Assessor
San Juan	Lopez S	9.75	440	\$150,200	\$341	assessed n			0	San Juan Co Assessor
San Juan	Lopez NW	5.1	290	\$74,550	\$257	assessed h		2460	0	San Juan Co Assessor
San Juan	Shaw M	0.81	200	\$70,000	\$350	assessed n		117940	4	San Juan Co Assessor
San Juan	Orcas SE	4.04	265	\$90,550	\$342	assessed n			0	San Juan Co Assessor
San Juan	Shaw S	2.7	950	\$142,500	\$150	assessed h			0	San Juan Co Assessor
San Juan	Orcas E	10.65	535	\$151,650	\$283	assessed h			0	San Juan Co Assessor
San Juan	Orcas E	1.62	150	\$70,750	\$525	assessed h		40280	4	San Juan Co Assessor
San Juan	Lopez E	2.2	100	\$65,000	\$650	assessed n		71430	4	San Juan Co Assessor
San Juan	San Juan W.	1.8	160	\$104,000	\$650	assessed n	tidelands	81360	5	San Juan Co Assessor
San Juan	Orcas SE	4.02	250	\$108,050	\$432	assessed n		9220	4	San Juan Co Assessor
San Juan	Shaw M	2.1	510	\$61,200	\$120	assessed n		2550	0	San Juan Co Assessor

A.1 Puget Sound Waterfront Property Survey

COUNTY	SITE	ACRES	FRONT FEET	PRICE	PRICE FRONT	PRICE TYPE	BBQ: FEATURES	BUILDINGS SCORE	SOURCE
San Juan	Orcas	0.50	100	\$85,000	\$850	market	pur,utr	2	Island Computer Services
San Juan	Eagle Pt.	0.80	150	\$79,500	\$530	market	h pur,utr	2	Island Computer Services
San Juan	San Juan I.	1.61	375	\$210,000	\$560	market	l	0	Island Computer Services
San Juan	Rocky Bay	3.11	240	\$149,500	\$623	market	pur	1	Island Computer Services
San Juan	Griffin Bay	0.75	100	\$89,500	\$895	market	pur,cove	2	Island Computer Services
San Juan	Davidson Head	0.50	100	\$75,000	\$750	market	pur,utr	2	Island Computer Services
San Juan	Mannah Heights	1.00	200	\$69,500	\$348	market	prc,par,utr,spt	4	Island Computer Services
San Juan	Mescott Bay	0.50	100	\$76,500	\$765	market	pur,utr,spt	3	Island Computer Services
San Juan	Reid Harbor	5.12	300	\$45,000	\$217	market	dock	1	Island Computer Services
San Juan	Mescott Bay	0.70	140	\$75,000	\$536	market	l	0	Island Computer Services
San Juan	San Juan	15.20	380	\$135,000	\$355	market	pur	1	Island Computer Services
San Juan	University Heights	0.50	100	\$120,000	\$1,200	market	l	0	Island Computer Services
San Juan	San Juan I.	5.00	700	\$75,000	\$107	market	h	0	Island Computer Services
San Juan	San Juan	79.25	360	\$549,000	\$1,525	market	h pur	1	Island Computer Services
San Juan	San Juan	0.89	185	\$185,000	\$1,000	market	n pur	1	Island Computer Services
San Juan	San Juan	3.87	600	\$180,000	\$300	market	n pur,utr,spt	3	Island Computer Services
San Juan	S. End	1.00	200	\$76,500	\$383	market	pur,utr	2	Island Computer Services
San Juan	Mescott Bay	5.00	755	\$187,500	\$248	market	beach	1	Island Computer Services
San Juan	Griffin Bay	1.50	120	\$99,500	\$829	market	h pur	1	Island Computer Services
San Juan	Eagle Pt.	6.17	375	\$174,500	\$465	market	h pur,utr	2	Island Computer Services
San Juan	Limestone	5.00	310	\$217,000	\$700	market	utr,par	2	Island Computer Services
Skagit	E Guemes Ch	9.6	700	\$31,300	\$45	assessed	h road	34200	4 Skagit Co Assessor
Skagit	Burrows Bay	5	2000	\$35,500	\$18	assessed	h	0	Skagit Co Assessor
Skagit	Padilla Bay	26	1600	\$90,000	\$56	assessed	h road	1	Skagit Co Assessor
Skagit	Padilla Bay	40.68	1300	\$18,900	\$15	assessed	l road	1	Skagit Co Assessor
Skagit	Padilla Bay	1.5	200	\$1,700	\$9	assessed	l water	8000	4 Skagit Co Assessor
Skagit	Ship Harbor	7.09	800	\$48,900	\$61	assessed	n road,water,septic	75900	4 Skagit Co Assessor
Skagit	Padilla Bay	47.75	1600	\$36,800	\$23	assessed	h water,septic,road	3	Skagit Co Assessor
Skagit	Bellingham Bay	3.74	200	\$85,860	\$429	assessed	l water,septic,road	3	Skagit Co Assessor
Skagit	Rosario St	55.1	1400	\$88,930	\$64	assessed	h	0	Skagit Co Assessor
Skagit	Sinclair I.	28.75	1670	\$119,380	\$75	assessed	h	0	Skagit Co Assessor
Skagit	Bellingham Ch	19.14	320	\$38,200	\$119	assessed	h road	1	Skagit Co Assessor
Skagit	Padilla Bay	35.8	1900	\$249,270	\$131	assessed	h road	1	Skagit Co Assessor
Skagit	Padilla Bay	34.78	1000	\$20,000	\$20	assessed	l	0	Skagit Co Assessor
Skagit	Rosario St	4	100	\$45,800	\$458	assessed	h easment,septic,water, road	51700	4 Skagit Co Assessor
Skagit	Rosario St	0.38	110	\$60,500	\$550	assessed	l road,septic,water	37200	4 Skagit Co Assessor
Skagit	Bellingham Ch	26.13	60	\$99,900	\$1,665	assessed	l water,road	2	Skagit Co Assessor
Skagit	Sinclair I.	36.34	1300	\$174,400	\$134	assessed	h road	1	Skagit Co Assessor
Skagit	Guemes Ch	14.52	440	\$217,800	\$495	assessed	l	0	Skagit Co Assessor
Skagit	Padilla Bay	5.15	1450	\$24,210	\$17	assessed	h	0	Skagit Co Assessor
Skagit	Rosario St	50	1600	\$85,850	\$54	assessed	l	0	Skagit Co Assessor
Skagit	Rosario St	0.65	79	\$43,400	\$549	assessed	h road,water,septic	29680	4 Skagit Co Assessor
Skagit	Rosario St	0.33	63	\$34,650	\$550	assessed	l easment,septic,water	41180	4 Skagit Co Assessor
Skagit	Bellingham Bay	2.15	100	\$57,280	\$573	assessed	l water,septic,road	3	Skagit Co Assessor
Skagit	Sinclair I.	30.8	1500	\$77,000	\$51	assessed	h	0	Skagit Co Assessor
Skagit	Bellingham Bay	2.72	122	\$64,990	\$533	assessed	n road	93000	4 Skagit Co Assessor
Skagit	Rosario St	0.39	250	\$300,000	\$1,200	assessed	l septic,water,road	3	Skagit Co Assessor
Skagit	Bellingham Ch	14.26	1700	\$28,500	\$17	assessed	n road	1	Skagit Co Assessor
Skagit	Sinclair I.	9.82	660	\$36,930	\$56	assessed	h road,water,septic	3	Skagit Co Assessor
Skagit	E Guemes Ch	10.5	400	\$31,500	\$79	assessed	h septic,water	2	Skagit Co Assessor
Skagit	Guemes Ch	0.6	130	\$122,100	\$939	assessed	l septic,water,road	67700	4 Skagit Co Assessor
Skagit	Sinclair I.	6	770	\$75,700	\$98	assessed	h road,water,septic	90800	4 Skagit Co Assessor
Skagit	Bellingham Ch	18.6	450	\$46,500	\$103	assessed	h road	1	Skagit Co Assessor
Skagit	Sinclair I.	29.05	3000	\$139,400	\$46	assessed	h road	1	Skagit Co Assessor
Skagit	Bellingham Ch	26.41	1900	\$106,400	\$76	assessed	n road	1	Skagit Co Assessor
Skagit	Padilla Bay	11	500	\$17,600	\$35	assessed	l	0	Skagit Co Assessor

COUNTY	SITE	ACRES	FEET	PRICE	FRONT FT	TYPE	BLANK FEATURES	BUILDINGS SCORE	OWNER
Skagit	Burrows Bay	206	1900	\$2,110,000	\$1,111	assessed	l road,water,septic	3	Skagit Co Assessor
Skagit	Bellingham Bay	1.35	66	\$20,960	\$316	assessed	h road	1	Skagit Co Assessor
Skagit	Sinclair I.	14.19	1400	\$35,400	\$25	assessed	n	0	Skagit Co Assessor
Skagit	Secret Harbor	10.75	1400	\$26,800	\$19	assessed	h	0	Skagit Co Assessor
Skagit	Bellingham Bay	34	2400	\$37,400	\$16	assessed	l	0	Skagit Co Assessor
Skagit	Padilla Bay	43.68	1400	\$20,300	\$15	assessed	l	0	Skagit Co Assessor
Skagit	Guemes Ch	17.15	790	\$514,500	\$551	assessed	l road	1	Skagit Co Assessor
Skagit	Bellingham Bay	3.53	187	\$82,090	\$439	assessed	h water,septic,road	21700	4 Skagit Co Assessor
Skagit	Burrows Bay	3.92	145	\$98,070	\$676	assessed	h	0	Skagit Co Assessor
Skagit	Ship Harbor	7.5	400	\$15,000	\$38	assessed	h water,septic,road	3	Skagit Co Assessor
Skagit	Burrows Bay	53.6	1400	\$86,510	\$62	assessed	l	0	Skagit Co Assessor
Skagit	Ship Harbor	8.86	500	\$17,700	\$35	assessed	h road	1	Skagit Co Assessor
Skagit	N. Fidalgo	1.68	197	\$210,000	\$1,066	market	l	0	Coldwell Banker
Skagit	Guemes	1.81	500	\$71,000	\$142	market	hm	0	Coldwell Banker
Skagit	Coronet Bay	0.90	144	\$60,000	\$117	market		0	Skagit Co. MLS
Skagit	Fidalgo	4.00	225	\$99,000	\$440	market		0	Skagit Co. MLS
Skagit	E. Fidalgo	0.22	96	\$65,000	\$677	market	ho	0	Coldwell Banker
Skagit	Allen I.	20.00	660	\$220,000	\$333	market	hm	0	Coldwell Banker
Skagit	Allen Island	10.50	700	\$135,000	\$193	market		0	Skagit Co. MLS
Skagit	N. Fidalgo	0.60	133	\$74,500	\$560	market	he	0	Coldwell Banker
Skagit	N. Fidalgo	1.23	185	\$134,500	\$727	market	n	0	Coldwell Banker
Skagit	Sinclair	0.24	75	\$10,000	\$133	market	hm	0	Coldwell Banker
Skagit	Quiet Cove	0.50	100	\$77,000	\$770	market	l road,water,tidelands	3	Fidalgo Realty
Skagit	S. Guemes	2.30	100	\$89,000	\$890	market	h	0	Coldwell Banker
Skagit	NE Guemes	1.00	220	\$110,000	\$500	market	n	0	Coldwell Banker
Skagit	N. Fidalgo	0.55	150	\$58,000	\$387	market	n	0	Coldwell Banker
Skagit	Pear Tree Cove	8.00	700	\$85,000	\$121	market		0	Skagit Co. MLS
Skagit	Fidalgo	20.00	1100	\$200,000	\$182	market		0	Skagit Co. MLS
Skagit	N. Fidalgo	0.78	184	\$114,500	\$622	market	hm	0	Coldwell Banker
Skagit	Dewey Beach	0.40	100	\$17,000	\$170	market	n road,water	2	Coldwell Banker
Skagit	Sinclair	44.00	1400	\$224,500	\$160	market	n	0	Coldwell Banker
Skagit	Dec. Pass	0.69	150	\$75,000	\$500	market	he tidelands	1	Coldwell Banker
Skagit	Sinilk Bay	0.21	100	\$65,000	\$650	market	h water	1	Southside Realty
Skagit	N. Fidalgo	1.09	100	\$78,500	\$785	market	hm	0	Coldwell Banker
Skagit	Fidalgo	8.15	750	\$177,000	\$236	market		0	Skagit Co. MLS
Skagit	Sinclair E.	82.00	1336	\$200,000	\$150	market	hm	0	Coldwell Banker
Skagit	Cypress	5.00	330	\$49,500	\$150	market	h	0	Coldwell Banker
Skagit	Guemes I.	4.00	400	\$136,500	\$341	market	l beach	2	Fidalgo Realty
Skagit	Skyline	0.25	80	\$80,000	\$1,000	market	l extensive prop. development	2	Skyline Realty
Skagit	Deception Pass	0.30	130	\$75,000	\$577	market	h water	1	Southside Realty
Skagit	Guemes	114.00	5348	\$3,000,000	\$561	market	he timber	1	Coldwell Banker
Skagit	Burroughs Bay	8.00	575	\$295,000	\$787	market	h	0	Southside Realty
Skagit	Fidalgo	96.00	2230	\$590,000	\$265	market		0	Skagit Co. MLS
Skagit	Fidalgo	0.30	40	\$60,000	\$1,500	market		0	Skagit Co. MLS
Skagit	Sinclair	0.22	75	\$10,000	\$133	market	hm	0	Coldwell Banker

APPENDIX F

Permits That May Be Required for Aquaculture Projects

Permits which may be required for an aquaculture project.

Federal Permits

Dredge and Fill Permits
Navigational Markings

Issuing Agency

Army Corps of Engineers
Coast Guard

State Permits

Aquatic Land Lease
Hydraulic Project Approval
Statement of Consistency with
Coastal Zone Management Act
Water Quality Certification
Water Quality Standards Modification
National Pollutant Discharge
Elimination (NPDES) Permit
Aquacultural Identification of
Private Sector Products
Registration of Aquatic Farmers
Fish Disease Control

Department of Natural Resources
Department of Fisheries or Wildlife
Department of Ecology

Department of Ecology
Department of Ecology
Department of Ecology

Department of Agriculture

Department of Fisheries
Department of Fisheries (develop jointly
with Agriculture)
Department of Social and Health Services

Shellfish Certification

Local Permits

Shoreline Substantial Development

County or City

**DRAFT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT
FISH CULTURE IN FLOATING NET PENS**

Prepared for:

WASHINGTON STATE DEPARTMENT OF FISHERIES
115 General Administration Building
Olympia, WA 98504

Prepared by:

PARAMETRIX, INC.
13020 Northup Way
Bellevue, WA 98005

January 1989

JOSEPH R. BLUM
Director



STATE OF WASHINGTON
DEPARTMENT OF FISHERIES

115 General Administration Building • Olympia, Washington 98504 • (206) 753-6600 • (SCAN) 244-6600

January 23, 1989

Dear Reviewer:

The enclosed document, together with the separately bound appendices, comprise the Draft Programmatic Environmental Impact Statement (PEIS) for Fish Culture in Floating Net Pens in the greater Puget Sound area. The Department of Fisheries is seeking your review and comment. This PEIS is being prepared at the direction of the Washington State Legislature by the Department of Fisheries. In preparation, Fisheries has consulted extensively with the Departments of Agriculture, Ecology, and Natural Resources; also, with numerous county officials and private individuals.

The PEIS is being prepared to assist state, county, and local decision-makers in evaluating requests for net pen sites by furnishing additional information on impacts of floating net pens.

A series of issues concerning the natural and built environments are considered, the principal ones being impacts on sedimentation, water quality, and aesthetics. Alternatives discussed in the PEIS include a no-action alternative (status quo) as well as impacts of increased levels of operation.

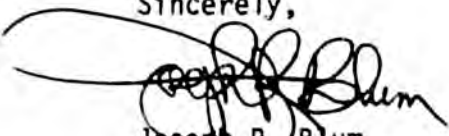
To facilitate public awareness, two public meetings have been scheduled to receive comments on the draft PEIS as follows:

Silverdale, Washington
March 1, 1989 7:00 p.m.
Central Kitsap High School Auditorium

Mount Vernon, Washington
March 2, 1989 7:00 p.m.
Skagit County Court House
Hearing Rooms B and C

The Department of Fisheries wishes to thank those who take the time to review this Draft PEIS and offer comments.

Sincerely,



Joseph R. Blum
Director

JRB:k1g

Enclosure

FACT SHEET

A. Nature and Location of Proposal: This non-project, or programmatic EIS (PEIS) evaluates the commercial culture of fish in floating net pens in the Puget Sound region. The objectives of this PEIS are to provide available information to regulators, the public, and the Legislature for evaluating the environmental impacts of net pens, and to describe measures that could mitigate any potential impacts. From this PEIS, state and local officials will develop policies for future development and regulation of the net-pen industry.

The location of 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 Departments of Fisheries, Ecology, Natural Resources, and Agriculture are preparing this PEIS. The nominal lead agency is the Washington Department of Fisheries. No specific actions are proposed at this time.

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

Responsible Official: Duane E. Phinney, Chief
Habitat Management Division
Washington Department of Fisheries

Contact Person: Ron Westley
Project Manager
Washington Department of Fisheries
115 General Administration Building
Olympia, WA 98504
(206) 753-6642

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

E. Authors and Principal Contributors:

<u>Name</u>	<u>Areas of Contribution</u>
Parametrix, Inc.	Principal author Sedimentation Net-pen modeling Water quality Introduction of Atlantic salmon Genetic impacts

	Marine mammals and birds
	Odors
	Noise
	Upland and shoreline use
	Aesthetics
	Navigation
	Commercial fishing
	Recreation
	Local services
Battelle Pacific NW Labs	Disease
	Human health
	Chemicals
Rensel Associates	Phytoplankton
Donald P. Weston	Technical review

F. Date of Issue of Draft EIS: February 6, 1989.

G. Date Comments are Due: All written comments are to be sent to the contact person (see Item C above) by 5:00 p.m., March 23, 1989.

H. Time and Place of Public Hearing: Two public hearings will be held to receive testimony on the Draft EIS.

March 1, 1989 7:00 p.m.
Central Kitsap High School
3700 NW Anderson Hill Road
Silverdale, WA

March 2, 1989 7:00 p.m.
Skagit County Administration Building
Hearing Rooms B & C
2nd & Kincaid, Mt. Vernon, WA

I. Nature and Date of Final Action: No specific action is proposed by the Department of Fisheries.

J. Type and Timing of Subsequent Environmental Review: Individual net-pen projects will be reviewed case-by-case under SEPA as they are proposed. Any subsequent regulations or policies developed by state or local officials pursuant to this PEIS will be subject to review under SEPA.

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

L. Cost to the Public for Copy of Draft EIS: The initial printing will be available to the public at no cost. The cost of additional copies will be based on the actual cost of reproduction and mailing.

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SUMMARY

OBJECTIVE OF PROPOSAL: No specific proposal is being made at this time. State and local policies may be developed for net-pen culture as the result of this PEIS, however, no actions are currently planned.

PURPOSE OF THIS PEIS: Recent commercial net-pen culture of fish 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, and anger and frustration by all parties.

To assist resolution of this conflict, the Washington State Legislature directed the Department of Fisheries to evaluate the environmental impacts of net pens on the biological and built (human) environments. This information is intended to be used by policy makers; including local government, state agencies, and legislators. This EIS was prepared by the Department of Fisheries with the Departments of Ecology, Agriculture and Natural Resources assisting as co-lead agencies.

MAJOR CONCLUSIONS OF THE DRAFT PEIS:

1. The major impacts of net-pen culture can be prevented by proper farm siting to assure dispersion of wastes, flushing of the site, and protection of sensitive areas.
2. The impacts of net pens are reversible, and after pen removal any affected areas will revert to their undisturbed state.
3. The accidental introduction of an exotic disease into state waters remains a risk. While existing import rules minimize this risk, it cannot be eliminated if animals are to be introduced from other areas.
4. Four levels of development were analyzed. Proper siting of 100 farms would not have a significant impact on the aquatic environment; however, small bays may be adversely affected by over-development.

MAJOR POTENTIAL IMPACTS AND ACTIONS TO MINIMIZE THESE IMPACTS:

1. Excess feed and fish feces can settle to the bottom, eliminating all animals immediately below the pens. Selecting deep sites with adequate currents disperses waste over a larger area, and minimizes any impact. Selection of pen sites away from important habitats will protect important fish and shellfish species.
2. Nutrients released from the fish farm can stimulate plankton production in nutrient depleted, poorly flushed bays. Excessive plankton blooms could adversely affect other organisms in the bay. Identification of sensitive bays, proper

placement of pens, and limits on total fish production can prevent adverse plankton blooms.

3. Escaped non-native fish could establish self-sustaining populations and compete with indigenous fish. Some escape from pens is inevitable, however, selection of fish which cannot reproduce locally and evaluations of new introductions through SEPA can prevent damage to local stocks.
4. Introduction of exotic disease with imported fish is greatest potential risk to native species. Careful screening of fish through existing disease regulations can minimize but not eliminate this risk. Development of local broodstock should be encouraged.
5. Impacts to marine mammals and birds appear to be limited and can be further minimized through proper siting of pens and use of predator control netting.
6. Visual impacts cannot be avoided and their significance will depend upon the specific site and the perceptions of the viewers. Moving pens offshore or in areas not readily visible and design of the pens can minimize impacts.
7. Pens can interfere with commercial and recreational navigation, and commercial fishing. Placing pens near shore, requiring clear marking, and avoiding navigation and fishing areas minimize conflicts. However, these actions are in direct opposition to those under 1. and 6. above.
8. No probable adverse impacts were found relative to human health, noise, odors, upland/shoreline uses, or local services which cannot be resolved through the actions presented above.

UNAVOIDABLE SIGNIFICANT ADVERSE IMPACT: No unavoidable adverse impacts were noted; however, efforts to minimize some impacts may exacerbate others. Thus in particular situations adverse impacts may be unavoidable.

PHASED REVIEW: This is a programmatic EIS that assesses the environmental impacts of net-pen fish culture. It does not assess the impacts of any individual proposal. While it will provide information which may be referenced by project proponents, each proposal must comply with SEPA on its own, individual merits. Public officials and agencies may elect to utilize the information presented in the PEIS to develop policies and rules for net-pen culture in Puget Sound. These actions would then be subject to SEPA.

A. BACKGROUND AND OBJECTIVES OF THE PEIS

BACKGROUND

Raising fish in floating net pens 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 continues to operate near Manchester in Kitsap county. Net-pen farms were also started in Europe, often 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 upon commercial fishing, which had declined severely. Consequently, a major effort was directed at developing salmon farming as a cottage industry, especially for former fishermen. 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. (For comparison, Washington commercial salmon fishing industry produces about 2950 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, lead to rapid growth of salmon net-pen 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 which have not been adequately answered.

To address these concerns, the Washington State Department of Fisheries (WDF), with funding from the Department of 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, the Departments of Ecology, Fisheries, Natural Resources, and Agriculture developed a set of recommended guidelines. These guidelines, the Recommended Interim Guidelines For the Management of Salmon Net-Pen Culture in Puget Sound, were intended to assist state and local decision makers in assuring that pens 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 net pens. Shoreline residents, commercial fishermen, and other concerned citizens have expressed concern about the possible effects of a growing net-pen industry on other, traditional uses of the state's waters. In response to these concerns and the growing controversy, the Washington State Legislature directed the Department of Fisheries to prepare an environmental assessment of the impacts of net-pen fish culture in Puget Sound. The Department elected to prepare this assessment as a programmatic environmental impact statement (PEIS) following the procedures of the State Environmental Policy Act (SEPA) for non-

project EISs. While not required by SEPA to be included in an EIS, WDF also contracted to complete a separate report on the Economics of Salmon Farming (See Appendix E).

On September 30, 1987, the Washington Department of Fisheries gave public notice of a determination of significance for the evaluation of fish culture in floating net pens. Pursuant to WAC 197-11-408, the Department requested written comments on the scope of the programmatic Environmental Impact Statement (PEIS). In addition to requesting written comments, the Department 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 the Department of Fisheries in Olympia.

OBJECTIVES

The objective of this PEIS is to assess the impacts of net pens on the biological environment and on human activities affected by net-pen development in Puget Sound (see Figure 1). The PEIS will be used by decision makers at the state and local level to develop policies and make permitting decisions. In addition, the PEIS will help state and local governments determine how net pens should be managed to minimize any adverse impacts. To address this anticipated use, the PEIS evaluates several scenarios of net-pen development, ranging from the existing industry of 13 farms to a possible industry of about 100 farms, producing 75 million pounds of fish annually. A total number of 100 farms is used to provide an upper range of industry development that is likely to occur within the next few years for assessing possible cumulative impacts.

The PEIS also attempts to identify approaches regulatory agencies could use to best manage the industry. These management approaches would assure farms are located in appropriate areas and operated in a suitable manner to prevent unnecessary impacts, even if these impacts are deemed to be non-significant. More specific actions are also identified which could be taken as necessary and appropriate to minimize impacts at a specific net-pen site.

Environmental objectives are identified for each element of the environment potentially affected by net pens. These objectives are consistent with the goal of minimizing any adverse impact. It is recognized that no activity can occur without some level of impact. However, it is the goal of this PEIS to assure that all reasonable efforts be made to limit these impacts. It is also recognized that net pens are just one source of environmental impacts in Puget Sound, and regulation of the industry should be consistent with the regulation of other activities having similar impacts. The ultimate goal of the Department of Fisheries is to assure the continued viability of Puget Sound as a resource to be used and appreciated by a wide variety of users.

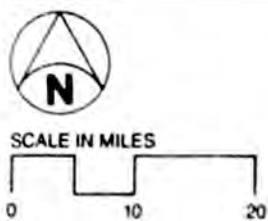
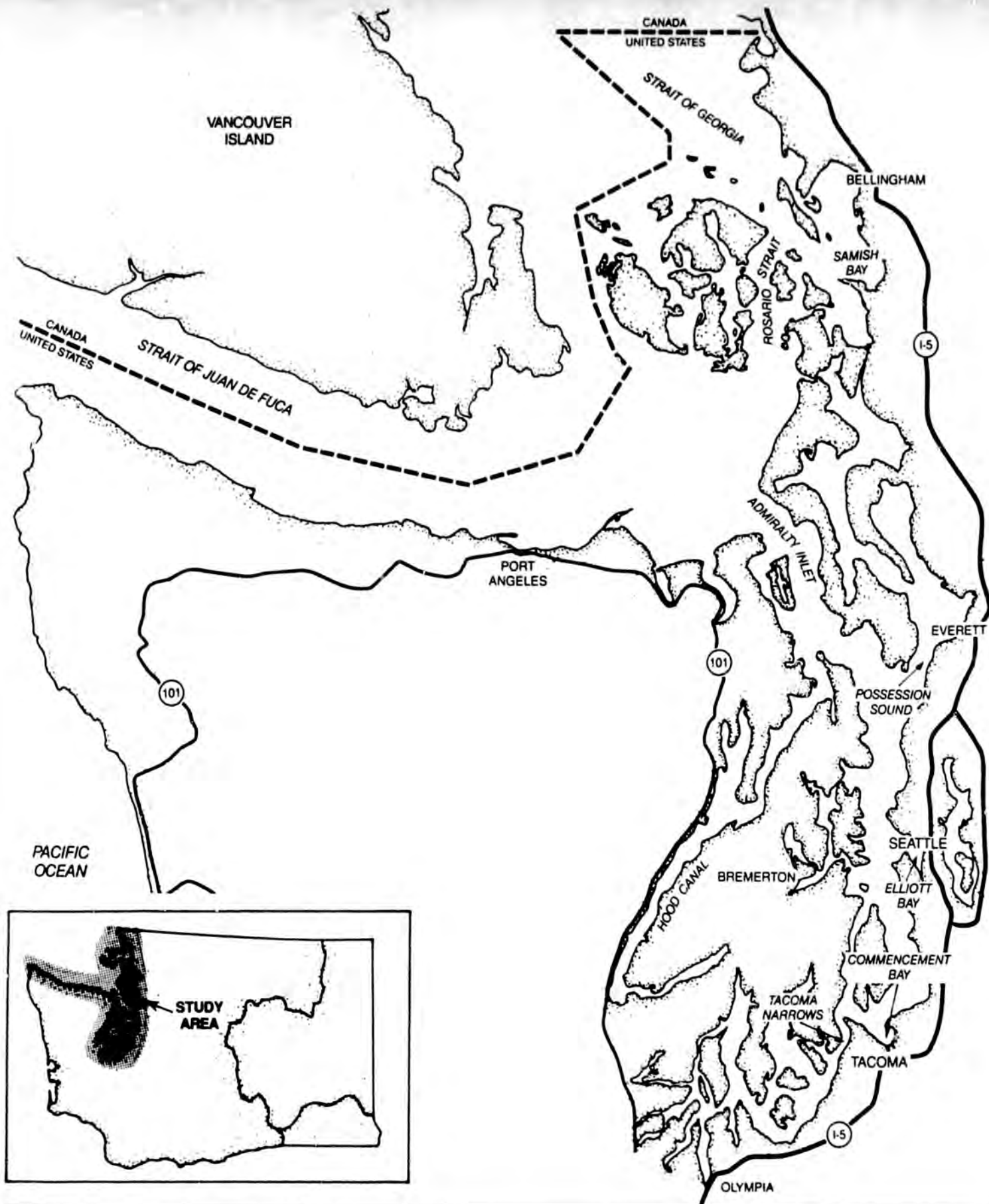


Figure 1.
Vicinity Map

B. BACKGROUND OF THE NET-PEN INDUSTRY

Salmon net pens have been in Washington state waters since the early 1970s. In Puget Sound, commercial net pens are primarily used to raise coho (*Onchorhynchus kisutch*) or Atlantic (*Salmo salar*) salmon for sale. Presently, there are 13 commercial net pen 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 pens 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. Although the purpose of delayed-release pens is to increase the number of salmon for commercial and sport harvest, this PEIS does not specifically evaluate the impacts of delayed-release pens. However, many of the environmental impact discussions in this PEIS also pertain to delayed-release pens recognizing that the smaller size and temporary nature of the net pens will result in proportionally reduced impacts.

A typical commercial net-pen facility operating in Puget Sound receives young fish from a freshwater hatchery. These fish are placed directly in net 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 upon the fish species and market demands. Proper husbandry practices, vaccination, and the periodic use of antibiotics in the feed protect the fish from disease until they reach marketable size. To protect the fish from predators extra nets surround the pens.

For the purpose of the impact analyses in this PEIS, a typical net pen is described below. This typical net pen is based upon the net pens currently used in Puget Sound.

Figure 3 illustrates a cross-section of a typical net-pen facility. The primary component of a floating net-pen system is a group of pens that float on the water separated by walkways 1 to 2 m (meter) (3-6 ft) wide. The number of pens at a net-pen facility, and the amount of surface water they cover, varies considerably. Currently, all new net pens in Washington state are limited to a total surface area of less than two acres (8100 m²). Figure 3 shows examples of a wide variety of pen configurations, but most pen facilities 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 1000 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 net pens in this PEIS, it is assumed the pens are arranged in a 30 by 300 m (100 by 1000 ft) rectangle.

Net pens 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 net-pen operations in Puget Sound have a maintenance building on the farm site for to store food and equipment, to provide temporary shelter for workers during inclement

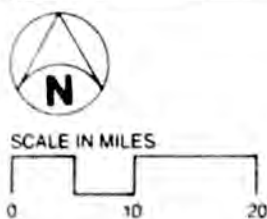
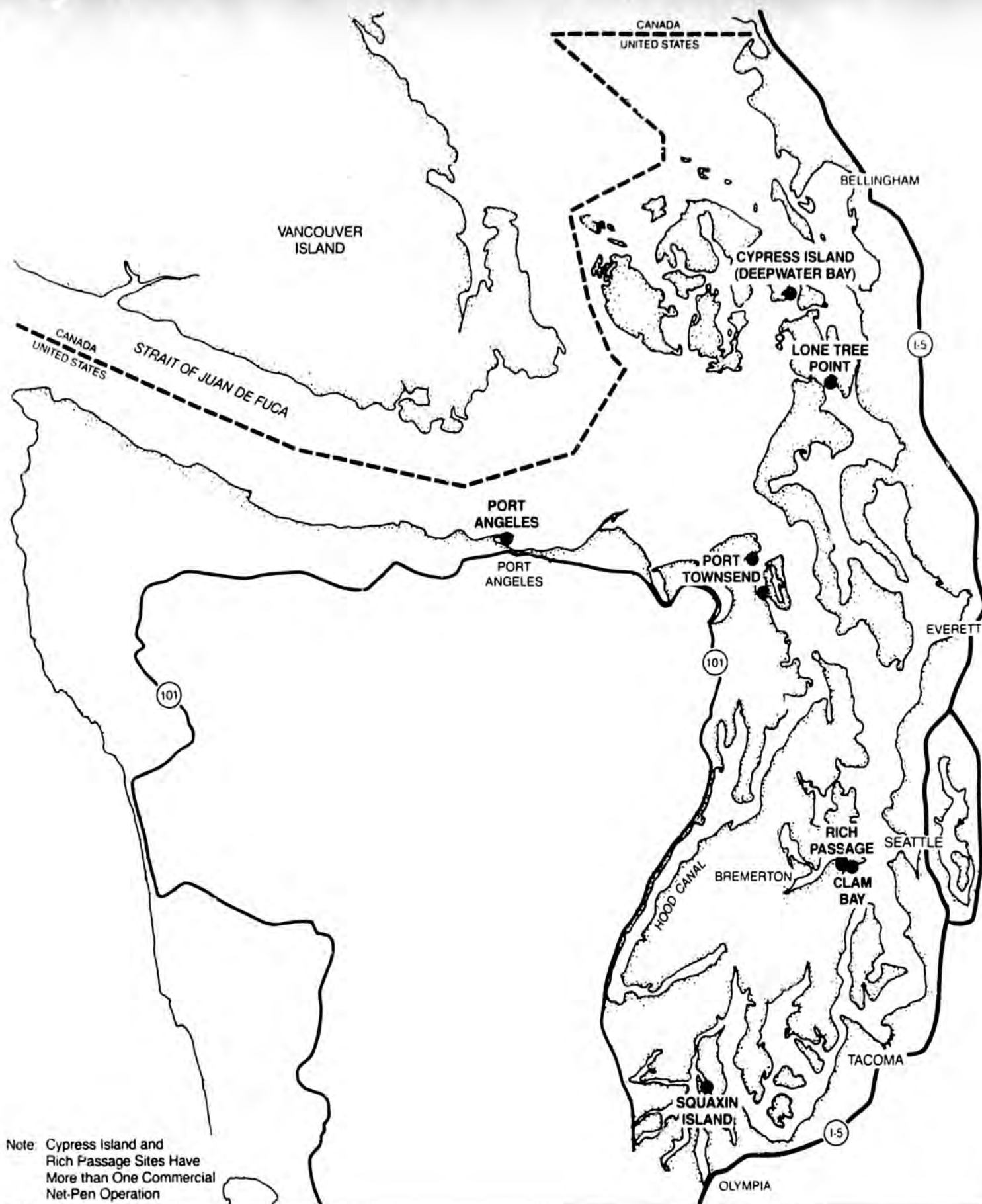
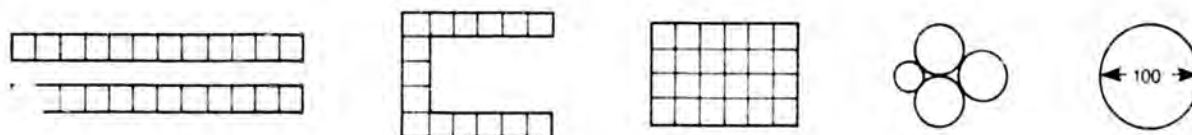
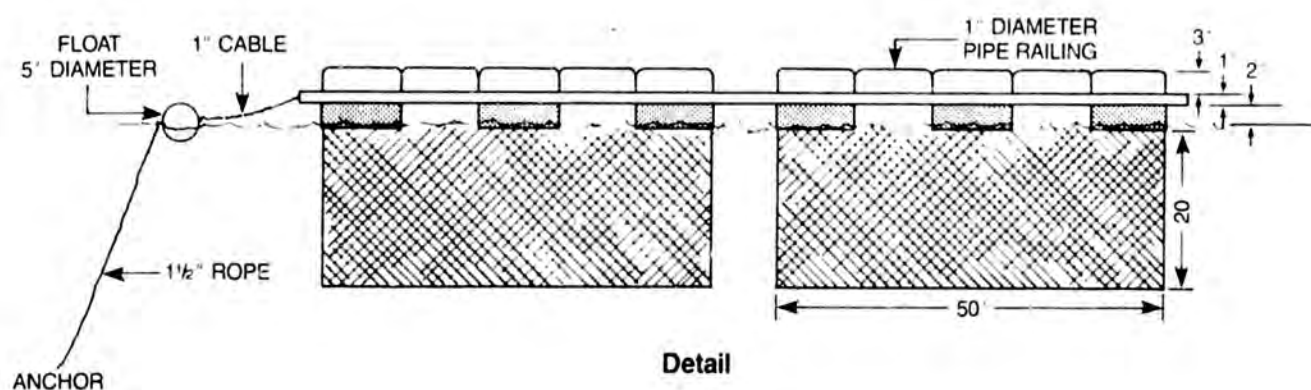
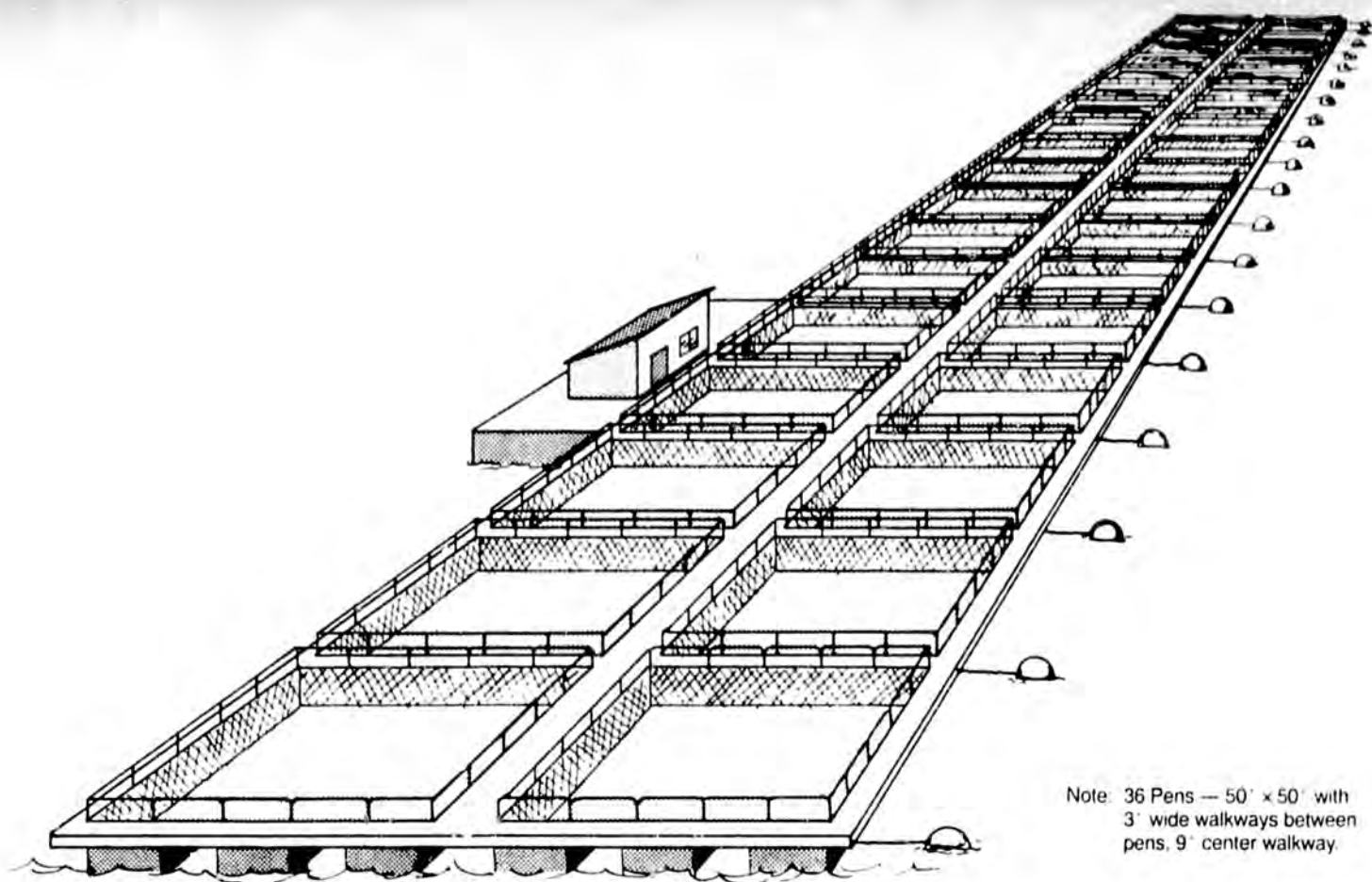


Figure 2.
General Locations of
Existing Commercial
Net-Pen Operations



Examples of Various Pen Configurations

Figure 3.
Example of Net-Pen Facility and
Various Pen Configurations

weather, and to provide security. These buildings vary considerably in color and shape, but most are roughly 3 m (8-10 ft) high and 9 to 12 m² (80-120 s ft) in size.

Nets, hung from the pen railings, have a 10 to 30 mm mesh (depending on the size of the fish), 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 m³ in the typical farm. A net is commonly placed over the top of nursery pens to prevent birds from eating small fish. A larger mesh perimeter net is used around the net pen for protection from potential aquatic predators.

The net pens are held in place by a series of anchors, anchor lines, and floats. A short length of cable or rope attaches the net pens to a large float from which a long piece of cable, chain, or rope connects each float to a 1360 to 2270 kg (kilograms) (3000-5000 lb) anchor on the bottom. The floats moderate the effects of weather or tidal currents that may tend to pull the net pens down. Although the number and placement of floats and anchors at an individual facility varies with the site, anchors are usually placed 4 times the water depth away from the pen's perimeter. Of the pens currently operating or proposed in Puget Sound, the area typically encumbered by the anchors is 5 to 10 times the surface area of the pens.

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

As an aid to navigation, net-pen operators are usually required to install navigation lights at their facilities. These lights are typically amber and located 1 to 2 m (3-6 ft) above the surface of the water. The U.S. Coast Guard (USCG) has established a minimum brightness standard that requires these lights (usually about 2 candlepower) be visible on a clear night for at least one mile (1.6 km [kilometer]). In addition, the USCG has established a standardized 6 second flash rate (0.5 second on and 5.5 seconds off) for lights associated with net pens.

Presently, the predominant species cultured in net pens 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 8000 m³ to encourage a small cottage industry, pens are stocked to maximal densities which may exceed 40 kg/m³. In Washington, where larger net-pen facilities are allowed, fish are stocked at optimal densities for growth and disease prevention. These stocking densities are generally 5 to 7 kg/m³. Thus, a two-acre farm would produce 225 to 450 MT (metric tons) (500,000-1,000,000 lbs) of salmon annually. For the purpose of this PEIS, it is assumed the average net pen facility is two acres in surface area and produces 340 metric tons (750,000 lbs) of fish per year.

C. LOCATION

The geographical focus of this document is 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 in Washington waters 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.

D. DESCRIPTION OF ALTERNATIVES

The objective of this programmatic EIS is to assess the environmental impacts of fish culture in floating net pens in Puget Sound. Four different levels of development are proposed as possible alternatives for development of the industry and assessment of the potential cumulative impacts resulting from expanded development. The range of development assessed is intended to bracket that range which is likely to occur within the next few years, depending upon the decisions made by state and local agencies.

The four alternative levels of development proposed for analysis are:

ALTERNATIVE 1 (NO-ACTION). About 25 acres (surface area) of farms producing 4500 metric tons (5000 tons) of fish annually. This describes the existing industry of 13 farms assuming full production.

ALTERNATIVE 2. Between 50 to 75 acres of farms producing about 8500 metric tons (9400 tons) of fish annually. It is expected that this would represent about 25 farms.

ALTERNATIVE 3. Between 100 and 125 acres of farms producing about 17000 metric tons (18700 tons) of fish annually. It is expected that this would represent about 50 farms.

ALTERNATIVE 4. Between 200 and 250 acres of farms producing about 34000 metric tons (37500 tons) of fish annually. It is expected that this would represent about 100 farms.

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 PEIS. A brief summary of existing regulations 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 net pens) to consult with agencies with specific expertise with respect to the environmen-

tal impacts involved. If a proposal is likely to have significant adverse environmental impacts, then the lead agency may require preparation of an environmental impact statement (EIS). Determination 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. All permits issued by state and local government are subject to SEPA, however, for a single project requiring several permits, SEPA compliance is only determined once, by the lead agency.

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 to provide for the management of the shorelines of the state by planning for and fostering all reasonable and appropriate uses in a manner that enhances the public interest and protects against adverse environmental impacts.

The SMA was established as a cooperative management program between local governments and the state. 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. The Department of Ecology provides technical assistance, reviews shoreline permits and master program amendments, and approves conditional use and variance permits to assure state-wide issues are addressed.

Substantial Development Permit (WAC 90.58). All development activities within the shoreline environment are subject to local shoreline master programs and to the SMA. Projects must demonstrate compliance with both local and state rules through the substantial development permit process.

Marine Lands Lease (RCW 79.01.568, .570). All net-pen activities will occur over state-owned, subtidal bedlands, managed by the Department of Natural Resources (DNR). Project will require a lease of these lands from the DNR and must comply with the rules and policies adopted by DNR, and attached to the lease agreement.

Hydraulic Project Approval (HPA) (RCW 75.20.100, WAC 220-120). All construction projects are subject to approval by the Department of Fisheries (WDF) to assure that fish and shellfish, and their habitats, are protected. Projects must demonstrate that they will not adversely affect important habitats or fish life.

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 to 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 or uninfected areas. All new introductions of exotic species will be assessed to determine their potential environmental impact under SEPA. Specific rules now exist for introductions of Atlantic salmon which permit the introduction only of eggs which have been certified disease free, disinfected, and held in quarantine for 90 days after hatching.

Waste Discharge Permit (RCW 90.48). Any activity discharging waste that may adversely affect water quality must have prior approval from the Department of Ecology (WDOE). The Department of Ecology is currently clarifying state policy on waste discharge permitting of net pens. In addition, WDOE is developing sediment standards for activities in Puget Sound. When implemented, these standards will also apply to net pens.

Recommended Interim Guidelines. These guidelines were developed by WDOE, DNR, WDF, and the Washington Department of Agriculture (WSDA) to provide guidance to state and local agencies concerning proper siting of net pens to assure significant adverse impacts to the aquatic environment are prevented. The guidelines are only recommendations representing the best available knowledge of the agencies at the time of issuance (1986). It is expected that these guidelines will be updated, and possibly formalized as the result, in part, of information developed in this PEIS.

Section 10 Permit. The U.S. Army Corps of Engineers (ACOE) reviews projects in state waters to assure they do not significantly interfere with navigation. As part of this review, other federal agencies such as the National Marine Fisheries Service, Fish and Wildlife Service, and Coast Guard may review the permit request.

State Agencies.

In addition to the rules and regulations, there are a number of different state, federal, and local agencies involved with management of the net-pen industry. A brief description of these agencies follows:

Department of Fisheries

The Washington Department of Fisheries' (WDF) mission is to preserve, protect, perpetuate, and manage the food fish and shellfish in the waters of the state (RCW 75.08.012). This jurisdiction includes all species taken commercially and recreationally from marine waters except for steelhead and cutthroat trout which are managed by the Department of Wildlife. In addition, WDF is responsible for disease control and prevention for all aquatic organisms cultured commercially, and for the registration and maintenance of statistics on the aquaculture industry.

Department of Natural Resources

The mission of the Department of Natural Resources (DNR) is to foster the commercial and recreational use of the aquatic environment for the production of food, fiber, income, and public enjoyment (RCW 79.68.080). The DNR administers the state's ownership interest in the intertidal and subtidal bedlands of the state. The DNR manages these lands on a multiple use basis following criteria established in WAC 333-30.

Department of Ecology

The Department of Ecology (WDOE) was created in 1970 to consolidate 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, WDOE became the central state agency concerned with protection

of the environment. In addition, WDOE is responsible for planning for the accommodation of competing interests in the use of these resources. WDOE is the primary agency responsible for controlling pollution and ensuring water quality standards are maintained through the administration and enforcement of federal and state laws.

Department of Wildlife

While the Department of Wildlife (WDW) has no direct management function related to net pens, 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 Army Corps of Engineers 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 review projects via SEPA and the SMA for compatibility with boating and other recreational activities.

Department of Agriculture

The Department of Agriculture (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 develops disease control and prevention rules with the WDF.

Local Government

Local governments reviews net-pen proposals through SEPA and local shoreline master programs. Any upland portion of a proposal would be reviewed under the zoning and building codes, comprehensive plans, and other regulations in place. See Section II.F, Relationship to Land Use Plans and Regulations, for a further discussion of existing plans and regulations pertaining to local governments.

Federal Agencies.

Federal involvement in regulating and permitting net pens is initiated through the U.S. Army Corps of Engineers (ACOE) 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

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

This agency reviews ACOE permits to assure that the proposed projects are compatible with protection of freshwater and anadromous fish, marine birds, marine mammals, and their habitats.

National Marine Fisheries Service

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

Environmental Protection Agency

The Environmental Protection Agency (EPA) is responsible for overall protection of the nation's water quality.

Food and Drug Administration

The Food and Drug Administration is responsible for assuring the safety and quality of food entering interstate commerce. Consequently, they are responsible for approving any chemicals such as antibiotics used in net-pen operations.

U.S. Coast Guard

The U.S. Coast Guard (USCG) reviews ACOE permits to assure net-pen proposals will not be a hazard to navigation. The USCG may require the net-pen farmer to supply aids to navigation to help achieve that goal.

A. THE NATURAL ENVIRONMENT

1. IMPACTS TO BOTTOM SEDIMENTS AND BENTHOS

Settling of organic matter, mostly from excess feed and feces, from the net pens affects bottom-dwelling plants and animals (benthos). At virtually all net-pen sites studied (Gowen and Bradbury, 1988; Earll et al 1983; Weston and Gowen 1988; Rosenthal et al 1988; Institute of Aquaculture 1988), the deposition of organic and inorganic particulate matter has resulted in changes to the bottom-dwelling plant and animal communities beneath and immediately around the pens. Accumulation of organic matter and the changes in these communities are the readily visible impacts of net-pen culture on the aquatic environment. Consequently, these effects have received considerable study around the world. The following discussion describes the changes to the bottom sediments and to the organisms living within these sediments. The effects on larger, mobile species are discussed in Section II.A.3 (Impacts to Aquatic Organisms).

a. Affected Environment

Net pens are usually located in nearshore waters 10 to 60 m (30-200 ft) deep with relatively flat bottoms and moderate currents. Depth of the nets and the need for water circulation below the pens prevents all but very small net pens from being located close to shore, while difficulties in anchoring in deeper water, as well as navigational concerns, usually prohibit deep sites. The nearshore benthic (bottom) habitats beneath or near the pens exhibit great variety and can support a broad and diverse range of biological communities. The dominant factor determining the nature of these communities is its substrate (physical bottom habitat) type (Lie 1968; Kozloff 1987). Most net pens are sited in areas having fine-grained sediments and moderately flat bottoms.

The substrates found in this nearshore zone (10 to 60 m) range from very fine-grained unconsolidated sediments (clays and silt) to solid rock, and all intermediate combinations of mud, sand, gravel, cobble and boulders. The substrate at any given site is determined by current velocities along the bottom which, at higher velocities, will erode finer materials and at lower velocities allow sediment in the water to be deposited. Other factors, such as the slope of the bottom and the organisms present, can also affect sediment type. The resultant substrates are quite uniform over many broad areas (for example, the broad mud flats of estuaries). Or, more commonly, they are a complex array of sediment types in apparently random patches.

Because they vary in physical characteristics, substrates can be inhabited by a variety of species, depending upon such factors as sediment mineral composition, salinity, slope, depth, and the organisms already present (Gray 1974; Rhodes 1974). Given the complex interactions that determine an organism's presence, it is not possible to consistently predict which specific organisms will be present in each habitat type or their abundance. It is possible, however, to predict with some certainty the types of organisms which will be found (Lie and Evans 1973). Thus, it may be impossible to predict the abundance

of a particular sediment-deposit-feeding organisms, but it is possible to predict the relative dominance of sediment-deposit feeders as a group.

The two most important determinants of species groups present in an area appear to be substrate type and its amount of organic material. Marine benthic communities in the Puget Sound region are arrayed upon a substrate continuum ranging from fine silt to hard rock, and from environments with very little available nutrient to those that have substantial added organic material (Lie 1968). In some areas, these determinants particularly substrate type, vary through the entire range within a very small geographic area, providing several different habitats with their appropriate organisms within a lateral distance of a few meters (Shimek 1983).

(1) Habitats. The marine habitats potentially affected by net pens are generally close to shorelines, in relatively shallow-water environments. 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 net pens could contain examples of virtually every shallow marine benthic (sea bottom) community found in the greater Puget Sound region, and generally contain a mosaic of at least several of them. Although these communities have often been described in the technical and popular literature, specific ecological relationships within most of them are poorly understood. Thus, a more generalized description of habitats is provided here.

Soft Substrates. Clay and silt together with variable quantities of sand, gravel, and shell fragments. 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 18 m [60 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.

Soft substrates are also inhabited by a number of other invertebrates. These include organisms such as sea pens (*Ptilosarcus gurneyi*), heart urchins (*Lorenia curdiformis*), 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 net pens on these fish are discussed in Section II.3.a.

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 net pens. Some of the areas considered for net pens might have hard-packed sand or gravel substrates or other 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, 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 to 20 m (50-66 ft).

b. Impacts of Net Pens on Benthic Communities

Benthic regions contain a mosaic of habitat types reflecting small-scale variations in bottom topography and current patterns. Thus any potentially affected area could include examples of virtually every shallow marine benthic community found in the greater Puget Sound region, and generally will contain a mosaic of at least several of them. Additionally, although these communities have often been described, specific ecological relationships within most of them are poorly understood. Fortunately, generalized interactions and responses in benthic communities have been examined sufficiently that predictions can be made regarding some of their major organisms and the effects of various changes on their ecosystems.

Sedimentation effects are the result of two major factors, additional particulate organic input in the form of uneaten food and fish feces, and inorganic sediment deposition. An additional factor contributing to 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 net-pen 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). It should be understood that due to lack of knowledge, coupled with the diversity and variability of habitats, qualitative predictions can be made, but predictive quantification of responses is impossible.

The major cost of raising fish is feed. A typical fish farm producing 340 metric tons (748,000 lbs) of fish annually will feed 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 and the food by calculating a food conversion ratio (FCR)--the ratio of food fed (dry weight) to fish produced (wet weight). Typically, average FCR's 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 fed during any period 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 percent nitrogen (Edwards 1978) and 44 percent organic carbon (Gowen and Bradbury 1987). A major research goal for the fish farming industry is to develop lower-cost feeds that provide 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, FCR's of less than 1:1 have been achieved, and most fish farmers now claim values between 1 and 1.5.

Even with the highest FCRs, a portion of fish feed is not eaten and settles to the bottom. Feed wastage has proven difficult to ascertain in field conditions. However, several studies in Europe have suggested that a range of 1 to 30 percent of the feed may be lost (Gowen et al 1985; Pencsak et al. 1982). Dry feed consistently showed the least amount of wastage (1 to 5 percent) while 5 to 10 percent 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 percent (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 percent. The use of automatic feeders increased wastage to 8.8 percent (Cross 1988).

Since food pellets do not decompose appreciably as they settle to the bottom, they are unlikely to experience substantial reduction in nitrogen or carbon, 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 feeds, which are available to the fish in the pens for longer periods, and feeds 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.

Of the feed consumed, about 26 percent is lost as feces (Butz and Vens-Capell 1982). Unlike feed pellets, fish feces are smaller and less uniform in size. Consequently, the settling rate of these particles will vary greatly, but will be less than that of feed pellets. The composition of the feces is dependent upon the chemical composition of the feed and its digestibility. Gowen and Bradbury (1987) estimated from the literature that about 30 percent of the consumed carbon would be excreted in the feces, along with about 10 percent of the consumed nitrogen.

From the information presented in the above paragraphs, estimates of the total particulate matter emanating from net pens, for eventual deposit on the sea bed, have been calculated. Weston (1986), assuming a FCR of 2:1 with 5 percent wastage and a third of the consumed food being lost as feces, estimated that 733 kg (1600 lbs) of sediment would be produced for every metric ton (2200 lbs) of fish grown. The Institute of Aquaculture (1988) estimated sediment production of 820 kg (1800 lbs), assuming 20 percent wastage and a 30 percent loss as feces.

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 culture activities) would reduce the total sediment production by 25 percent. Using the Institute of Aquaculture's estimate of sediment production as one extreme, the total sediment production from one typical, 340 metric tons farm would be 279 metric tons (307 tons) annually. Assuming a FCR of 1.5 and 5 percent wastage, sediment production could be reduced by 40 percent 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 percent of the carbon and 71 percent of the nitrogen coming from the feces.

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, pulp mill 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 fine particles, whether organic or inorganic. At high rates these may clog the filtering apparatus of filter-feeding organisms such as clams, various sea anemones, and sea pens. 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 net pens decreases 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 derive energy from sources other than oxygen.

Chemical change due to organic enrichment is the other major mechanism by which the benthos are affected. As discussed above, 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.

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 in color. 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 net pens.

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 ($ml\ O_2/m^2/hr$).

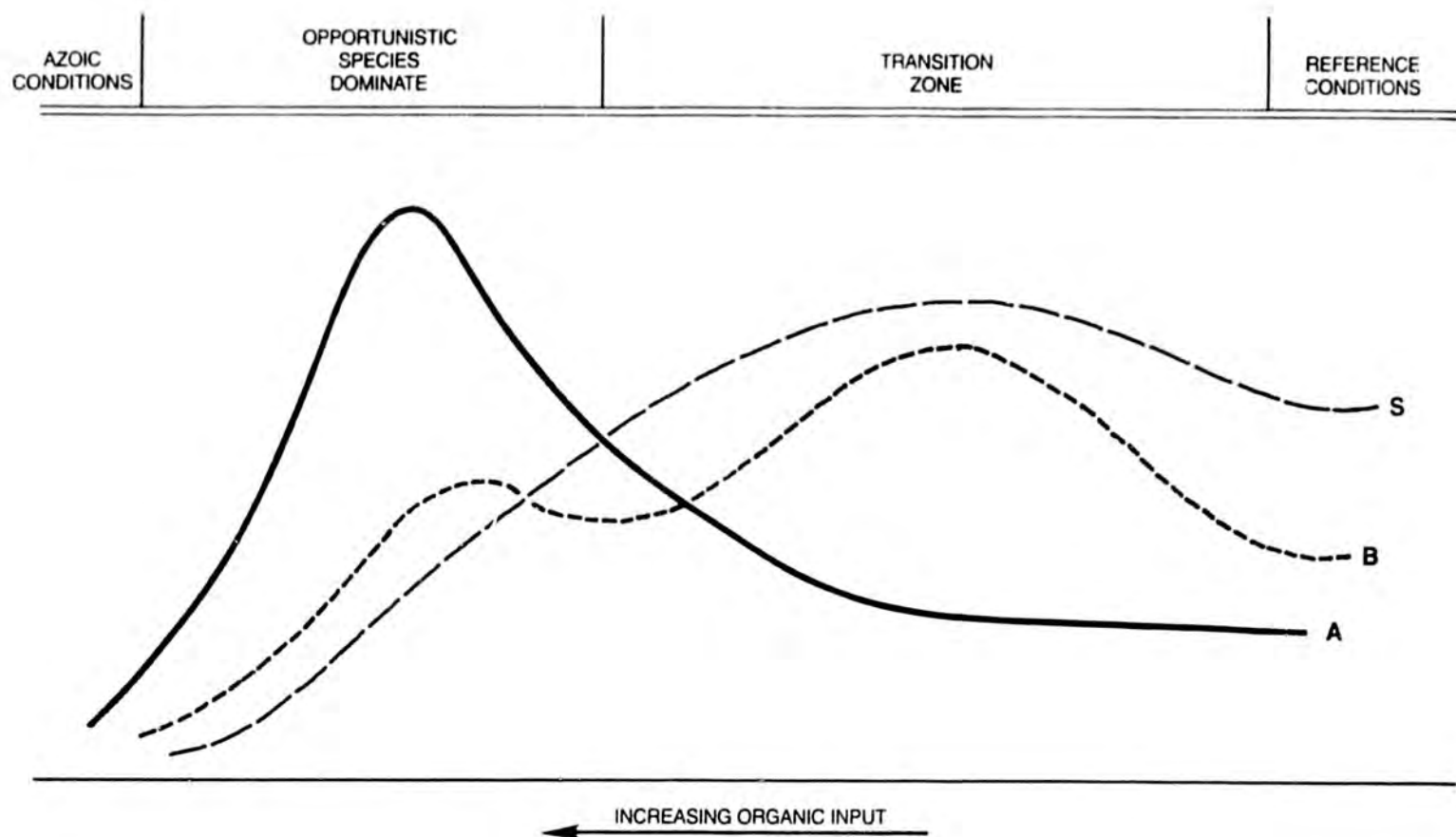
Another method for assessing the impact of organic deposition is the reduction oxidation (redox) potential. This measures sediment oxygen content at different depths to determine depth of the boundary between aerobic and anaerobic sediments. At this point (the redox potential discontinuity or RPD) oxygen 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 net pens 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. Feed 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).

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 net pens. 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.

In undisturbed sediments a stable, diverse benthic community exists comprised of filter- and sediment-feeding organisms and predators. Many of these animals are relatively 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



Source: Pearson and Rosenberg 1978

S Number of Species
B Biomass
A Total Macrofaunal Abundance

Figure 4.
Generalized Trends
in Organism Diversity

encourages colonization by additional species. Thus both species diversity and biomass (total weight) of the benthic organisms increases, and the benthic community is enhanced. Pearson and Rosenberg (1978) refer to this as the "transition zone."

Earll et al. (1984) observed benthic conditions below 25 net-pen facilities in Scotland. He noted that the redox potentials were reduced to a distance of 20 to 30 m (66-98 ft) from the pens and that *Beggiatoa* first appeared 10 to 15 m (33-49 ft) from the pen perimeter. Outside this zone, the sediment surface appeared normal and was light brown in color 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 to 100 m (121-328 ft) from the pens.

High species abundance and diversity, representing both pre-existing species and newly colonized species, were found in a zone 15 to 120 m (49-393 ft) from pens 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 pens, and that opportunistic species dominated the zone between 15 and 120 m (49-393 ft), with the inner boundary of the transition zone being 20 to 25 m (66-82 ft) from the pen boundary.

In studies conducted at Clam Bay, Kitsap County, Weston and Gowen (1988) estimated that normal benthic communities extended to within 150 to 450 m (492-1475 ft) of the pens. This site is one of the world's largest fish pen facilities and has been in operation for 17 years. Other observations at the same site (Pease 1984b) noted an increased abundance of geoducks in the area, and abundant congregations of anemones near the pens wherever objects provided solid substrate for attachment. It was also noted that in rocky areas having stronger currents, this zone apparently extended to the boundary of the pens. The only deposits of food occurred in the lee of protruding rocks. Elsewhere, the rocks were almost totally covered with anemones, and kelp was also abundant. Mobile predators are also abundant in this area, including flat fish (Pease 1984b) and crab (Earll et al 1984; Cross 1988). Weston and Gowen (1988) concluded that changes in the biological community extended beyond the zone where chemical changes were detectable. This indicates the increased biota consumes the organic matter, not allowing it to accumulate.

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 are able to 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 in Figure 4, while the number of organisms increases dramatically, the diversity of species declines.

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. capittata. The total number of species in this zone was about 20 percent of that in undisturbed sediments. The number of individuals, however, was 2 to 3 times normal with total biomass slightly below normal. All of the organisms were polychaete worms, with C. capittata representing 80 percent 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 affects 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/m²/day. It was estimated that the total area affected below this net pen (540 m²) was 6000 m². Similar observations from studies of pulp mill and sewage treatment plant discharges reported an affected area of 5 to 23 km².

Earll et al. (1984) observed that redox potentials were depressed were depressed within 20 to 30 m (66-98 ft) of the pens. Sediments were brown to grey in color 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 anenomes and small crab and fish which foraged into the area. The presence of anenomes was explained by their ability to extend above the sediments into unaffected water. Stewart (1984) concluded that this zone extended from 3 to 37 m from the pens. This zone was also distinguished by being relatively smooth. This 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 (50-200 ft) down current (east) from net pens 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 pen 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 pens. Pease (1984) reported that geoduck abundance increased in this area away from the pens. No geoducks were found in the area occupied by Beggiatoa. However, in a more recently developed site in British Columbia, geoducks were observed in within the more distant area occupied by Beggiatoa (Cross 1988).

At higher rates of sedimentation, even the opportunist cannot survive. At this point, the anoxic layer reaches the sediment surface, depriving the animals of oxygen and exposing them to toxic H₂S. 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 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 pens above the sediments (Braaten et al. 1983). Such affects have only been reported in stagnant areas with little water circulation.

Azoic zones (zones devoid of any animals) are reported under most net pens, except those in areas of depth greater than about 60 feet and/or high currents and the affected area is limited to that immediately below the pens (Weston 1986). Earll et al. (1984) observed dark, black sediments under most net pens observed. This zone was usually demarcated by a "halo" of dense Beggiotoa mats, which covered and stabilized the underlying sediments. The absence of Beggiotoa under the pens 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 Beggiotoa growth. No live animals were observed in this zone, however, 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 pen perimeter.

Similar observations are reported by Gowen et al. (1988) extending 3 m (10 ft) from the pens. 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 net pen complex. 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 pens was 50 to 200 g/ m^2 /day total solids, about 20 times higher than background.

A similar azoic zone has been observed beneath the net-pen 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 net-pen complex, BOC averaged 125 ml O_2 / m^2 /hr. Pease (1984) observed that the area under the pens was completely covered by Beggiotoa and food particles, overlying a layer of black sediment 1 to 2 inches deep. Under this layer was a substrate which would have been suitable for geoducks, which are abundant in the area. No geoducks were observed under the pens, however. The covering mat of Beggiotoa, unlike the bare sediment reported by Earll et al. (1984) suggests that the current velocities over the sediments are sufficient 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 pens estimated deposition of 52.1 kg dry wt./ m^2 /yr and 29.7 kg dry wt./ m^2 /yr at the pen 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. Weston and Gowen (1988), however, 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, towards the upcurrent end of the facility, 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 net pens 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 meters (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 pens may have been limited by their recent operation (18 mo.) 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). Net pens installed in Puget Sound after the Recommended Interim Guidelines, have not resulted in accumulations of sediment or azoic zones. These guidelines recommend a minimum of 15 meters (50 ft) below the bottom of the pens and a minimum current velocity of 5 cm/sec.

The effects of organic enrichment of the sediments begins quickly after installation and operation of the net pens. 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 a period of 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 pens. Biological recovery may take much 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 3 to 8 years to recover.

A number of factors determine the impacts of net pens on the bottom sediments and benthos. Among these are:

1. Loading. The poundage of fish reared in the pens is proportional to the amount of organic matter deposited from the pens. The greater the density of fish, the more concentrated the deposition of organic waste.

2. Pen size. Larger pens, with the same loading, deposit sediments over a relatively smaller area (Earll et al 1984). Thus the effects are more concentrated, however, the size of the area affected is less.
3. Water depth and current velocity. In deeper water and faster currents, the dispersion of wastes will be greater.
4. Pen configuration. Pen configuration and orientation to the predominant currents can significantly affect the dispersion of wastes (Fox 1988, See Appendix B).
5. Bottom current velocity. High bottom current velocities can erode and disperse sediments regardless of dispersion in the total water column.
6. 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.
7. 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 percent wastage, and up to 27.0 g/m²/day organic matter deposition on the bottom. The use of automatic feeders resulted in wastage of 8.8 percent and a maximum deposition of 88.1 g/m²/day (Cross 1988).
8. Bottom sediments and community. The benthic community will also affect the impact. Areas of high biological productivity may be able to assimilate higher organic deposition. However, adverse impacts may have greater significance due to the importance of such productive areas. Conversely, areas having few organisms may have less assimilative ability but creation of an azoic zone may have less effect on the biological community.

Modeling

While the previous information describes the types of impacts which have occurred at various net-pen 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). The Recommended Interim Guidelines (SAIC 1986) presented minimum depth and current recommendations for siting net-pen complexes of various sizes, based on reported observations of sediment accumulations reported in Weston (1986). These recommendations provided a "best guess" of the conditions under which sediment dispersal by currents would prevent any significant accumulations of organic material below the pens. In general it is recommended that large, commercial fish farms be located in areas with a minimal average current of 5 cm/sec (0.1 knot) and at least 60 feet between the bottom of the pens and the sea bed.

Weston (1986) reviewed several sediment models and concluded that none were adequate to predict the fate of particles deposited from a net pen. As part of a multi-year study of net-pen impacts in Scotland, Gowen et al. (1988) presents a conceptually simple model which divides a net pen into 1-m² squares and calculates where particles of feed and of feces from each square will accumulate on the sea bed after several tidal cycles. Tests of the model at six relatively small (672 to 2460 m²) 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 m²) farm at Clam Bay, Kitsap County and a 1184 m² 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.

In general, the model has proven to be a good predictor of general sediment impacts at net pen sites, despite inherent limitations. These limitations include: only using 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 pens. 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 net pens (Gowen et al. 1988). See Appendices A and B for further discussions of this model and comparison with other models.

c. Mitigation Measures

Several measures can be taken to prevent harmful accumulations of organic wastes below net pens. These include:

- Avoiding sites overlying important biological communities (for example, geoduck and other clam beds and important spawning areas) where they may be adversely affected;
- Where accumulation is unavoidable, select sites having little biological productivity;
- Maximize dispersion to avoid creation of azoic zones. This can be accomplished by the following measures:
 - Select areas of deep water and/or with high currents. Selection of such areas could utilize existing models such as Gowen (1988), or Parametrix (1988), or other models developed for this purpose.
 - Orient the configuration of pens perpendicular to prevailing currents.

- Use clusters of pens as opposed to a single array.
- Use single-point moorage to allow pens to swing over a larger area.
- Rotate pens from one site to another to allow recovery of an area or to remove pens before impacts occur.
- Limit density of fish in pens to prevent concentrated deposition over a small area (for example, use larger pen area to raise same number of fish).
- Utilize slow-settling, highly digestible feed to minimize waste and feces, and to maximize food conversion rate.
- Use feeding methods that maximize ingestion and food conversion.
- Use underwater blowers to maximize dispersion and to remove accumulations.
- Use mechanical techniques such as vacuuming to remove accumulated wastes under the pens.
- Use collection devices below pens (these methods have been used in Europe at some sites with mixed success [Braaten et al. 1983]).

d. Unavoidable Adverse Impacts.

Some organic enrichment of the benthic community is unavoidable. Impacts can be minimized to those which result in biostimulation (transition zone) by the methods presented above. If accumulation is allowed, the impact of this accumulation can be minimized by selection of locations which have limited biological productivity and where the extent of the impacts is restricted to the area of the pens.

2. IMPACTS TO WATER QUALITY

Net-pen aquaculture 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.

The objective of the mitigation measures discussed in this section is to prevent any alteration of water quality that will adversely affect aquatic organisms using the water column. In addition, operations of net pens must not allow water quality changes to exceed those allowed by state and federal water quality rules.

Background, Puget Sound Circulation

To understand the potential water quality impacts of salmon net pens in Puget Sound, it is desirable to understand the basic dynamics of Puget Sound.

For this PEIS, 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). Inner 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. Inner Puget Sound alone covers an area of 2630 km² (768 square nautical miles) at high tide with a volume of about 169 km³ (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 km³ 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 to 50 m. 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. Refer to Figure 8 for a generalized cross-section of this two-layer movement.

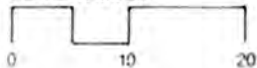


Source: Strickland 1983

Note: Depth in meters



SCALE IN MILES



Main Basin of
Puget Sound

..... Sills

Figure 5.
Major Sills in Puget Sound



SCALE IN MILES

0 10 20

- > Current Movement
- Eddy
- Slack

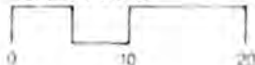
Figure 6.
Generalized Surface Water
Movement at Flood Tide
in Puget Sound



Source: Puget Sound Water Quality Authority 1986

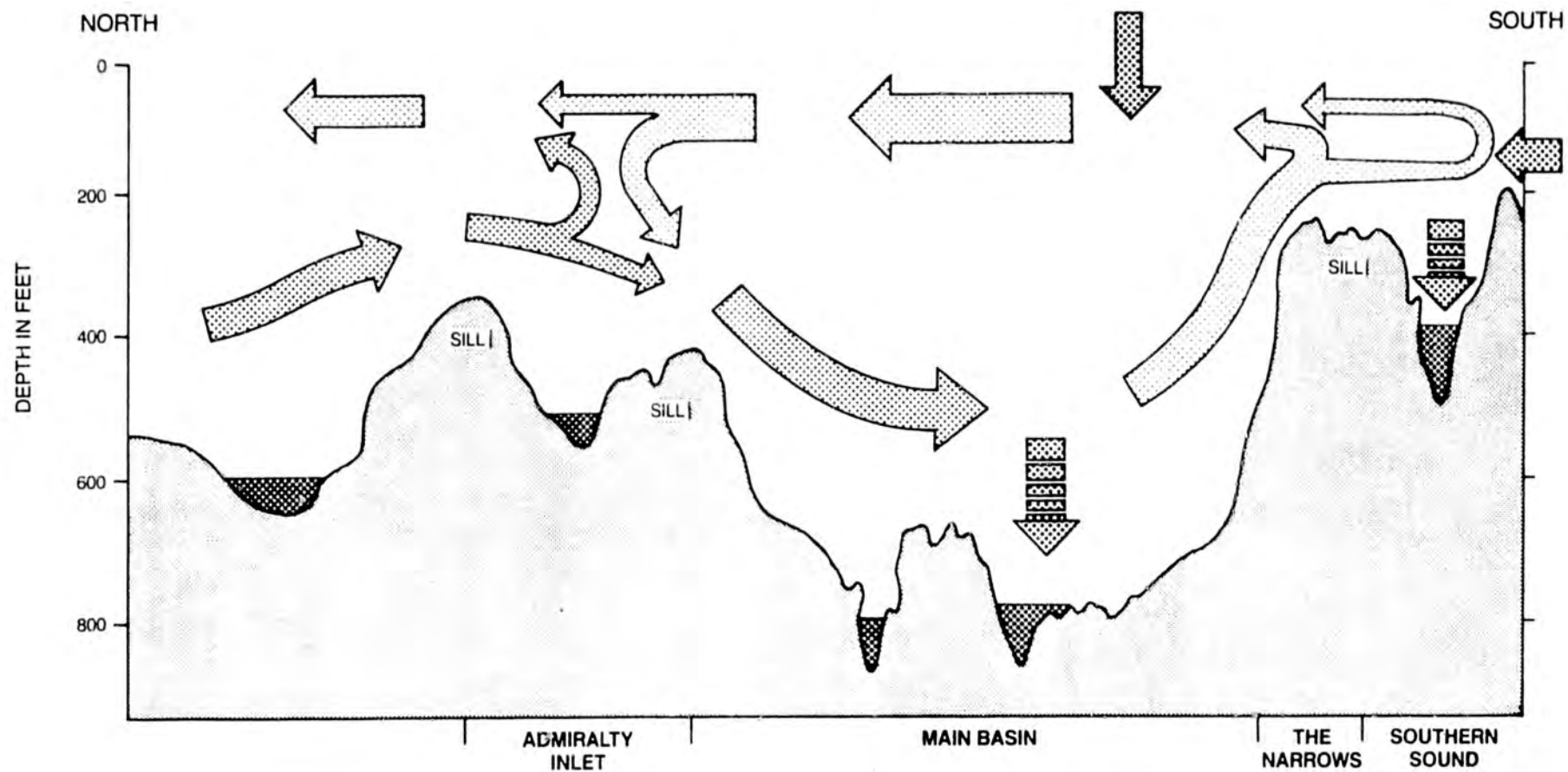


SCALE IN MILES



- Current Movement
- Eddy

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

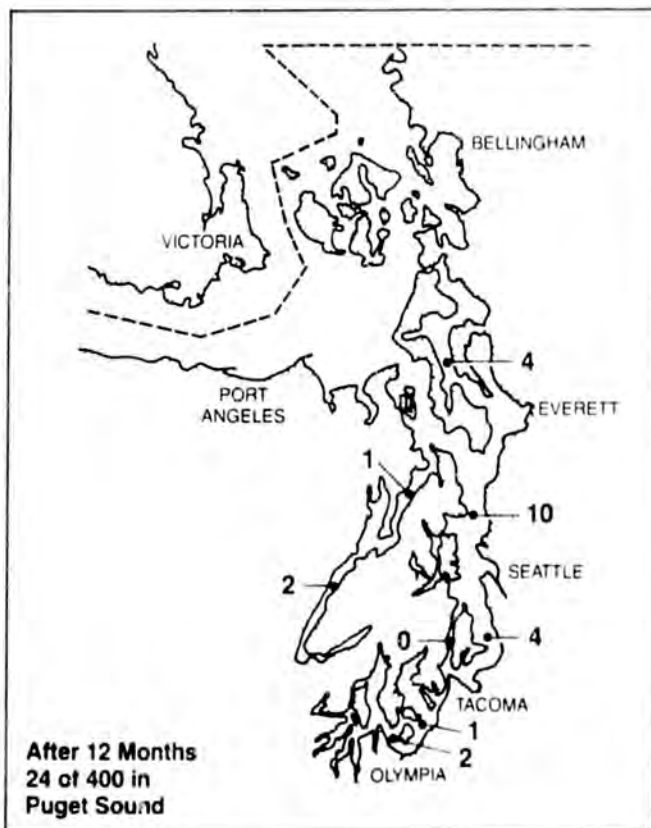
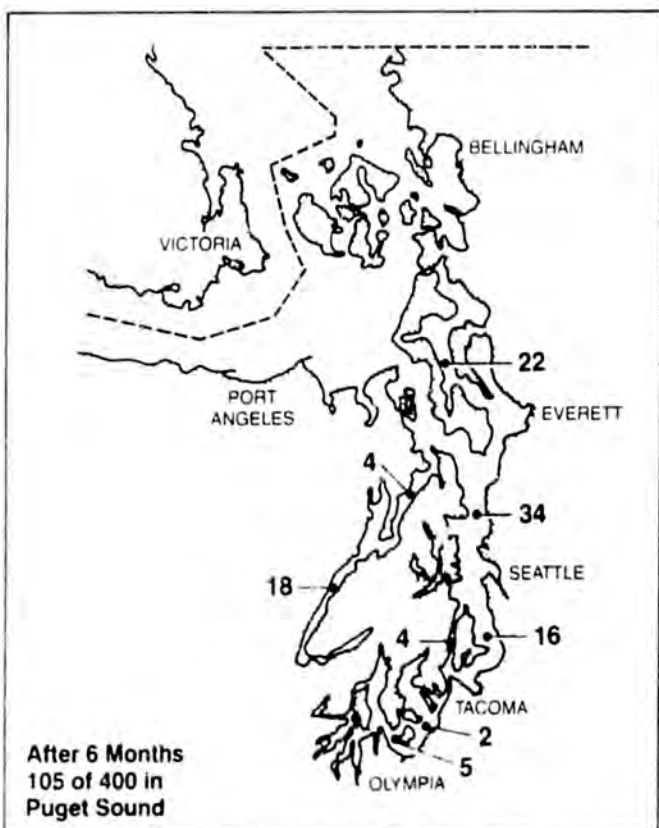
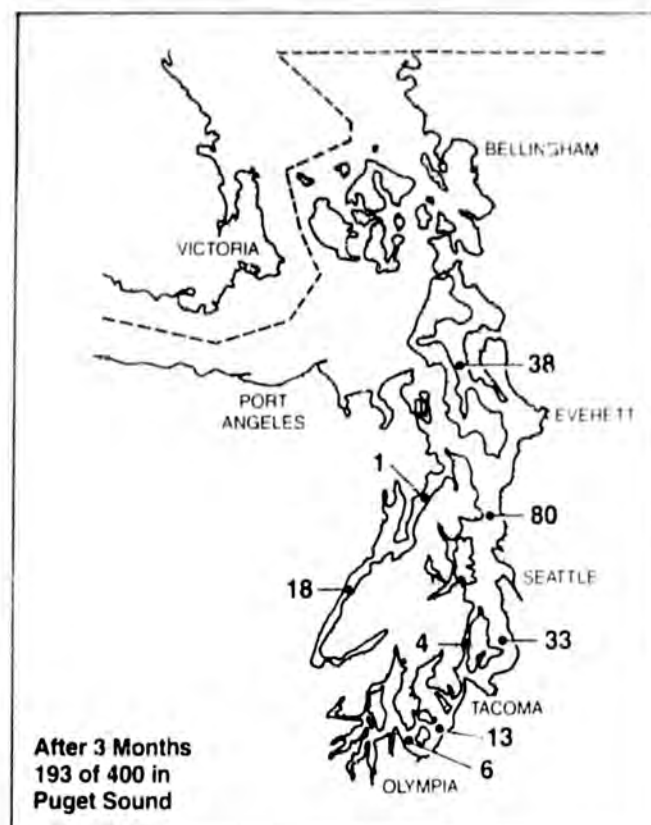
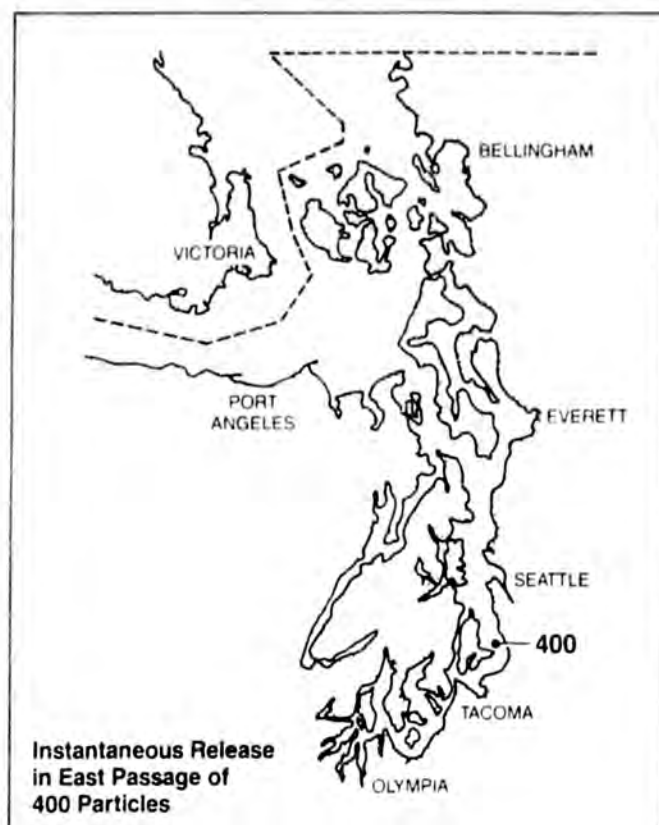
In addition to tidal driven water exchanges, meteorological conditions can cause large intrusions of saline, coastal water. According to Cannon (1983), "in the Strait of Juan de Fuca, the waterway connecting the Sound with the Pacific Ocean, winter storms with predominantly southerly winds along the 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).

An important feature of Puget Sound is the presence of major sills such as 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 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 ten 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 agrees with a 50 percent average recycling of surface water at the Admiralty Inlet sill (Alyn Duxbury, personal communication 1988).

Figure 9 tracks the course of 400 computer modeled parcels of water instantaneously released into the Sound and carried by currents. Approximately half of the parcels are left in the south after three months. Six months after the water parcels are released, 25 percent remain. After a year, 5 percent 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 the Sound's typically cold surface water temperatures). During summer months, 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 very rich in nutrients and are relatively saline. These conditions support abundant and sustained phytoplankton growth, which is the basis of the aquatic food chain, and also supports 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 which 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



Source: Puget Sound Water Quality
Authority 1986

Figure 9.
**Theoretical Dispersion of
Water Parcels in Puget Sound**

nutrients, which allows for the production of phytoplankton, and results 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 as are typical at the head of Budd Inlet.

Hood Canal is adjacent to, but separate from, the main basin of Puget Sound with a 51 meter (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 which 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.

a. WATER QUALITY STANDARDS

(1) Affected Environment

Water quality in Puget Sound is monitored, assessed, and protected by the Washington Department of Ecology (Ecology). Water quality criteria have been established in Chapter 173-201 WAC, 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 1.

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.

The primary causes of water quality impairment in the state's estuaries are bacteria, organic enrichment, and low dissolved oxygen (Ecology 1988a). The primary sources of bacteria problems are from agricultural runoff, on-site wastewater disposal (septic tanks), and municipal wastewater (sewage) treatment plants. 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).

Table 1. Marine water quality standards in Washington state.

Criteria	Waterbody Classification			
	<u>AA</u>	<u>A</u>	<u>B</u>	<u>C</u>
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

The Department of Ecology is currently in the process of clarifying state policy on discharge from aquaculture operations. The discharge permit for net-pens is discussed in Section I.D, Alternatives.

Exacerbation of organic enrichment and dissolved oxygen problems are a potential water quality concern for the operation of net pens. 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 the incoming tide. 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 is dependent 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 describes the oxygen levels of concern to marine life.

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 to 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.

The Washington Department of 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 meters during the summer months of the last five 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.

Figure 10 identifies 25 of the 46 monitoring stations that do not always meet the Class AA standard for dissolved oxygen. 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 ten 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.

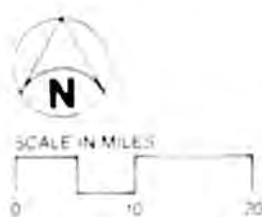
In summary, dissolved oxygen problems in Puget Sound most commonly occur in certain embayments that have poor circulation, such as southern Hood Canal, Budd Inlet, and Holmes Harbor. These problems typically occur during periods of low tidal exchange in late summer and autumn, and are related to phytoplankton blooms. Dissolved oxygen problems also occur in many other areas in summer and fall from the natural upwelling of deep bottom waters.

(2) Impacts on Water Quality Standards

Potential water quality impacts of net pens are based on state water quality standards (See Table 1). This section separately describes the potential impacts that a net pen may have on each water quality variable.



Source: Ecology, 1988b



- Meets Class AA
- Does Not Meet Class AA (7 mg/l)
- ▲ Does Not Meet Class A (6 mg/l)
- ◆ Does Not Meet Class B (5 mg/l)

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

Turbidity. Turbidity is a variable that indicates the clarity of water. During net cleaning, turbidity could significantly increase down current of net pens. 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 pens. The loss of fish food and feces from net pens 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

A study in Clam Bay, Washington, reported that floating net pens did not affect turbidity (NMFS 1983). Turbidity ranged from 0.5 to 2.0 NTU throughout the study, but 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 net pens.

Pease (1977) reported that a net-pen facility 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 net pens and at a control site. On one occasion the pH was between 0.15 to 0.3 units less at the three net-pen 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 floating net pens would not affect water temperatures in Puget Sound. Net pens 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). Net pens 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 net pens from increased marine bird and mammal activity (See Section II.A.5, Marine Mammals and Birds). Or fecal coliform levels could possibly increase from the failure of a facility's septic system.

Nutrients. Nutrients are primary substances that are required by organisms for growth. Some of the essential nutrients include nitrogen, phosphorus, hydrogen, and carbon. The operation of net-pen farms releases nutrients into the water from fish feces and from uneaten feed. The primary nutrients of interest in relation to net pens 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 net pens is composed of organic carbon and nitrogen (Liao and Mayo 1974, Clark et al. 1985). About 22 percent 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 percent 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 net pens (6-30 m) 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).

In order to characterize the amount of nitrogen produced from net pens, the State of Washington Department of Natural Resources adopted a set of monitoring guidelines from the "Recommended Interim Guidelines" (SAIC 1986). These monitoring guidelines are requirements for new and existing net pens.

Using these guidelines, several studies have recently been conducted near salmon net pens in Puget Sound to document nutrient and ammonia production. These studies have assessed the dissolved nitrogen concentration upstream, at the pens, and farther downstream. In addition, the studies assessed the pH, temperature, current speed and direction, facility configuration, and exposure to the water current. By calculating nutrient production from the fish stock in the pens, an estimate of actual versus theoretical nutrient production is possible. When sufficient data have been collected, the results will provide an accurate index of dissolved nitrogen production specifically for marine net pens.

The effects of nutrients will not be discussed here, but will be covered in the following sections on ammonia toxicity and phytoplankton productivity.

Toxicity. Toxic chemicals would not be introduced into the net pens from fish stock or food. The potential impact of toxicants leaching from treated nets and of antibiotics is discussed in Section II.B.2, 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 been shown to raise 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 net pens in Puget Sound, typically about 2 percent, will be of the toxic, un-ionized form.

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 net pens, is 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). Salt water 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 net pens. This results in much greater dilution of waste products such as ammonia in net pens when compared to freshwater hatcheries or municipal sewage discharges (Weston 1986).

Recent near-field studies in Washington state (Milner-Rensel 1986; Rensel 1988b,c) have shown increased concentrations of ammonia immediately downstream or within the net pens. Total ammonia values typically have increased from 3 to 55 percent 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 net pens (ammonia plus nitrate and nitrite), that was 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 pens.

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 net pens. 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 net pens, toxic concentrations of un-ionized ammonia were not approached.

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 pens. 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 net-pen operations on dissolved oxygen concentrations near the pens is highly variable. The loss of dissolved oxygen depends on the water exchange rate near pens, fish density, and fish feeding rate. If the water exchange rate near the pens is high, there will be less reduction of dissolved oxygen. If the fish density and fish feeding rate are high, there will be increased dissolved oxygen.

In general, the dissolved oxygen requirements of salmon raised in net pens limit the impact net pens 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 net pens are likely to occur within the net pens and immediately down current. Thus, the impact of low dissolved oxygen is likely to affect the net-pen operation before having an effect on the surrounding environment.

The impact of net pens on dissolved oxygen have been estimated by mathematical modelling 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 net-pen sites have shown a decrease in dissolved oxygen ranging from near zero to 1.5 mg/l. These net pen 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 Sechart 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 net pen in an embayment may cause a greater reduction of dissolved oxygen if the area of decreased oxygen from one net pen overlaps the area of decreased oxygen from another net pen. In this case, both net pens may be capable of operating without a significant reduction in dissolved oxygen, but the proximity of one net pen to another could result in localized dissolved oxygen reductions in violation of state standards.

Field measurements around individual net pens indicate that the region of dissolved oxygen impairment around a net pen is less than 50 meters (165 ft). Consequently, the

potential of one net-pen facility affecting the dissolved oxygen near a second net pen is highly unlikely if the net pens are placed even 100 meters (330 ft) apart. It is highly improbable that sediment impact requirements and aesthetic considerations would allow siting net pens closer than a few hundred meters apart. In addition, as discussed above, a single net-pen operation rarely reduces dissolved oxygen concentrations to the point of violating state standards. Consequently, the potential for five net pens violating the dissolved oxygen standards is no greater than for one net pen unless the pens are placed extremely close together.

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

(3) Mitigation Measures

The most effective mitigation measure for dissolved oxygen impacts from net pens is the siting of these facilities in areas that historically have dissolved oxygen levels above 6 mg/l. These sites should have adequate current speeds and water depths to ensure oxygen levels would not drop below state criteria. Current speed and water depth criteria that will ensure no sedimentation impacts would also ensure no water quality impacts. These criteria have been discussed in the Sedimentation section (II.A.1).

Mechanical means of aeration can mitigate low dissolved oxygen levels at sites that occasionally experience adverse conditions. Aerators, mechanical devices that either mix air and surface water or pump air into the water, are commonly used in freshwater fish hatcheries to prevent low dissolved oxygen levels. These devices are capable of raising dissolved oxygen levels by several milligrams per liter, depending on their type, number, and application. Aerators are also available for use at some existing net pens (Rensel 1988). One other contingency would be to separate net pens into smaller groups that would have less impact on dissolved oxygen levels.

Mitigation of potential turbidity impacts would involve monitoring during net cleaning. If this monitoring identifies turbidity impacts, then operational contingencies such as cleaning nets more frequently or on shore could be employed.

(4) Unavoidable Adverse Impacts

Net pens would have an impact on dissolved oxygen and turbidity in Puget Sound. However, the impact would not be significant enough to violate state water quality standards.

b. 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, the Washington Department of 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 net-pen operation 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 net pens.

Although never documented, increased plankton growth from net pens would not necessarily be an adverse effect as phytoplankton are the base of the marine food chain. However, greatly increased growth of marine phytoplankton could have adverse effects on dissolved oxygen concentrations at depth, on fish and shellfish survival, and, in rare cases, on aesthetics of nearshore waters.

(1) Affected Environment

Phytoplankton are present in Puget Sound throughout the year although their abundance is normally reduced during winter months. Winter et al. (1975) found that growth rates of phytoplankton populations were relatively 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. The term "bloom" refers to 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 recurring 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, and thus, temporal changes in the crop size are determined by imbalances in the rates of growth and rates of death. Grazing by zooplankton also contribute 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 supply of nutrients and trace metals.

Finally, the crop size may be indirectly controlled by factors that determine the growth rates and death rates of the cells that comprise the population. Factors that exert indirect control on the size of the crop include physical factors such as light intensity, water temperature, and water movement (vertical mixing caused by tides and weather and transport to the ocean by horizontal flow). These physical 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 assessment of the fate of discharged nitrogen is not easily made. Nonetheless, the fate of nitrogen discharged from net pens will generally be the same as that of naturally occurring nitrogen. If the natural concentrations of organic nitrogen in 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 state of 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.

The U.S. Environmental Protection Agency 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. Accordingly, 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 the 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 that are 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).

Existing Marine Phytoplankton Problems. 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 impact shellfish and finfish aquaculture, there is a continuing and increasing monitoring effort worldwide (Tangen 1987), and specifically in the Pacific Northwest (Rensel et al. in press).

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 1200 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 (Collins 1978).

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 meters per hour (Darley 1982) to 20 meters per hour (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), 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 Quatermaster

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 net pens 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 after some fixed period of 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). Low concentrations in surface water of nitrogen and possibly phosphorus, in other cases, 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).

Noxious phytoplankton appear to have caused occasional kills of fish reared in net pens 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. in press). 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, and most species of Chaetoceros are considered benign or beneficial as food for shellfish and zooplankton.

(2) Impacts on Phytoplankton

Ammonia toxicity and dissolved oxygen depletion are two potentially measurable water quality impacts from net pens. In addition, salmon net pens may also 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 result in the increased production of phytoplankton. Phytoplankton forms the basis for the aquatic food chain in all aquatic systems and moderate increases in primary production will usually result in increased production of zooplankton, filter-feeding fish and shellfish, and the larger predator fish which are harvested by sport and commercial fishermen. Phytoplankton is also a major source of oxygen.

In unusual cases, however, excessive growth of phytoplankton may result in eutrophication. This occurs in poorly flushed, shallow bays with high nutrient levels that allow

high-density phytoplankton growth. Eutrophic bays often are noted by visible color changes (phytoplankton blooms) and the accumulation of small attached algae near shore and decaying macroalgae and phytoplankton on beaches. This accumulation of organic matter results in the same sediment impacts as described under net pens, 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 which only occurs in very limited areas of Puget Sound for short periods of time. 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 build up of high levels of organic matter on the bottom (phytoplankton cells). During nighttime, when there is no sunlight to power 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 result in the reduction of 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 2 to 3 years, while those grown in the relatively nutrient- and phytoplankton-poor waters of Hood Canal reach market size in 4 to 5 years.

In the past, Puget Sound net pens located in restricted embayments (Henderson Inlet in southern Puget Sound and Shoal Bay near Lopez Island), severe losses of salmon and other aquaculture species occurred in some years (Rensel and Prentice 1980; Dr. A. Bill, personal communication 1988). Such losses contributed to the eventual removal of those facilities. There are presently no large, commercial net-pen farms operating in restricted Puget Sound waters with the exception of small, delayed-release projects operated seasonally by the Department of Fisheries and cooperating tribes or sport fishing groups. These delayed-release facilities typically rear fish for one to five months and release all of their fish before summer, thus avoiding natural, but noxious phytoplankton blooms and higher water temperatures that may occur in summer and early fall.

Since few net-pen facilities 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 net pens 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 net pen impacts on

phytoplankton is difficult. There is a possibility that effects of net pens on phytoplankton were overlooked by selecting reference areas too close to the net pen location.

Studies of the effects of salmon net-pen culture on phytoplankton populations were conducted for this PEIS under what may be described as the worst-available conditions (Rensel 1988c). Although the net-pen farm studied had successfully reared salmon for many years, it represented an example of worst-available case for analysis of ecological impacts. The net-pen farm at Squaxin Island was relatively large, situated in shallow waters where there is seasonal nutrient depletion of surface waters. Nutrient production and phytoplankton growth rates were assessed during a period of maximum fish biomass and a month later, after release of 60 percent of the fish biomass. Effects of the pens were compared before and after the fish release, as well as by the more typical means, such as comparison to reference stations.

During the period of maximum fish biomass, minor increases in dissolved nitrogen ($\text{NO}_3 + \text{NO}_2 + \text{NH}_4$) were seen downstream of the pens during one tidal period, but not during the next. Total ammonia was significantly elevated within the pens compared to existing concentrations, but pen ammonia concentrations were well below the maximum exposure limits for salmonids and other sensitive coldwater fish. On one tide, elevated dissolved nitrogen was found from ammonia within the pens, but 30 m (98 ft) downstream approximately 80 percent of the ammonia had been oxidized to nitrate, presumably by microbial nitrification.

Before fish release, chlorophyll *a* concentration, a measure of phytoplankton density, appeared to be greatly elevated during one tidal period at the net-pen study site, but was only slightly greater during the next tide. After release of most of the fish, there were no statistical differences of chlorophyll *a* at any location or during either tidal period. The rate of primary productivity by phytoplankton (C-14 method) was similarly greater near the net pens than the reference stations during the first tide, but was less than the reference stations during the following tide. A similar trend was seen after release of most of the fish, but the difference between production rates at each station were not statistically significant due to replicate sample variance.

The ratio of total nitrogen to phosphorus before release of the fish indicated that growth limiting conditions did not exist for diatoms (Redfield 1958; McCarthy 1980; URS 1986). Therefore, nutrients contributed by the net pens were probably not the cause of the observed short-term phytoplankton enhancement near the pens. Enhanced growth rate and standing stock of phytoplankton were not observed a few hours later during the following tidal period, or during either tide of the sampling period after 60 percent of the fish were released.

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 net-pen farm. Additionally, water exchange into the 50 meter (164 ft) deep Loch Spelve is restricted by a shallow sill, only 4 meters (13 ft) deep. Although localized elevated ammonia was seasonally observed immediately around the net-pen 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 net pens, 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, (that is low total nitrogen load that could be proportionately more perturbed by added nutrients);
- dissolved oxygen depletion, usually at depth; and
- 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. A ranking is not included here, however, as the specific location of a proposed net-pen 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.

Nitrogen flux (input and output to neighboring waters) through each embayment is used as an index of nutrient sensitivity in the Recommended Interim Guidelines (SAIC 1986). A one-percent increase in the flux (not to be confused with the concentration) due to net-pen aquaculture is allowed. 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 Recommended Interim Guidelines rely upon measurement of dissolved nitrogen in the surface layer only, and ignore the deeper, nutrient-rich layer which may be much larger (such as in central Hood Canal). The Recommended Interim Guidelines, as presently stated, result in a much more conservative estimate of the one-percent 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 in regard to the true one-percent flux of nitrogen.

Moreover, the Recommended Interim Guidelines calculation of nitrogen flux do 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 is dependent on a number of factors including phytoplankton crop size, phytoplankton growth rate, grazing by zooplankton, and to a lesser degree, sedimentation (Harris 1986). The Recommended Interim Guidelines legitimately did not consider these unquantified factors, and sought instead to utilize the existing Department of Ecology data base. That data base includes dissolved inorganic nitrogen (that is, nitrate, nitrite and ammonia) and total phosphate. But does not include total nitrogen and phosphorus data that could, under some circumstances, be useful in estimating the true nutrient depletion of any particular embayment. While total nitrogen to total 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, action to adjust the ration of N:P availability (Smith 1984; Harris 1986; Paerl 1988).

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 far field nutrient and phytoplankton modeling relating to net-pen aquaculture has recently been developed (Parametrix Inc. et al. 1988; Kiefer and Atkinson 1988).

Near field impacts (ammonia production and oxygen consumption) from net pens may be easily modeled using models that conservatively approximate a pipeline passing through the net pens. These models neglect lateral mixing that would tend to reduce the measurable effects. Far field 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 (Broecker 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 near bottom 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 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 net pen if other net pens are in the same embayment. The area immediately around the net pen (nearfield) is usually independent of other net pens as long as the pens are adequately spaced as discussed in the dissolved oxygen section. The far field consists of the remainder of the embayment and is affected by the cumulative impact of all the net pens in the embayment.

To estimate the cumulative impact of several net-pen farms on phytoplankton in a nutrient sensitive embayment, three factors are 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 the purpose of analysis here, it is necessary to consider a hypothetical embayment. This embayment is tidally flushed, is relatively small, has five net pens, 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, basal metabolism/mortality, and loss from the system through the zooplankton pool. Photosynthesis is considered to be either light or nitrogen limited and zooplankton grazing is dependent 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 1.7×10^7 m² was chosen to represent a smaller bay near full development with five net pens in operation.

A dilution rate (D) of 20 percent was selected using an exchange rate with source waters outside the embayment of 27 percent per tidal cycle based on data from the 19 sub-

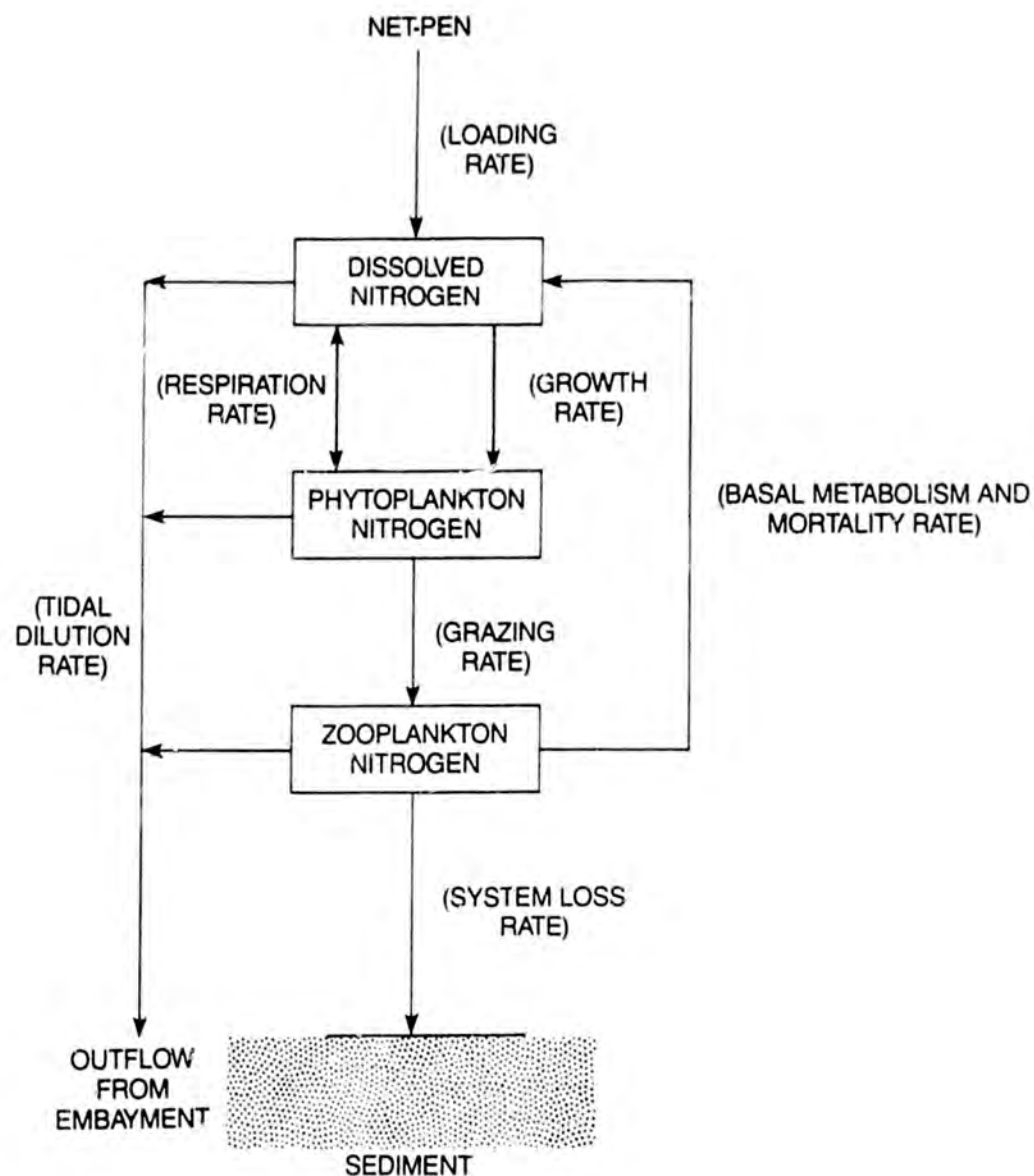


Figure 11.
Schematic Representation of the
Processes Simulated in the Keiffer
and Atkinson Phytoplankton-Nutrient Model

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:

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

where: J = mass nitrogen loading from the net pens (kg/day)
 F = the fraction of nitrogen produced by the net pens 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})

areas of Puget Sound discussed in the Recommended Interim Guidelines (SAIC 1986). Assuming a reflux coefficient of 0.5, the flushing factor would be 13.5 percent per tidal cycle. With approximately 1.5 tidal cycles per day, this results in 20.2 percent flushing per day.

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

Loading of dissolved nitrogen produced by fish per day was taken as 0.25 g/kg fish/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 net pens in a single embayment are presented in Table 2.

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 one percent. 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 percent 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 utilized 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 present at this time in the form of the standing crop of phytoplankton, particularly in the late spring and early summer.

Based on the model, the summer phytoplankton crop would increase approximately 2 percent from five farms. This run of the model assumes that nominal conditions of phytoplankton abundance are $3.0 \mu\text{l}$ chlorophyll *a*. Under normal conditions, there is a range of phytoplankton abundance varying from about 1 to $15 \mu\text{l}$ chlorophyll *a*.

It should be noted that the modelling discussed assumes a well-mixed condition throughout the surface mixed layer and ignores near field effects from the net pens. It also conservatively assumes no mixing of nutrients from the deeper layer to the surface. The actual siting of net pens could be determined from a modelling of individual embayments to determine the flushing rate and circulation patterns within an embayment and to evaluate near field conditions around the proposed net pens.

Modelling is more critical in the siting of more than one net pen in an embayment. In particular, the net pens should be situated such that the near field conditions from multiple net pens 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 net-pen farms is not expected to adversely affect the embayment in terms of phytoplankton abundance. Extremely small, shallow, or poorly flushed bays would be more sensitive to nutrient loading from net pens, but proper analysis of proposed net-pen sites could identify such embayments.

Table 2. 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).

	<u>Dissolved Nitrogen</u> (mg/l)		<u>Phytoplankton</u> (mg/l)		<u>Zooplankton</u> (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

(3) Mitigation Measures

Mitigation measures to reduce or eliminate nutrient-related impacts would only be necessary in nutrient sensitive or potentially nutrient sensitive marine waters. Other

areas of the state are not sensitive to the effects of nutrients from net pens. Meeting these considerations would prevent nearshore algal enrichment impacts that have occurred in the very shallow nearshore areas due to urbanized (nutrient rich) streamflow (Thom et al. 1984, 1988).

- Prior to siting of net pens, determine if the area is nutrient sensitive.
- Where available, examine existing data bases on nutrient sensitivity (for example, SAIC, 1986);
- Where data is unavailable or incomplete, require evaluation of nutrients and algal density (chlorophyll *a* or cell counts).
- If nutrient sensitivity is indicated, adverse impacts can be avoided by:
 - Restricting fish farms in areas already exhibiting hypereutrophication;
 - Limiting total fish production within a sensitive area to that which will not adversely affect existing biota. (Predictive models, such as those of Parametrix or Kiefer-Atkinson, can be used to estimate allowable fish production);
 - Locating pens where flushing will remove dissolved waste material from the area (for example, near bay entrances where flushing is likely to be greatest).

In sensitive areas, nutrient production could be minimized by operation changes, such as:

- Reducing feed wastage through careful fish cultural practices (pen design, stocking densities, feeding methods) and the use of slow-sinking feed.
- Reducing the amount of nitrogen in the feed or increasing the digestibility of the nitrogen in the feed to reduce ammonia excretion.
- Integration of fish culture with the culture of aquatic plants and shellfish which could utilize and remove nutrients and phytoplankton from the water.

(4) Unavoidable Adverse Impacts

Adverse impacts from nutrient input and phytoplankton productivity have not been demonstrated in nutrient-rich waters. Impacts in sensitive areas can be avoided if the proposed net-pen site has adequate water volume and flushing. In confined embayments, net-pen operations could result in adverse phytoplankton production if total fish production exceeds the assimilative capacity of the bay.

c. 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 tissues of indigenous biota, and whether use of antibiotics encourages growth of bacteria resistant to antibiotics.

(1) Affected Environment

Antibiotics. Three antibiotics are currently registered for use in fish farming applications by the U.S. Food and Drug Administration (FDA). These are (1) oxytetracycline (OTC), (2) a potentiated sulfonamide marketed under the trade name Romet, and (3) sulfamerazine. 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 net-pen 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 demonstrated effective against furunculosis and enteric redmouth disease in freshwater fish hatcheries. Due to its relatively recent licensing, little information is available on its efficacy in seawater net-pen farming.

Sulfamerazine, while licensed for use on cultured fish, receives little use today in Washington for disease control in salmon culture because it is not as effective as OTC in controlling bacterial diseases of salmon.

The FDA practices a more conservative policy toward the licensing of 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 percent, in comparison with chloramphenicol's 99 percent and oxolinic acid's 14 to 38 percent. 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. The authors also note that since about 90 percent of OTC administered in fish feed is excreted in the feces in the form of the parent compound (that is, as the chemical form added to the feed). That means use of the drug could contribute to the development of antibiotic resistance in bacteria near the fish farm. 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 that are used in fish farming and 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 which 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). It is also known that the 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 population 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 the several factors. They are occurrence of antibiotic resistant bacteria in association with aquaculture depends on the diversity, frequency, and dosage of antibiotic administration, and environmental conditions of culture including temperature, dilution of the antibiotics, and the containment of the fish and associated bacteria.

The reports of antibiotic resistance from Japan 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, studies (Austin 1985; Austin and Al-Zahrani 1988; Aoki et al. 1984) have noted that the increased level of antibiotic resistance associated with antibiotic use around fish farms was soon reduced after antibiotic use stopped. This phenomenon has 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, V. 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 to resistance was performed under laboratory conditions at 25° C (77° F). The studies demonstrated the potential for transfer under controlled laboratory conditions and 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 little 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 with regard to 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 net pen. 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 (1986) 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 percent of the starting concentration) for OTC in marine sediments was about ten 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 three of the four farms at levels from 0.1

to 4.0 mg/kg (ppm [parts per million]) of dry matter. This level would potentially be high enough to be inhibitory to 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.

Another study, the Wekell and associates study (1989), 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."

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 state. Their use for most purposes is now prohibited by state legislation. Therefore, organic tin antifoulants are no longer used by the net-pen industry in Washington. Their use has also been virtually eliminated in net-pen farming in other parts of the world as well. 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.

(2) Impacts of Chemicals

Although some technical details require further study, the issues surrounding antibiotic use in fish farming have received some detailed study. 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 net pens. One Norwegian study found concentrations of one antibiotic may have been close to inhibitory

levels in three of four farms. The concentrations of antibiotics outside of the immediate proximity of the fish pens 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 net-pen 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 net-pen farming in the Puget Sound region would not favor the development of antibiotic resistance. In addition, the 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.

Antibiotic resistance tends to disappear when antibiotic administration is stopped. Shellfish held within a net-pen complex did not accumulate detectable levels of OTC. This observation and the calculated dilution of antibiotics away from the fish pens further suggest that any quantities of antibiotics accumulated in shellfish, or other benthic or planktonic marine invertebrates not near the pens would be substantially 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 which 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 in fact, required for salmon net-pen farming, is one key environmental factor that can prevent the laboratory-documented resistance transfer from occurring in association with salmon net pens in Puget Sound.

(3) Mitigation Measures

No substantial environmental impacts were identified under the legal use of antibiotics in fish farming in Puget Sound. Nonetheless, since some risk of drug resistance can result from improper and excessive antibiotic use, such use should be conducted in a controlled and documented manner. Alternative means of health management should be employed where appropriate. To achieve this goal, the following measures are recommended:

- Vaccination by effective protocols currently in place can be considered an effective mitigation measure for limiting the use of antibiotics.

- Educational programs presented by appropriate state government agencies on the use of antibiotics for fish farmers are recommended.
- Control of the application of antibiotics by veterinarians or other appropriate professionals could reduce the likelihood of their misuse. In addition, or alternatively, a requirement for fish farms to report antibiotic use to a state regulatory agency could help ensure their proper use.
- Further research to verify that shellfish held outside an immediate net pen environment do not accumulate significant levels of antibiotic is desirable, as well as research to establish any potential amounts of the antibiotic in sediments near fish farms in Puget Sound.

(4) Unavoidable Adverse Impacts

Identified adverse impacts can be mitigated through the measures identified above.

d. SUMMARY

Net-pen aquaculture can potentially have a wide range of impacts on water quality. Some water quality determinants such as temperature, pH, fecal coliforms and toxicity are virtually unaffected by net pens. Other determinants are affected only during some periodic activities in the operation of net pens. This is the case for turbidity which may be impaired during net cleaning.

The primary water quality indicators of concern are dissolved oxygen, nutrients, and antibiotics. Nutrients are only a concern in certain nutrient sensitive embayments where they potentially cause large increases in phytoplankton populations and possibly causing nuisance algal species. Dissolved oxygen and nutrient impacts are usually very localized in the immediate vicinity of a net pen and decrease rapidly with distance away from the pens due to diffusion and biological activity. Antibiotics have not been shown to cause the development of antibiotic resistant bacteria except in highly controlled laboratory experiments. The development of antibiotic resistant bacteria in Puget Sound is virtually impossible at the low temperature and low concentrations of antibiotics around net pens in the Sound.

Mitigation methods are capable of reducing or eliminating all adverse water quality impacts from net pens. Mitigation methods fall into two broad categories: siting of net pens and operating procedures. Proper siting involves choosing sites with adequate circulation and tidal flushing and avoiding shallow, constricted embayments. Field studies are required to adequately identify the circulation and flushing characteristics of a proposed net-pen site. Model studies can be used to estimate the propagation of water quality impacts away from net pens. This is particularly true for dissolved oxygen and nutrients. Modelling becomes more critical if multiple net pens are proposed in the same embayment. In this case, modelling can be used to determine the location and

orientation of a net pen with respect to other net pens and to estimate the overall impact of the net pens on the embayment.

Operating procedures can be used to reduce a number of impacts from net pens. Choice of feed and feeding procedures can reduce feed loss and resulting dissolved oxygen depression and nutrient enrichment. Use of aerators in periods of low dissolved oxygen in late summer can reduce the possibility of dissolved oxygen being reduced to concentrations below state standards. Operation of aerators could also raise dissolved oxygen above ambient (existing) concentrations and result in net pens having a positive impact on dissolved oxygen. Careful and controlled use of antibiotics would virtually eliminate any adverse impacts associated with the use of antibiotics.

Water quality impacts from net-pen operations are a legitimate concern. However, through an analysis of operating practices, field studies, and mathematical modelling, mitigation methods are available to avoid significant water quality impacts.

3. IMPACTS TO AQUATIC ORGANISMS

a. FISH AND SHELLFISH

This issue concerns the potential effect net pens 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.

The objective of the mitigation measures identified in this section is to prevent impacts that would adversely affect the habitat value to food fish and shellfish in the area around and under the proposed pens, and to prevent adverse impacts to fish and shellfish populations.

(1) Affected Environment

There are a number of commercially valuable species of 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 net pens on the industry are discussed in Section II.B.3.

In addition to the commercial fishing industry, recreational fishing is a major activity which is 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 catch various species of shellfish 4.6 million pounds of clams, oysters, crab, and shrimp. In addition, 756,000 marine fish were taken by boat-based sport fishers.

Discussed below are some of the species that could be affected by net pens and important habitats to consider.

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 giganteus*), 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 pounds) of clams in beds covering about 5400 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 1800 to 2300 MT (4-5 million lbs) 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 net pens. All commercial oyster harvest is from farmed beds which 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. Three commercially harvested sea urchins occur in Puget Sound waters: the red urchin (*Strongylocentrotus franciscanus*), the green urchin (*S. droebachiensis*), and the purple urchin (*S. purpuratus*). 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.

Salmon. The five species of Pacific salmon found in the northwest use shallow nearshore areas as juveniles for foraging on small epifaunal organisms. Adults migrate through Puget Sound concentrating near points of land and river mouths when returning to spawn. Some adult salmon are present in Puget Sound during the entire year.

Herring. Pacific herring (*Clupea harengus pallasii*) 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 which have been mapped

by the Washington Department of Fisheries. 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).

Lingcod. Lingcod (*Ophiodon 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 preys 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 on the bottom 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.

(2) Impacts on Fish and Shellfish

The primary impacts net pens are likely to have on fish and shellfish populations are the result of the net-pen structure and sedimentation that may occur under the pens. The effects of sedimentation upon the benthic community have been discussed in Section

II.A.1. In general, at low rates of deposition, filter feeders such as clams will be enhanced, but at high levels immobile will be displaced from the area below the pens. Weston (1986) reported that mobile predators/scavengers are attracted to the area around aquaculture facilities to feed on excess feed and on the small organisms, including opportunistic worms, which are enhanced around the pens. Weston's review reported increased densities of crab, flatfish, starfish, perch, lobsters and other predators and surface feeders from sites in all around the world. In Puget Sound, Pease (1977, 1984) observed increased numbers of crab, and various fish around net pens and mussel rafts. It is likely that shrimp numbers in the immediate vicinity of net pens will also increase.

The net-pen structures also provide a habitat in the open water environment to attract fish such as seaperch and rockfish in larger numbers than would normally be found in an open-water portion of Puget Sound. Net pens 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.

The presence of floating objects apparently provide protection from predation for small fish (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 reported associated with net pens in Puget Sound include shiner and surf perch, true cod, lingcod, dogfish, sculpins, and flatfish.

Fish and mobile invertebrates are expected to be enhanced around the periphery of net pens, unless organic deposition results in anoxic conditions in the water. This is only likely in areas of stagnant water with very poor circulation (Earll et al. 1984). In such situations, H_2S production would most likely have severe impacts on the fish held in the pens where they are unable to escape the toxic water. Consequently, the risk is somewhat self-limiting.

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 net pen directly above such a bed in shallow water could create an azoic zone immediately below the pens, 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 which are critical to specific life stages, which could be adversely affected by sedimentation.

The depths of water necessary for net pens preclude direct impacts to intertidal shellfish and fish habitats.

(3) Mitigation Measures

The presence of net pens may enhance several species, however, improperly sited or operated pens could adversely affect fish and shellfish or their habitats. Adverse impacts can be avoided by:

- Minimize sedimentation impacts as described under Mitigation Measures in Section II.A.1.
- If pens are located where sedimentation may adversely affect fish and shellfish, avoid important habitats.
- Require surveys of the proposed site to determine the presence or absence of significant habitats.
- Where adverse impacts are unavoidable, require mitigation through enhancement of the affected species at the site or in the immediate area.

(4) Unavoidable Significant Adverse Impacts

Potential adverse impacts to fish or shellfish can be avoided by proper siting and operation of the net pens. With the mitigation measures presented, no significant adverse impacts are anticipated.

b. IMPORTATION OF EXOTIC FISH SPECIES

Commercial farming of fish frequently involves the use of species which are not indigenous to the area or which have been specifically bred for use in net pens. There is a concern that Atlantic salmon would escape net pens and compete directly with native Pacific salmon populations. There are also concerns that Atlantic and Pacific salmon raised in net pens would interbreed with wild salmon stocks potentially causing a long-term genetic impact.

The objective of the mitigation measures discussed in this section is to minimize any adverse impacts to fish species indigenous to Puget Sound.

(1) Affected Environment

Net-pen 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, and 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 exotic 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 exotic species worldwide, however well meaning, 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 II.A.3. Disease). Exotic importations, thus, 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 which may be considered for culture in the future, it is impossible to examine the possible interactions with native. As an example of the possible genetic interactions and possible mitigative measures, the introduction of Atlantic salmon into Puget Sound will be evaluated.

(2) Impacts of Exotic Fish Importation

Genetic Impacts. There is a concern that Atlantic salmon raised in net pens would escape and interbreed with wild salmon stocks potentially causing a long-term genetic impact. Atlantic salmon belong to the genus Salmo. 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.

Available information indicates that Atlantic salmon introductions pose no direct genetic threat to steelhead or cutthroat trout stocks. Steelhead trout and cutthroat trout, formerly Salmo gairdneri and S. clarkii, have recently been reclassified by the American Fisheries Society. Their new names, Oncorhynchus mykiss and O. clarkii reflect fundamental differences to the genus Salmo. This reclassification is based in part on the inability of steelhead and cutthroat trout to successfully cross with other members of the genus Salmo. Under the best conditions (laboratory experiments), researchers have been unsuccessful at crossing these two groups (Lindbergh 1984; Refstie and Gjerdren 1975).

In addition, Atlantic salmon spawn several months earlier than Pacific Coast steelhead and cutthroat trout, and would not have the opportunity to attempt such hybridization (Heggberget 1988; Mahnken 1988). There are no native stocks of Atlantic salmon or other Salmo species with which the cultured stocks could interbreed.

Local experts agree that wide spread net-pen culture of Pacific salmon in Puget Sound poses a minimal threat to wild salmon populations in terms of genetic degradation (Mahnken 1988; Hershberger 1988; Waples 1988). However, because the subject is complex, a fairly detailed discussion is presented here. The issue centers around the scenario of net-pen farmed fish escaping, maturing and interbreeding with wild populations.

Different river systems generally have genetically different stocks of salmon. Because the characteristics of each river are unique, selective pressures on the populations in those

rivers have lead to genetic adaptations which 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, that important adaptive genetic traits would be diluted.

Some interbreeding of stocks occurs naturally as fish stray from one river system to another. This is the mechanism by which rivers have been naturally propagated with fish, such as 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.

The Washington Department of Fisheries considers it undesirable to interbreed indigenous wild salmon populations with stocks of grossly different genetic character. Net-pen farmed fish may or may not be grossly different from stocks in adjacent rivers. This variation could lead to a concern of 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 net-pen farm escapees inappropriate for natural conditions. For net-pen farms, there are two potential sources of fish 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 pen site. The second source might be from fish from the nearby river system that are highly inbred due to long-term genetic manipulation within a hatchery environment.

In hatcheries, individuals are actively or passively selected for many genetic traits suiting them to that environment. These traits may be deleterious or useless in the natural environment. Passive selection includes such traits as tolerance to crowding stress, disease, and 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 fish in a hatchery. In the wild, it is a necessary behavior pattern. Traits actively selected for in-breeding programs--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. It should be noted, however, that a large portion of salmon in the North Pacific are from hatchery stocks. While in the natural environment, these fish are exposed to all the environmental pressures of wild fish which will tend to select out 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 discrete (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. As such, interbreeding of two distant wild stocks could reduce the fitness of the progeny.

Another potential genetic impact 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 differential survival 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 stocks of trout (*Salmo* sp.) compared to wild stocks (Allendorf and Phelps 1980; Ryman and Stahl 1980; Stahl 1983). In some cases, this condition results in the 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 in part be due 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 only encompasses seven generations.

The degree of genetic degradation of wild populations by net-pen escapees depends on two basic factors. The first factor is the extent of genetic difference between the net-pen fish and wild fish. The second factor is the degree of interbreeding between the two groups. "Normal" hatchery fish (released into marine waters, growing to maturity in the wild) may or may not 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 outplanted into wild populations. This can result in homogeneity in genetic character of the two groups.

Net-pen 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, net-pen 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 net-pen fugitives and wild fish depends on the proportion of the two populations within a stream and the spawning times of the two groups. For the net-pen 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. Four factors affecting the number of net-pen fugitives entering any particular stream are: (1) the number of fish escaping; (2) the marine mortality rate (determining the number surviving to adulthood); (3) the success of homing these fish to the net-pen site; and (4) the proximity of the net pen 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 net-pen 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 net-pen fish transplanted from distant locations. Such fish, fugitive from net pen farms, would be expected to stray more widely and thus disperse to a greater degree than strays from locally derived stocks (Quinn 1982). It should be pointed out that wild fish stray to some degree naturally. Quinn (1982) has proposed that straying is a evolutionary alternative to homing and that the two processes are in dynamic equilibrium.

If interbreeding does occur between net-pen fish and wild fish, any detrimental genes net-pen fish contribute to the wild population would tend to disappear over time. The mechanism causing detrimental genes to disappear is differential survival. Fish carrying detrimental genes will suffer higher mortality because they are less competitive. From the time of escape on, the potential for survival of fish bred for performance in net pens would be reduced compared to regular hatchery and wild fish. Such net-pen fish would be accustomed to regular feeding of pelleted food in a predator-free environment. The degree of competitive disadvantage of these fish is not presently known however.

Hatchery trout have demonstrated lower survival 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 coming in the form of wasted reproductive effort (less fit genotypes would be lost due to natural selective pressures).

This discussion considers potential impacts of escaped fish interbreeding with wild stocks on purely theoretical grounds. Impacts associated with interbreeding between wild stock and net-pen fish is undocumented. Since potential impacts can only occur with returning, mature, escaped fish (and major escapements are rare), the numbers of fish involved are expected to be small. 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 one percent of the returning adults stray from hatchery release sites (Quinn 1988), then one million smolts fit into this category. About eight million chinook and coho smolts are intentionally released from net pens in Puget

Sound by WDF and Tribal facilities (WDF 1988). Therefore, a total of about nine million cultured smolts are released into Puget Sound annually that would produce adults available to interbreed with wild stocks. Because it is highly unlikely that escapement from net-pen farms would approach this number, it would not produce a different or a greater effect.

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.

Because Atlantic salmon will not successfully hybridize with Pacific salmon or steelhead, the potential for genetic impacts of escaped Atlantic salmon from net pens to Pacific salmon and steelhead is slight to non-existent. Assessing the potential impact of farmed Pacific salmon or steelhead on wild populations is difficult given the speculative nature of the issue. Local experts agree that significant genetic impacts of wild populations due to widespread net-pen farming in Puget Sound is unlikely (Seidel 1988; Mahnken 1988; Herschberger 1988). The most likely scenario for an impact would be where large numbers of genetically different 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 escaped fish, these maladaptive genes would disappear gradually due to selective pressure, making any impacts temporary. Compared with the large numbers of hatchery releases, the genetic impact of escaped farmed fish on wild stocks would be negligible.

Impacts to Native Fish Populations. While the introduction of new or exotic 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 to provide increase sport and commercial fishing opportunities; to replace native stocks which have been decimated by disease, environmental changes, and over harvest; for pest control; 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, Pacific (Japanese) oysters which are 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.

The introduction of an exotic species into a new area always poses unavoidable risks. These risks can be minimized; however, 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 salmon net pen culture. Pacific salmon from Washington state are being

farmed in eastern Canada, Chile, New Zealand, and Japan. Atlantic salmon, which are the basis for this industry, are now grown in the northeast Pacific.

The potential for impacts from introducing Atlantic salmon to Puget Sound depend on two variables: (1) that significant numbers of fish escape from the net-pen facilities, and (2) the ability of fugitive fish to out compete resident stocks of salmon and steelhead. The numbers of salmon escaping from existing net pens in Puget Sound is unknown. However, several hundred fish were captured in the commercial fisheries in 1988. 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 net-pen engineering is developed to the point where catastrophic structural failure is rare. There are, however, uncontrollable events, such as ships straying from shipping lanes or perhaps a 1000-year storm event, which may break up net pens. However, net-pen facilities 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 when they are introduced into the pens. 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 the Puget Sound vicinity (DNR 1987). Additional freshwater hatcheries produce smolts used to stock these net-pen operations. All culture operations have the potential to make inadvertent releases. Theoretically these releases could establish a wild population of Atlantic salmon in Washington.

In the past, the Washington State Departments of Fisheries (WDF) and Wildlife (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 yrs. there have been over 3000 incidences of escapement from the National Marine Fisheries Service (NMFS) net-pen facilities at Clam Bay in Puget Sound. The escaped fish were sea-conditioned Atlantic salmon weighing between 1/2 lb. and 13 lb. (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 ranged in size from 4 to 12 lbs. and indicate that Atlantic salmon are indeed escaping from netpens and surviving in the wild. Occasional Atlantic salmon have also been observed in the Nooksak, Skagit, and Nisqually Rivers and are being monitored by the Departments of Fisheries and Wildlife, and by 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).

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 (*Salmo gairdneri* [now *Oncorhynchus mykiss*]) effectively. Lindbergh (1984) interviewed a number of researchers with WDF, 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 for continual restocking by the various natural resource agencies.

(3) Mitigation Measures

While the current culture of Atlantic and Pacific salmon appears to have little potential to significantly affect the genetic viability of native stocks, or to successfully compete with these stocks, future introductions of new species may pose potential threats. To minimize or prevent such threats, several measures can be taken:

- Review each application for the transfer or import of fish for culture and deny applications that pose a probable risk of adversely affecting native fish stocks or other aquatic organisms.
- Where indigenous species are cultured, use stocks approved by WDF which would have greatest similarity to local stocks near culture area or which would have least chance of interbreeding (for example, fish which do not spawn at the same time as the local stocks).
- Establish operational requirements for net pens, such as mesh size of smolt pens, to minimize risk of escape.
- Encourage commercial, sport, and tribal fisheries to harvest escaped fish, and/or permit farm operator to conduct a targeted fishery for escaped fish in the immediate vicinity of his pens.
- Where necessary, establish minimum distances net pens should be sited away from streams with wild populations vulnerable to genetic degradation.
- Where significant risk of interbreeding or establishment of deleterious self-sustaining populations exist, only permit the culture of sterile or mono-sexual individuals.

(4) Unavoidable Adverse Impacts

Some escapement of farmed fish is inevitable despite all practical efforts to contain them. While current culture activities do not appear to pose a significant risk to native species, future proposals may. It is impossible to predict what species may be proposed for future culture and decisions about these must be made on a case-by-case basis at that time.

c. DISEASE

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

The objective of the mitigation measures discussed in this section is to prevent any adverse impacts to aquatic organisms through the importation of harmful pathogens, and transfer of diseases from farmed fish to wild fish and shellfish near the net pens.

(1) Affected Environment

Infectious Fish and Shellfish Diseases. Net-pen 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 seawater net pens in Washington state. Past research on diseases of salmonids has emphasized conditions occurring during their freshwater phase of development. With the increase in seawater aquaculture, infectious diseases of salmon from net pens 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.

Introduction of Exotic Pathogens. Some fish diseases are restricted in their geographic distribution since the affected fish are limited to living in certain areas. Thus, a risk of introducing exotic fish pathogens (that is, those which 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 not known. 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 net-pen reared fish has led to the discovery of previously undescribed diseases. Research on fish diseases has previously been directed towards those diseases occurring in freshwater because the major fish culture operations were freshwater hatcheries. Observations of new diseases in seawater net pens are indications that they occur naturally in wild salmon during their seawater phase of development, as 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. A specific concern in North America are Atlantic salmon eggs imported from Europe and the potential risk of introducing viral hemorrhagic septicemia disease (VHSD). This viral disease may be transmitted vertically from the adult brood fish to eggs and fry. The virus can infect the egg while the egg is still in the mother and be passed to the offspring. Although the virus causes severe disease in salmonids in Europe, it has not been detected in North America.

Washington state importation laws (WAC 220-77), administered by the Washington Department of Fisheries, and federal statutes protecting fish (Title 50 of the U.S. Code of Federal Regulations, part 16.13), administered by the U. S. Fish and Wildlife Service (U.S. Department of the Interior) require certification that all salmon eggs not contain this virus or other significant fish pathogens before fish can be 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. These federal and state regulations have been successful to date in preventing the introduction of exotic fish diseases such as VHSD.

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 net pens. Wild salmon and non-salmonid fish can be reservoirs for ectoparasitic sea lice (Copepoda) of pen-reared salmon; and 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 state resources.

There are, however, examples of diseases that 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 (Dogel and Lutta 1937; Dogel 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. Meyers (1979) demonstrated that viruses pathogenic for freshwater fish were isolated from oysters from Long Island Sound, New York. Although oysters are known to concentrate certain chemicals, there is no evidence this ability is a mechanism for disease transmission to wild fish and shellfish.

Many reports indicate that vibriosis is a significant disease of 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 percent of oysters in a sample 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. tubiashii (Hada et al. 1984), is recognized as a bivalve mollusc pathogen at certain locations in Europe and the east coast of 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.

(2) Impacts of Diseases

Introduction of Exotic Pathogens. A primary concern with the growth of the net-pen 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. One such pathogen, viral hemorrhagic septicemia (VHS), develops during the salmon's freshwater phase. All eggs imported into Washington must be certified free of VHS. Fry from these eggs are then maintained in quarantine for 90 days and, at the discretion of the WDF, any exhibiting abnormal mortality are subject to further examination. If no exotic pathogens appear during this quarantine period, the fry may be released from quarantine for eventual stocking into net pens.

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 Washington Department of Fisheries. 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.

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 the Washington Department of Fisheries. In addition, salmonid eggs imported from foreign sources must be individually permitted and inspected by an agent of the U.S. Fish and Wildlife Service under Title 50 of the U.S. Code of Federal Regulations.

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 the Washington Department of Fisheries and the U.S. Fish and Wildlife Service if increased requests for importations are made. However, a higher level of Puget Sound net-pen production has already increased the financial incentive to maintain regional broodstock and egg production. This should reduce the number of salmon egg importations and the associated risk of disease introductions.

Transmission of Disease To Wild Fish. Review of the technical literature indicates the risk of transmission of disease from net pens to wild fish is possible but not likely a significant problem. Fish disease control regulations, cited above, are in place in Washington to prevent the importation of exotic infectious diseases. It is such 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 greater risk from the transmission of infectious diseases than wild stocks. Diseases observed in net-pen 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 may, in fact, be greater from the large numbers of hatchery fish released into state waters, than from the relatively small numbers of captive fish in net pens.

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 net pen 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 the east coast of 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.

(3) Mitigation Measures

The risk of introducing exotic salmon pathogens could be reduced further by the following measures:

- Legal measures could be implemented to eliminate imported salmon eggs from other continents. However, the current system of certifying salmon eggs has been effective in preventing the introduction of exotic diseases such as viral hemorrhagic septicemia.
- Development of enough regional brood stock to support the salmon net pen 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.
- Future introductions of fish to Washington waters could continue to be made from disease-free stocks by using the regulatory framework now in place.

- One of the most important mitigation measures would be educational efforts by regulatory agencies for the fish farming industry. Voluntary compliance with fish disease control regulations is the most effective insurance that regulations will be followed. Educational efforts will increase the level of awareness in the industry of the potentially damaging effects of infectious fish diseases.
- Technical certification procedures could be periodically revised as appropriate to incorporate new technology.
- A requirement for the reporting of fish disease outbreaks could contribute to the control of diseases. The diseases subject to reporting could be determined by representatives from government, academia, private institutions, and the fish farming industry.

(4) Unavoidable Adverse Impacts

Adverse impacts can be mitigated through the measures identified above and through the fish disease control regulations now in place.

4. MARINE MAMMALS AND BIRDS

There are two issues of concern regarding the relationship between wildlife and salmon net-pen facilities. 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 net pens sited near sensitive wildlife habitats.

The objective of the mitigation measures identified below is to prevent adverse impacts to marine mammals, birds, and other wildlife, especially those classified as threatened or endangered.

The following information and analysis is based on communications with people experienced in net-pen culture and resource managers familiar with marine bird and mammal habitats.

a. Affected Environment

Animal Depredation. The presence of captive fish and a floating habitat usually attracts predatory birds and marine mammals to net-pen facilities. 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, net-pen operators have developed methods to discourage or prevent depredation by birds and marine mammals.

The severity of the problem to the fish farmer 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.

The Recommended Interim Guidelines suggest that net-pen operators locate their pens at least 1500 feet (458 m) from bird and mammal habitats of special significance such as haulout areas (See Figure 12) to reduce potential conflicts.

The interim guidelines also recommend using non-lethal techniques to protect net-pen fish from predators. Predator control methods must follow federal and state rules, and net-pen operators must possess all necessary permits.

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 preventative 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 salmon net pen operations in Washington. These are the harbor seal, California sea lion, northern sea lion, and river otter.

Seals and sea lions rest or haul out on shorelines and floating objects such as log rafts. 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 occur 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.

In 1972 Congress enacted the Marine Mammal Protection Act which prohibits 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). Any lethal control may only be taken with permission of the National Marine Fisheries Service. Since implementation of the Marine Mammal Protection Act, seal and sea lion populations in Puget Sound and other Washington bays have increased in size and range. The Department of Wildlife estimates that the harbor seal population in Puget Sound is increasing at the rate of 8 percent annually.

River otters are found primarily in quiet shoreline areas containing freshwater streams (EPA 1987). Otters can be found in appropriate habitats throughout southern Puget



Updated: Jeffries (WDW) 1988
 Source: Puget Sound Water Quality
 Authority 1986

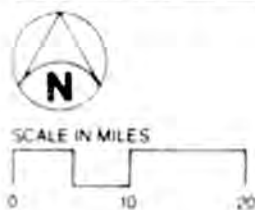


Figure 12.
Seal and Sea Lion
Haulouts in Puget Sound

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 net-pen facilities. 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.

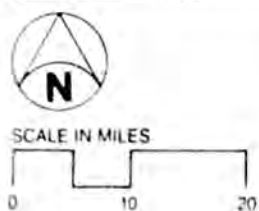
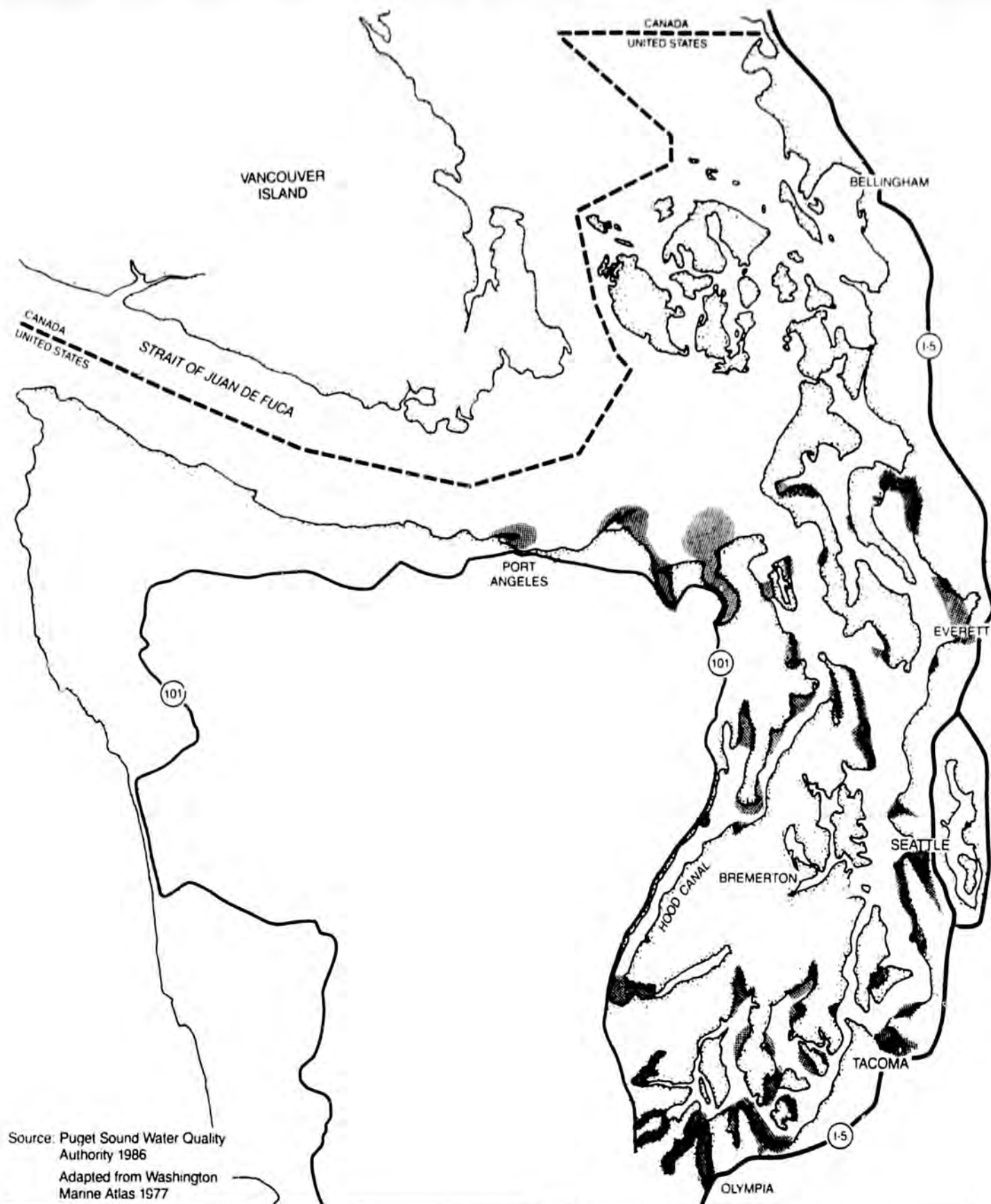
Harbor seals and sea lions may damage and kill fish by biting through the netting of the rearing pens. Occasionally the attacks damage the netting, which in addition to predation, may allow large numbers of valuable fish to escape. Observers often do not distinguish between California and northern sea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

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

Predation by birds is not a significant problem at most net-pen facilities due to the use of anti-predator nets, strings placed in parallel over the pens, and the normal level of human activity associated with net-pen operation. Birds are only a problem while small fish are available. Once net-pen fish have grown too large for birds to eat, there is little need for netting over the pens. Some net-pen farmers use dogs to chase birds off the pens.

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

The U.S. Fish and Wildlife Service (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.



 Waterfowl Area

Figure 13.
Major Waterfowl Habitats
in Puget Sound

Predator Control Methods. Surrounding the growing pens with protective nets is the primary predator control method at Washington net-pen facilities. 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 three to nine feet 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 net-pen facilities 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 net pens, driving the anti-predator and pen net together and biting through the nets.

Net-pen 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. These AHDs have been used extensively to attempt to control predation near the Ballard Locks in Seattle 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 net-pen farmers have also used AHDs. Marine mammals sometimes evade the noise by approaching the pens with their heads out of water, or approaching within the acoustic shadow formed by the pens (Boldt 1988). Resource agencies and net-pen 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 net-pen farmer, but has showed limited success in predator control (Forster 1988; Lindbergh 1988). No Washington net-pen facilities use lithium chloride for predator control (Gibson 1989).

The Marine Mammal Protection Act provides a permit system that allows harassment or selected killing of certain marine mammals that threaten aquaculture facilities. Non-lethal methods must be tried before lethal methods. The National Marine Fisheries Service (NMFS) has jurisdiction over marine mammal protection, with support from the Washington Department of Wildlife (WDW). NMFS has enforcement authority to fine or incarcerate offenders (Scordino 1988).

Sensitive Wildlife Species and Habitats. The USFWS, NMFS, and the WDW maintain data bases 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.

Peregrine falcons and bald eagles are protected by the Endangered Species Act. Neither of these species is a threat to net-pen fish, but both may be affected by net pen siting decisions. USFWS has jurisdiction over federal permits for developments that may affect these birds. While USFWS has not issued permits for activities related to net pens in Washington, they do review Army Corps of Engineers permits and may attach conditions to the permit as necessary. When no federal permit is required for a development, WDW 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 between development activity and eagle and roost sites.

b. Impacts on Wildlife

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

Net-pen operations 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 facility 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.

c. Mitigation Measures

The following mitigation measures could be implemented to reduce the potential impacts of proposed net-pen facilities on wildlife:

- Identify all sensitive wildlife habitats and areas where animals congregate.
- Consult with appropriate resource agencies to determine potential predator problems and effective prevention techniques.

- In reviewing and approving projects, develop buffers separating net-pen facilities from habitats of special significance.
- During the siting process, develop site-specific distance standards separating net-pen proposals from habitats of special significance to account for local conditions.
- Install properly designed anti-predator nets before placing fish in the net pens, and keep the nets taut.
- Follow established federal and state guidelines and permitting procedures for controlling predators.

The proximity of feeding or breeding grounds, or other significant wildlife habitat, should be considered when siting a net-pen facility. Net pens should not be located near wildlife habitats of special significance. These include seal and sea lion haulout and resting areas, seabird nesting sites or colonies, and areas specifically identified as critical for feeding or migration of birds or mammals.

The Department of Ecology, with the Departments of Fisheries, Natural Resources and Agriculture, recommended interim guidelines to reduce potential conflicts between wildlife and net-pen facilities. These guidelines recommend that operators locate net pens at least 1500 feet (457 m) from bird and mammal habitats of special significance where the pens are incompatible with these habitats. Depending upon the characteristics of the site and the nature of the net-pen proposal, this separation may be increased or reduced as appropriate. Particularly sensitive features may require more than 1500 feet (457 m) as a buffer, while other features may require less.

Farmers could minimize problems with predatory animals by siting facilities away from areas where these animals congregate. During the proposal stage, operators should demonstrate they have consulted with appropriate resource agencies, determined the potential for predator problems, and evaluated preventive control measures.

All net-pen farmers should be encouraged to install anti-predator nets before beginning operation. The anti-predator net should be separated from the pen net by at least three feet (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 feet (0.9 to 2.7 m) below the bottom of the pen 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 five inches (12.7 cm) to avoid accidental entrapment of animals. Perimeter fencing on the pens would prevent resting and haulout of seals and sea lions on the pens. A seven-inch (17.8 cm) stretch mesh net, or parallel strings over the top of the net pen would stop birds from entering from above.

d. Unavoidable Adverse Impacts

Properly sited and operated net pens will not have significant adverse impacts on marine mammals or birds. Some habitat loss may occur for some species, while other species may benefit. Specific impacts will depend on the pen site and the associated wildlife.

B. THE BUILT ENVIRONMENT

1. AESTHETICS

The issue of aesthetics (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.

Net pens are commonly placed in open water where no man-made structures exist. The above-water portion of these pens alters views from adjacent vessels or boats moving through the area and may alter views from nearby land areas. Many people perceive any structure placed in open water as creating an adverse aesthetic impact.

The objective of the various possible mitigation measures discussed below is to minimize visual impacts that may reduce the aesthetic value of the area surrounding the net pen facility.

a. Affected Environment

Puget Sound and adjacent waters, where net pens 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 appear as rows of green-sloped mountains with craggy and snow-covered peaks forming a jagged skyline.

The nature of 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 monotonous and static on cloudy, calm days or dynamic and high-lighted 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. This activity 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 aesthetically unusual or distinctive. An example of an aesthetically unusual location is Dungeness Spit. In its 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 aesthetically unique.

Other locations may be aesthetically 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 PEIS does not attempt to identify unique or aesthetically distinctive views. These must be identified by shoreline regulators wherever any such views exist. This analysis discusses potential effects on these views from net pens and possible mitigation for impacts.

b. Impacts on Aesthetics

Aesthetic 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 salmon net pens that may affect views, how these features may be perceived, and how alternatives may affect views.

Background. Aesthetic impacts from floating net pens 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.

Net pens have floats and railings that typically extend about 1 m (39 inches) above the water. They also commonly include a small building extending about 3 m (10 ft) above the water (See Section I. B. Background and Figure 3).

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

Net-pen structures become less evident as the observer/facility distance increases. Typical net-pen facilities at distances greater than 450 - 600 m (1500 - 2000 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 net-pen facility, 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, net pens 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 net pens vary significantly for different observers. Some observers consider a net-pen facility to be an aesthetic intrusion, while others consider the same facility to be a neutral or interesting part of the visual environment. Some observers find net-pen facilities interesting and attractive in a manner similar to a fish hatchery.

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

Description of Impacts. The aesthetic impact of net pens depends on the distance between the observer and the pens, on the altitude of the observer, and on the surrounding views. In general, only viewers within about 2000 ft (600 m) are likely to see the net pens as anything more than a thin line on the horizon. Only viewers in the immediate vicinity of the net pens will have their scene substantially altered by the presence of the net pens.

The relationship between the location of the observer and the distance of the facility from shore affects visual impacts. In general, views from residences on the shoreline are primarily oriented toward the water. Figure 16 is a schematic representation of the impacts associated with the placement of a net pen relative to the shoreline. Situation A of Figure 16 places the net pen 300 feet from shore. While the facility will be visible for 4,434 ft (1351 m) along the shoreline, it will not be a major visual impact to the observer in the example. However, when the net pen is moved 1000 ft (305 m) from the shoreline as in situation B, it falls within the predominant viewscape of the observer.

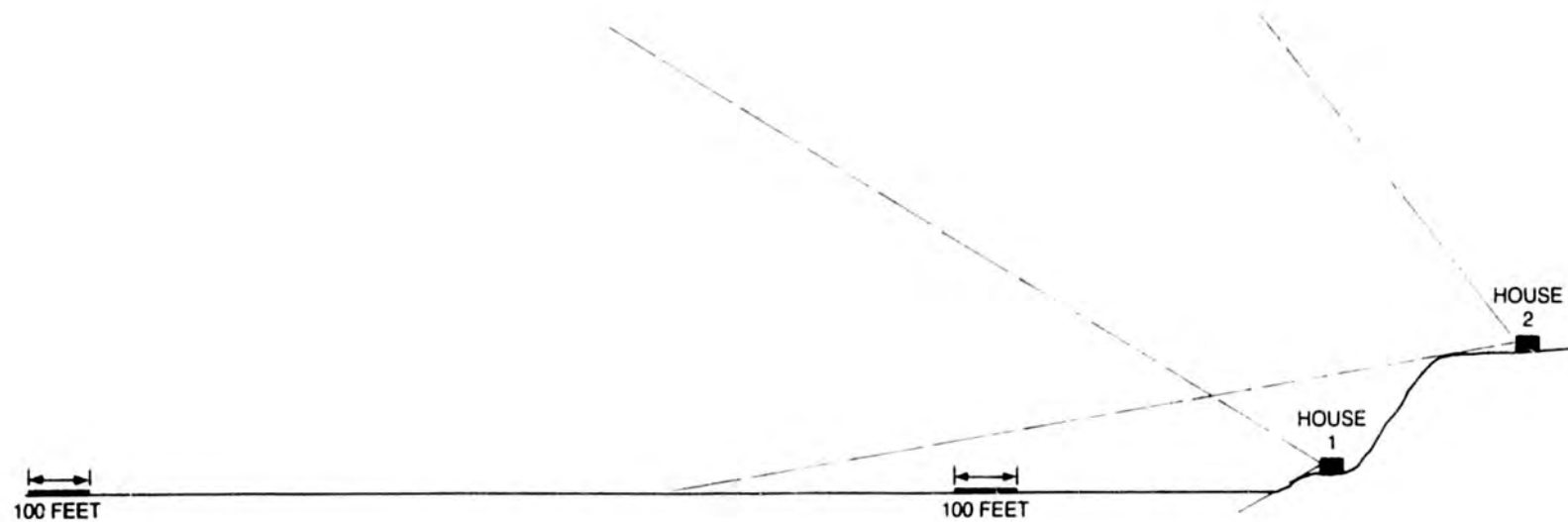
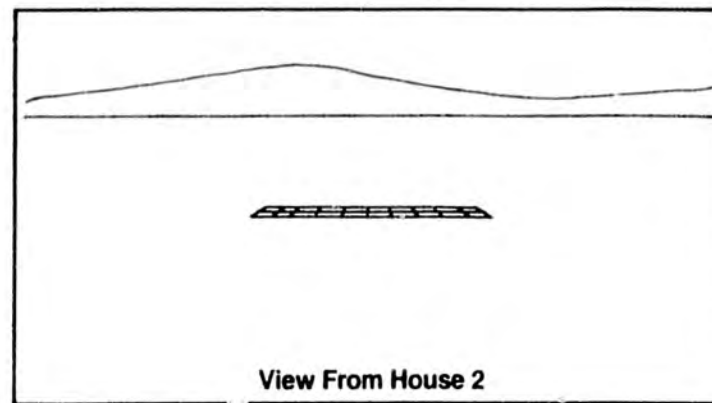
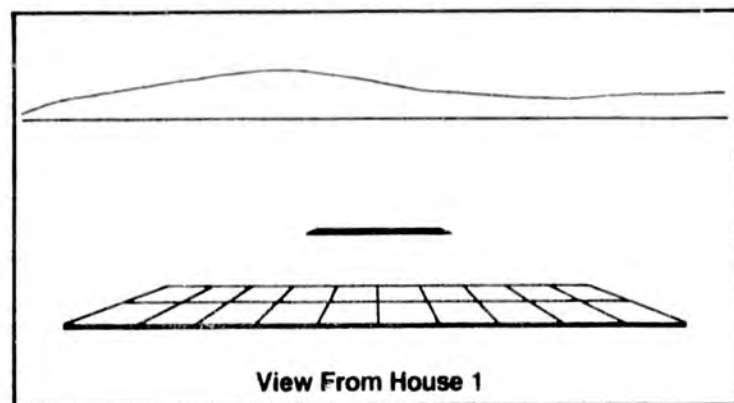
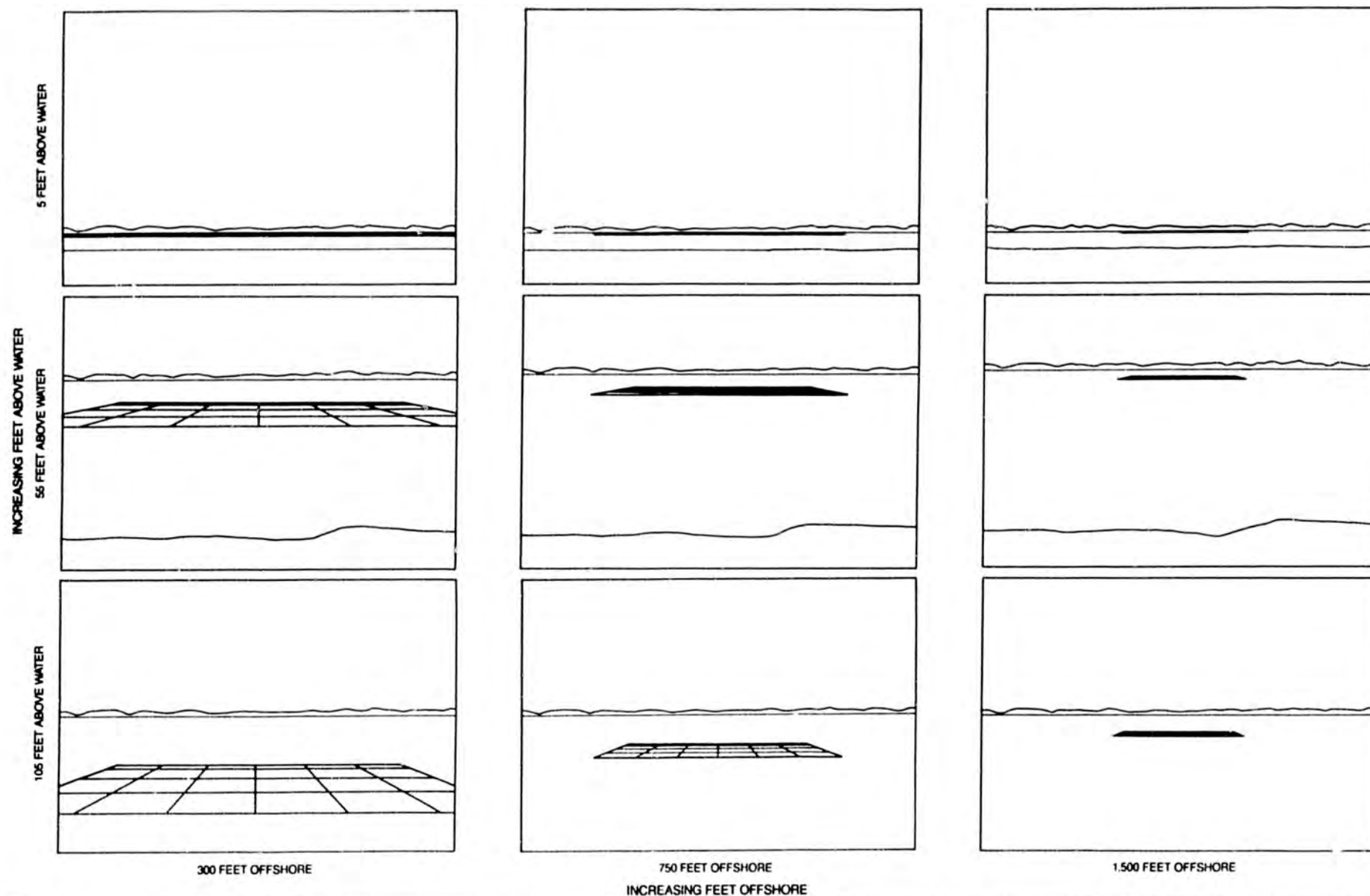


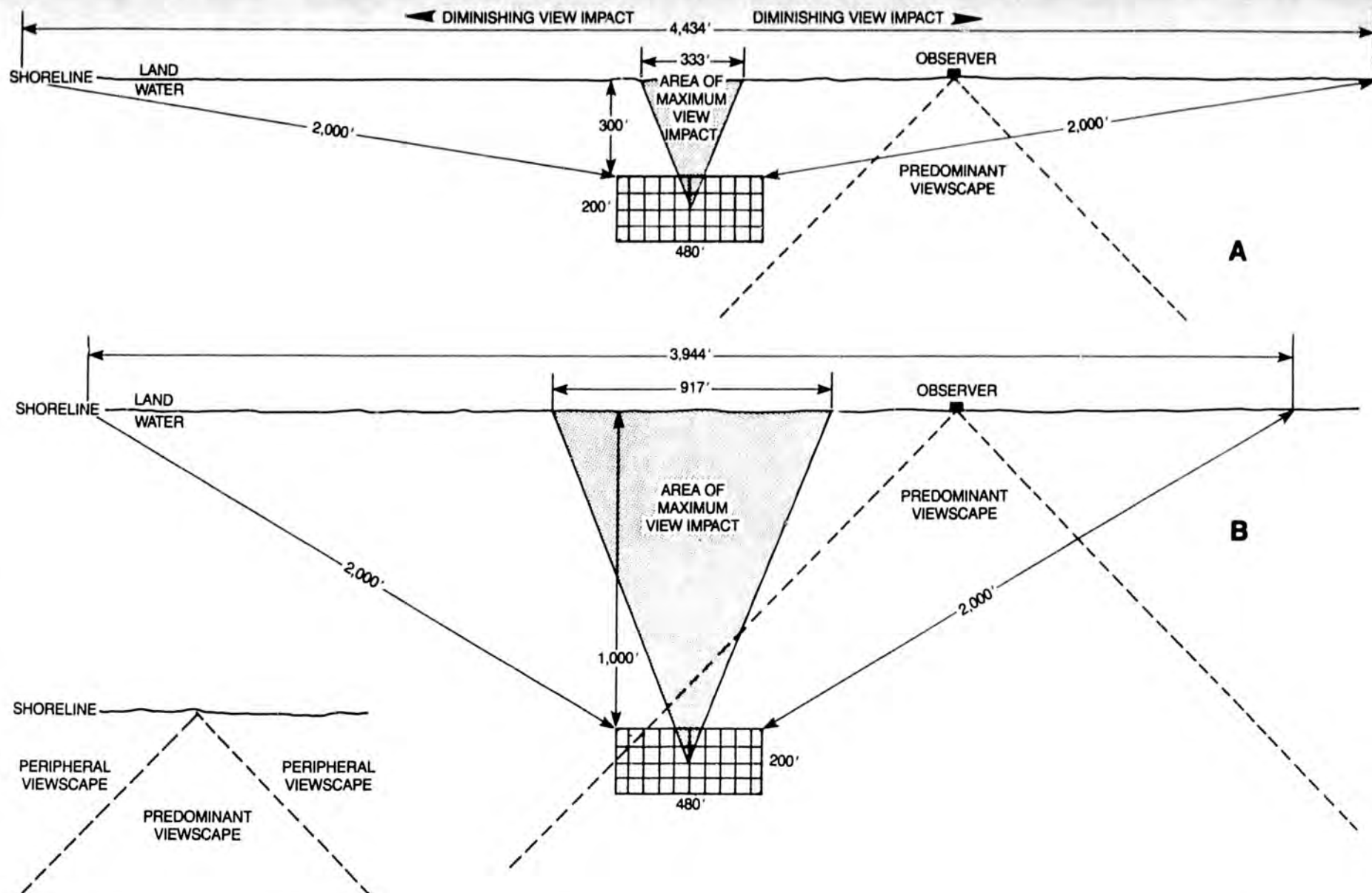
Figure 14.
Topography of the Shoreline
and Views of Net Pen Facilities



Source: EDAA, 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.

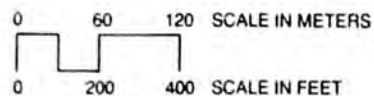


Figure 16.
Schematic Example of
View Impacts Related to
Distance and Orientation
of Net-Pens

Yet, now, the facility in situation B is visible from only 3,944 ft (1202 m) of the shoreline. This hypothetical example is included to indicate that placing a net pen as far from shore as possible is not always the most effective way to minimize aesthetic impacts. Because the orientation and location of views will vary from case to case, each net-pen proposal should be evaluated separately to determine the effect of distance and orientation on views.

Figure 17 illustrates the horizontal angle of view occupied by a net pen depending on its orientation and the position of the observer. There are a variety of pen configurations; however, a net-pen facility (200 feet by 480 feet [61 m by 146m]) at a distance of 300 feet (91 m) from shore is used as an example. For observers on the shore immediately in front of the net pen, 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 net-pen orientation with the long dimension perpendicular to shore begins to have the greater visual impact, although, at these distances, the visual impact in either case would probably not be substantial. Although the net pen would occupy a definite horizontal angle in the field of view of an observer at water level, at distances approaching or exceeding 2000 feet (610 m), the net pens would tend to merge with the water line and be nearly indiscernible to the observer.

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

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

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

Figure 18 illustrates a hypothetical placement of five net pens in a typical Puget Sound embayment using the upper end of Carr Inlet as an example. A 2000-foot (610 m)

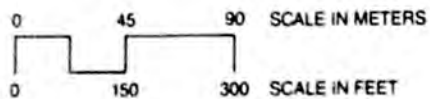
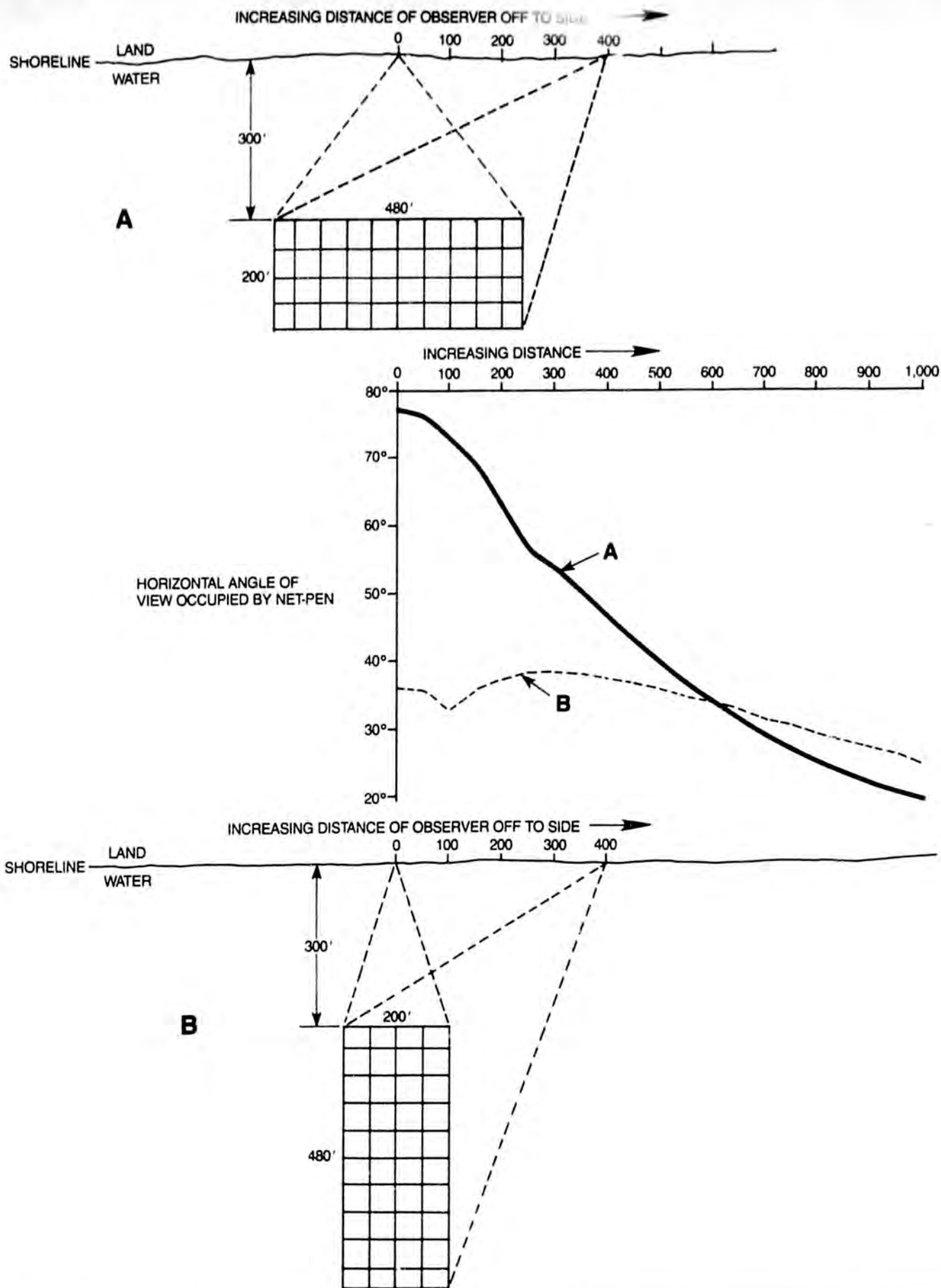


Figure 17.
Effect of Net-Pen
Orientation and Observer
Distance on Visual Impact

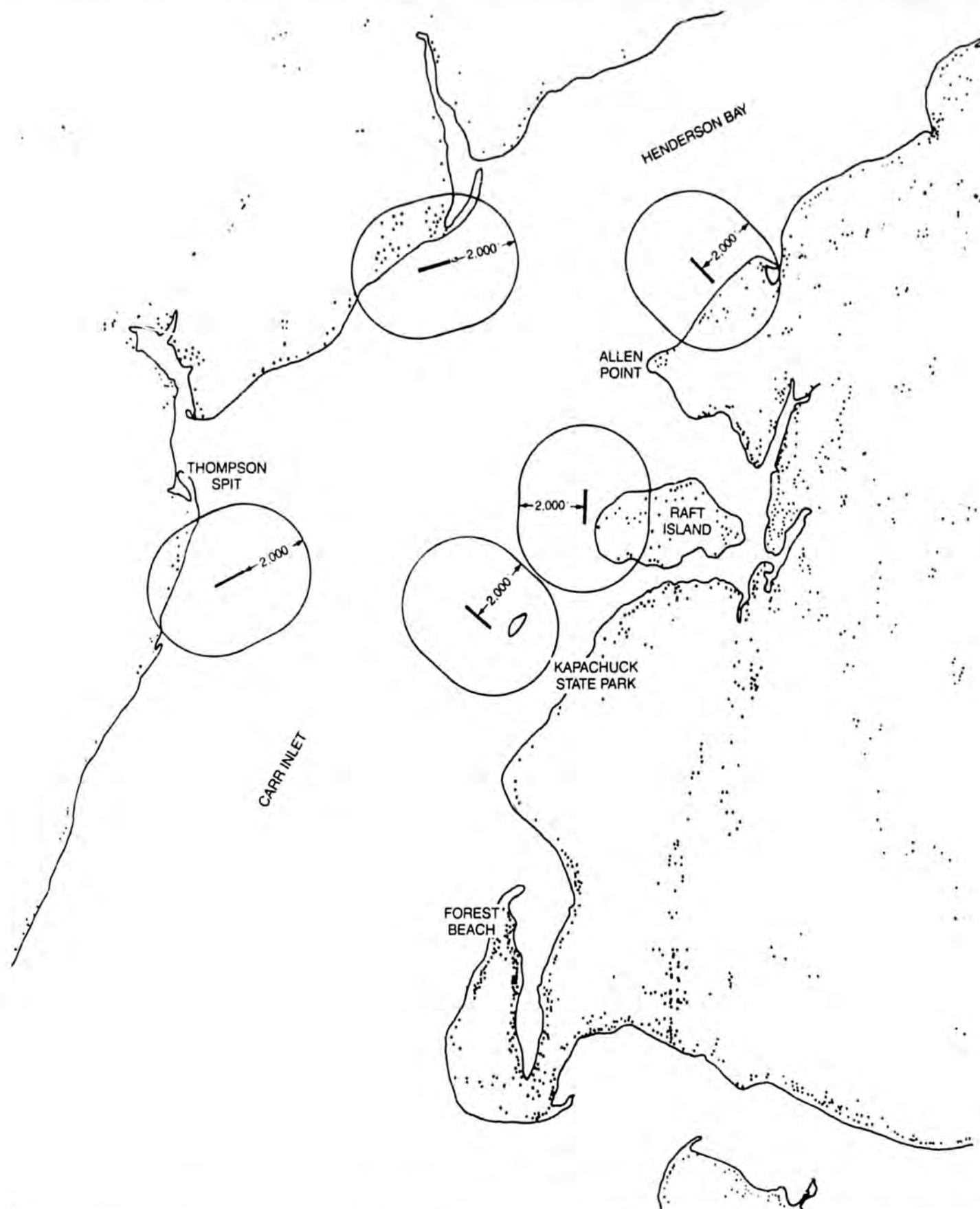


Figure 18.
Hypothetical Layout of Five
Net-Pens in a Puget Sound
Embayment: Carr Inlet Sample

radius is drawn around each net pen to illustrate the probable maximum extent of visual impact. This figure illustrates that at a density of more than five net pens per embayment, the net pens could be spaced so that no shore observer is within 2,000 feet (610 m) of more than one net pen at any time. This indicates that with adequate spacing of pens, the cumulative impact of several net pens in an embayment could be minimal. In other situations where there are few aesthetically sensitive observers, it may be appropriate to more closely space pens to avoid placing net pens in areas having more observers.

The cumulative effect of multiple pens sited closely together would be another potential impact on aesthetics. Figures 19, 20, and 21 illustrate how net-pen density could be controlled through spacing of pens. Similar measures could be adopted into local shoreline master programs.

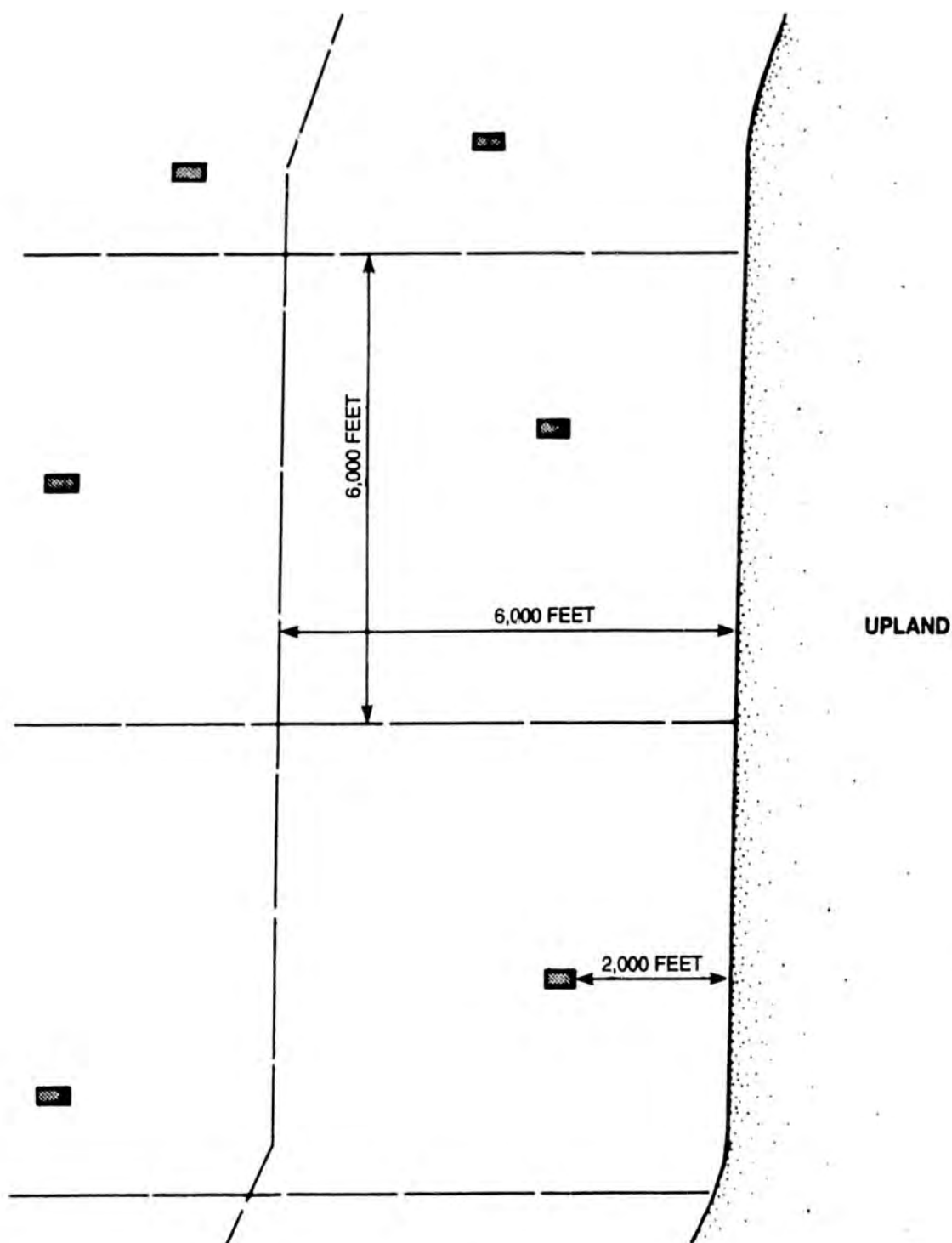
c. Mitigation Measures

Mitigation measures for aesthetic impacts can modify either the design or location of net-pen facilities.

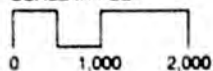
Design. The design of net-pen structures may serve to either increase their visibility or to visually submerge them in their surroundings. Increasing visibility, which could, for example, serve as an architectural statement, could be appropriate in some urbanized areas. In many areas, however, net-pen structures should be designed to be visually unobtrusive. The following items describe some design measures that serve to help visually submerge a net-pen structure.

- Structures should project the minimum distance above the water surface necessary for safe and efficient operation of the facility.
- Net-pen facilities could consist of small sets of pens grouped together instead of a large pen complex to avoid extensive visual elements.
- Materials used in net-pen structures should be non-reflective, somber-hued, and gray, green, or blue in color.
- Lighting provided on the structure should be the minimum necessary for safe operation and navigation and directed away from land areas, if possible.
- Equipment used in the net-pen operation and not a functional part of the net-pen structure should be stored on land.
- The number and size of buildings on the floats should be kept to a minimum.

Location. The distance between net pens and adjacent shorelines can mitigate the aesthetic impacts on views, but may increase conflicts with navigational use and

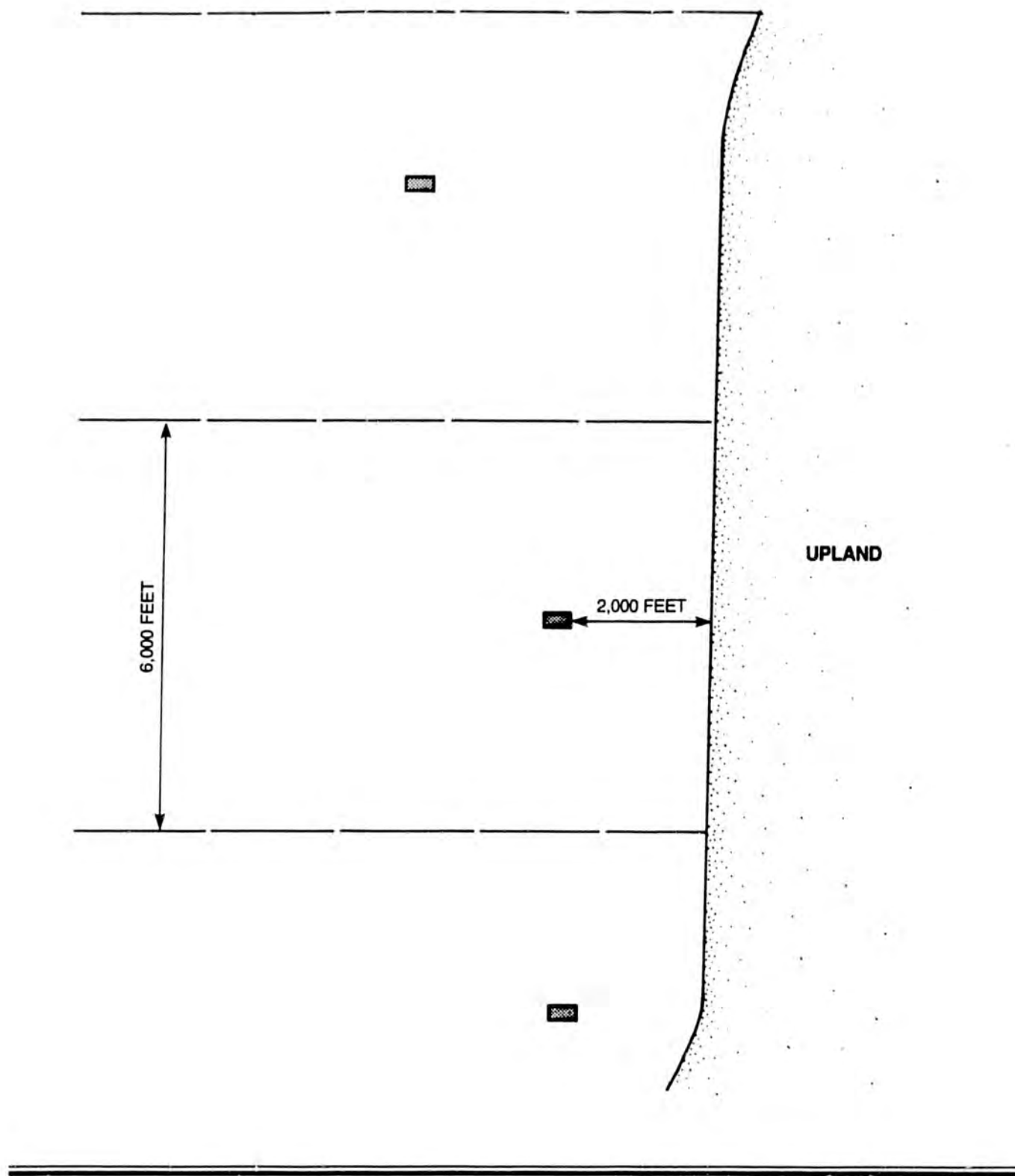


SCALE IN FEET



Two Acres
of Net Pens

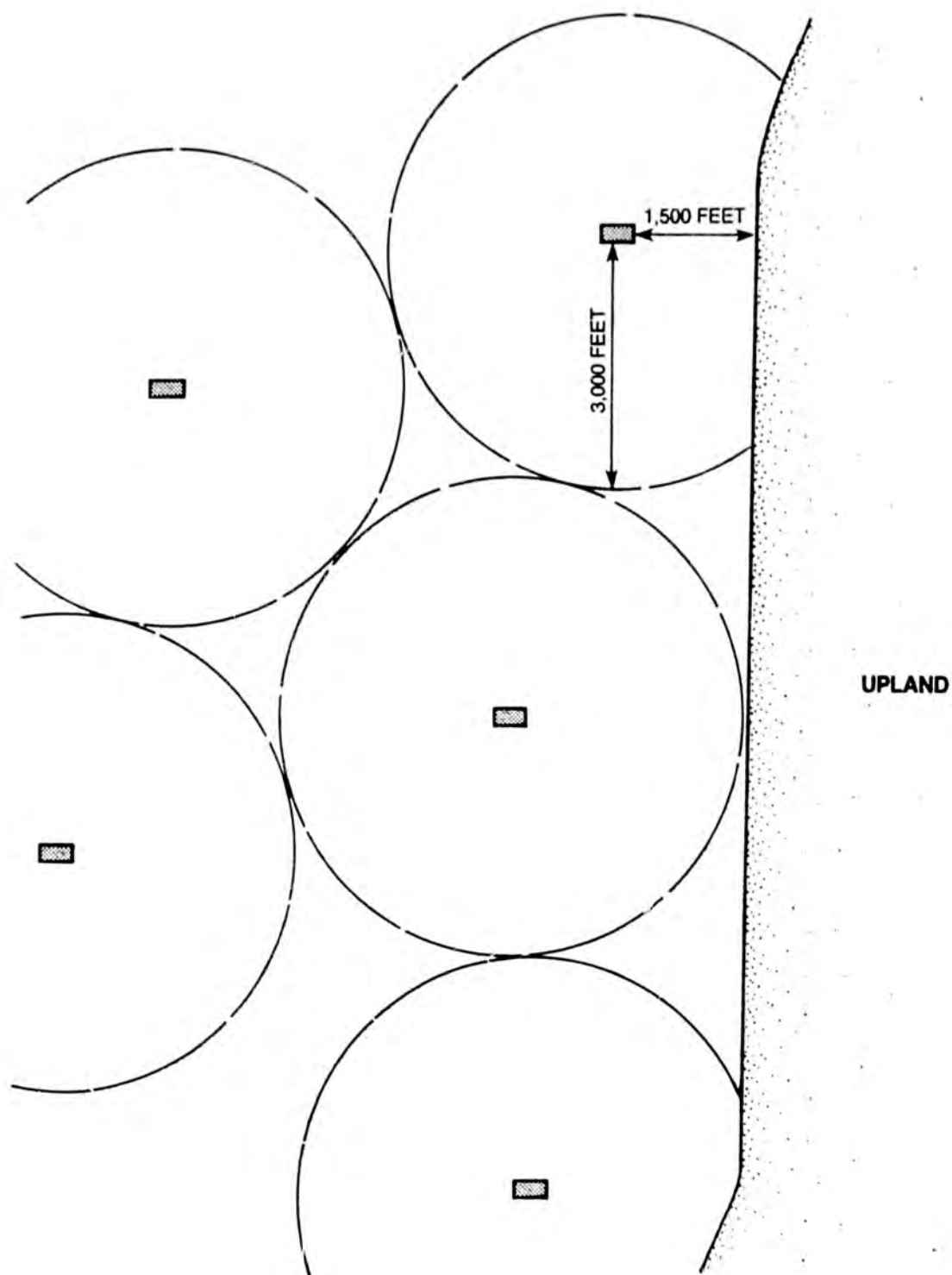
Figure 19.
Net-Pen Density Control,
Area by Square Footage



SCALE IN FEET
0 1,000 2,000

 Two Acres
of Net Pens

Figure 20.
Net-Pen Density Control,
Area by Shoreline Footage



SCALE IN FEET
0 1,000 2,000

Two Acres
of Net Pens

Figure 21.
Net-Pen Density Control,
Area by Radius

commercial fishing. Where low-level shorelines are nearby, the net pens can be sited 600 m (2000 ft) or more away to minimize visual detection of the pens. In areas of high shoreline bluffs, the visual impacts may be minimized by placing the pens close to the shorelines where they can only be seen from the edge of the bluff.

Implementation. Mitigation described in the preceding paragraphs would be applicable to most net-pen proposals. Ideally, an aesthetic analysis taking account of each site's particularities should be prepared for each proposed net-pen facility.

One method of aesthetic analysis is set forth in the Aquaculture Siting Study (EDAW and CH2M Hill 1986). This 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 aesthetic 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.

As an alternative, design and location guidelines could include the requirement that applications for aquaculture facilities include an aesthetic analysis describing the proposal's compliance with those guidelines. Without prescribing the nature of the aesthetic analysis, this requirement would not be particularly rigid and it could be adapted to the needs of each local jurisdiction.

d. Unavoidable Adverse Impacts

Despite application of mitigation measures discussed in earlier paragraphs, some adverse aesthetic impact would occur as a result of locating net pens in Puget Sound and surrounding waters.

2. NAVIGATION

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

The objective of the various mitigation measures discussed in this section are to minimize interference by the net-pen structures with normal, safe navigational use of the surrounding waters by commercial and recreational vessels.

a. Affected Environment

The waters of Puget Sound comprise roughly 6500 km² (2500 sq mi) 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 II.B.8, Recreation).

Presently, siting decisions for net-pen proposals are made on a case-by-case basis. The U.S. Coast Guard (USCG) has the responsibility for reviewing all proposed structures in Puget Sound for potential navigation hazards through the Army Corps of Engineers permitting process. Any structure that may interfere with navigation must receive permission from the Corps (Section 10 permit). The impacts of a structure on navigation are considered by local government as part of the permitting process under the Shoreline Management Act. In addition, the Washington State Parks and Recreation Commission reviews applications for proposed net pens. This review specifically evaluates the potential navigation hazard to recreational boaters visiting Washington marine parks.

The Coast Guard 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 net pens to install private aids to navigation to reduce the potential for collision. 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.

b. Impacts on Navigation

A group of floating net pens, like an island or dock, is a fixed object in the water. Net pens 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 net pens break loose from their anchors during severe weather conditions they could become a hazard to vessel traffic. If net pens 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 a net-pen facility 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.

Pens located near shore would affect navigation in a manner similar to a long dock, a marina, or a series of anchored boats. Commercial traffic will tend to stay in deeper water, thus avoiding such areas and boaters must always be wary of anchored vessels near shore. The further offshore the structure 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.

Net pens may also have a beneficial impact on navigation. In more remote areas, typical of recently permitted pen sites, net-pen facilities can provide a point of assistance/refuge for boaters. The net-pen sites are usually staffed 24 hours a day and have some form of sea-to-land communication.

c. Mitigation Measures

In addition to the existing Coast Guard review, the following measures could be implemented to reduce potential impacts to navigation.

- Encourage consultation with major recreational and commercial boating organizations during the siting evaluation process to identify areas of special importance to boaters.
- Avoid placing net pens in established navigation areas.
- Notify all marinas and ports near the net-pen facility, recreational boating groups, and commercial shipping associations of the precise location of net pens and their aids to navigation.
- Using site-specific conditions, establish a distance around net pens that would provide adequate clearance for navigation.

- Where necessary, require navigation lights on all four sides of net pen facilities as a minimum number necessary for safety.
- Use highly visible colors in the design of the facility.
- Assure that bonding is established to facilitate rapid clean up of net pens broken loose by severe storms.
- Site pens close to shore.
- Place pens adjacent to existing structures.
- Consolidate farms into areas of limited navigational use.

Mitigation measures that make net pens more visible and reduce potential navigation impacts (such as bright colors and numerous aids to navigation lights) may increase aesthetic impacts.

d. Unavoidable Adverse Impacts

Siting net pens in Puget Sound would create some unavoidable adverse impacts to navigation by the addition of new stationary objects in the water that boats would have to navigate around.

3. COMMERCIAL FISHING

Since net pens occupy space in the water, there is the potential for commercial and tribal fishing boats to run into or have their nets become entangled with net pen facilities. The resulting displacement of fishers from accustomed fishing areas is then 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 objective of the mitigation measures discussed in this section is to minimize any impacts on the opportunities for commercial fishers to successfully harvest wild fish and shellfish from waters near net-pen operations. A further objective of the mitigation measures in this section is to prevent disruptions of the equitable allocation of fish between fishing groups and between tribal and non-tribal fisheries as directed by federal court orders.

a. Affected Environment

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 1200 licensed boats in 1986 that harvested 19 million pounds. Table 3 lists the number of licenses issued to various segments of the Puget Sound commercial fishing industry in 1986.

Management of fishery resources in Washington is complex. In an effort to effectively manage fishery resources to achieve a sustainable yield, the state regulates where, when, and for how long the commercial fishing industry can fish for specific species. The Washington Department of Fisheries administers many different management programs for commercial finfish and shellfish harvesting, but the most complex is the salmon program. The salmon harvest management program is designed to the specific spawning requirements for each salmon stock, and designed to maintain the court-ordered balance of allocation between treaty and non-treaty fishers.

Table 3. Number of Puget Sound salmon, bottomfish, and shellfish commercial fishing licenses by gear type, 1986.

<u>Gear Type</u>	<u>Number</u>
<u>Salmon</u>	
Gill Net	1188
Purse Seine	343
Reef Net	50
Troll	707
<u>Bottomfish</u>	
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
<u>Shellfish</u>	
Beam Trawl	26
Geoduck Clam	13
Ring Net	178
Shellfish Pot (Crab)	247
Shellfish Pot (Non-crab)	173

Source: Ward and Hoines 1986.

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.

Each year a management plan is established between the Tribes and WDF for each salmon species. These management plans include harvestable amounts for each species, the time periods during which fish will be harvested, and specific harvest plans and conservation measures. Federal court rulings dictate the amount of fish that will be allocated to treaty and non-treaty fishers from the harvestable total.

Treaty tribes are constrained to fish only in "usual and accustomed" fishing areas, and non-tribal fishers generally fish only in marine areas. 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 number of areas and the locations of boundary lines vary between fisheries (marine fish, shellfish, and salmon). Figures 22 and 23 show the Puget Sound salmon management and catch reporting areas. Within these areas, fishery managers can reasonably predict the origin of a particular stock of fish, or the mix of stocks. To control both the increased fishing effort of recent years and provide court-mandated allocations to tribal and non-tribal fisheries, fishing areas and seasons have been reduced. As a result, when fishing is allowed, virtually all areas within an open management area are fished to one extent or another.

Management periods define the time "window" during which fishery managers will regulate the harvest of each fish stock. Table 4 provides the basic management periods for each species and management area. Management periods are based on the central 80 percent 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 specific dates for harvesting of fish during these management periods are established annually by the Tribes and WDF for all salmon species that originate in Puget Sound, and by the Fraser River Panel of the Pacific Salmon Commission for Canadian origin Pink and Sockeye salmon.

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. As discussed in the previous paragraph, 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. Table 5 shows the number of salmon caught in 1986 by various gear types for the various management areas.

The number of areas in Puget Sound open simultaneously for commercial salmon fishing ranges from 1 to 9 (Clocksin 1988, personal communication). When only a few areas

Table 4. Generalized salmon management periods by management area.

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	
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		
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	---	
7C	4/15-	-MID OCT		10/15-10/26	10/27-12/7		
7D		-9/7		9/8-10/26	10/27-12/14		
8	4/15- <2>	-8/13	8/22-9/15	9/2-10/27	10/25-11/28	6/24-7/13	
8A	---	7/21-9/9	8/9-9/9	9/10-10/21	10/22-11/30	---	
8D		7/21-9/21		9/22-11/12	11/11-12/17		
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	
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	
10A		7/1-9/14		9/15-11/2	11/3-11/30	6/10-8/4	
10C		7/1-9/28		9/28-11/30		6/10-12/31	
10D		7/15-10/5		10/6-12/14		6/10-12/31	
10E		7/1-9/13		9/14-10/11	9/28-12/31		
10F		7/1-9/14		9/15-11/30		6/10-8/4	
10G		7/1-9/28		9/29-11/30		6/10-12/31	
11	4/15-6/29	7/1-9/10	8/18-9/10	9/11-10/21	9/10-1/8	---	
12	4/15-6/29	7/17-9/6	7/16-8/24	9/7-10/18	8/16-12/7		
12A	4/15-6/29	---	---	9/6-10/7	8/26-12/21		
12B	4/15-6/29	7/17-9/6	7/16-8/24	9/7-10/18	8/16-12/14		
12C	4/15-6/29	7/24-9/6	7/23-8/31	9/11-10/25	8/26-12/21		
12D	4/15-6/29	7/24-9/6		9/11-10/25	8/26-11/27		
13	4/15-6/29	7/1-9/24	8/10-9/25	9/25-11/6	9/17-1/15	---	
13A	4/15-8/10	8/8-9/16	8/16-9/17	9/17-11/9	10/23-12/31		
13C		7/15-10/13		10/14-11/30	10/12-1/16		
13D		7/1-9/21		9/22-10/12	9/17-12/31		
13E		7/1-9/21		9/22-10/12	10/12-12/31		
13F		7/1-9/21		9/22-11/6	11/7-12/12		
13G		7/1-9/21		9/22-11/6	11/7-12/12		
13H		7/1-9/21		9/22-10/12	10/12-12/31		
13I		7/1-9/21		9/22-10/12	10/12-12/31		
13J		7/1-9/21		9/22-10/12	9/22-12/31		
13K		7/1-9/21		9/22-11/6	9/22-12/31		

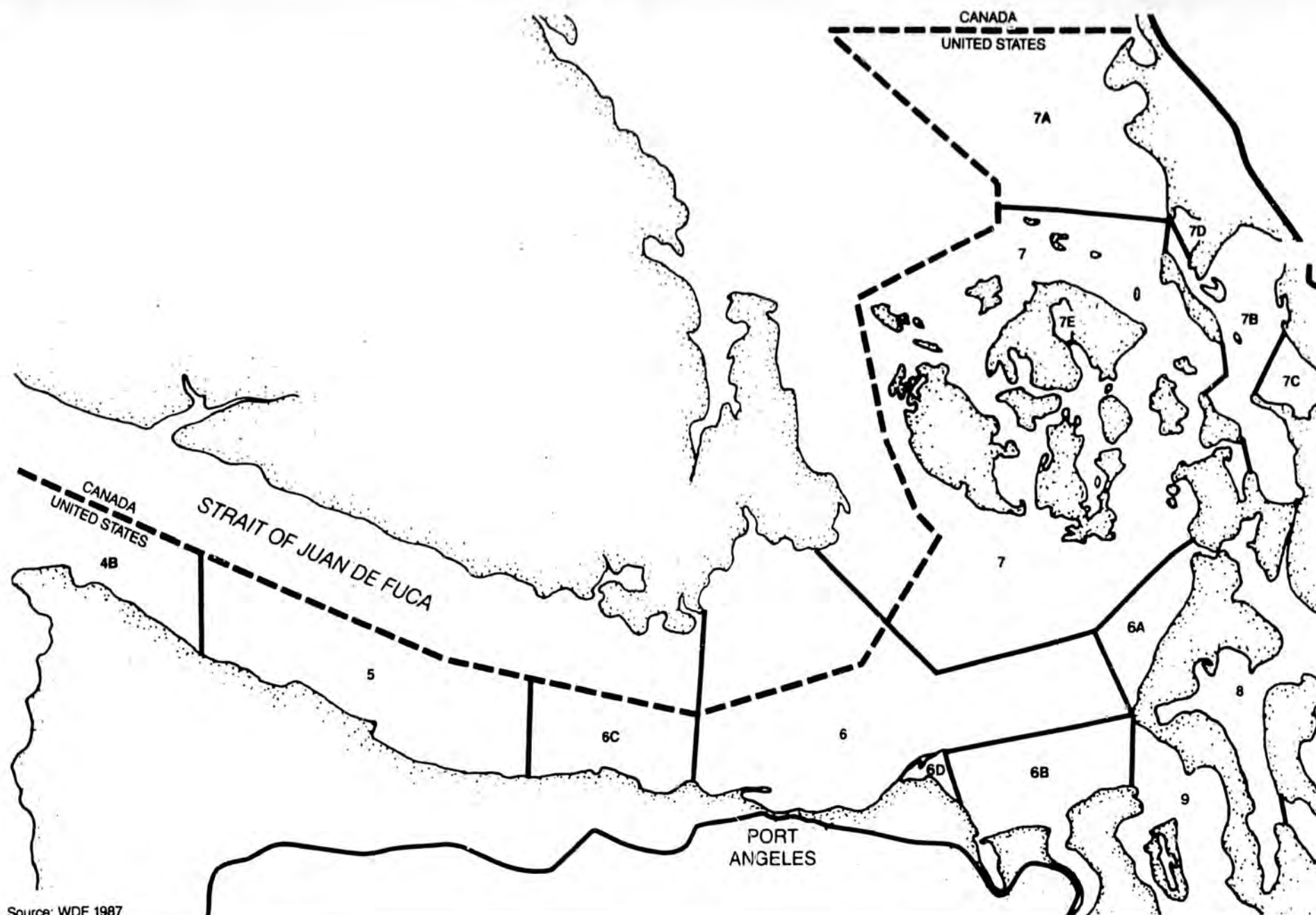
<1> MANAGEMENT PERIODS ADJUSTED ANNUALLY FOR ADMINISTRATION OF FISHERIES

<2> MANAGEMENT PERIOD CURRENTLY UNDER TECHNICAL DISPUTE; SUBJECT TO CHANGE ACCORDING TO LONG RANGE MANAGEMENT PLANNING.

<3> MANAGEMENT PERIOD CURRENTLY UNDER TECHNICAL REVIEW

(---) STOCK PRESENT BUT NO MANAGEMENT PERIOD ESTABLISHED.

() STOCK NOT PRESENT



Source: WDF 1987

SCALE IN MILES
0 5 10



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

are open at one time, commercial boats from all over the Sound will congregate in these areas, creating an intensive use of the water. 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, and 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 bag-like net where they are captured. Reef netting zones established by statute, are primarily located in the San Juan Islands.

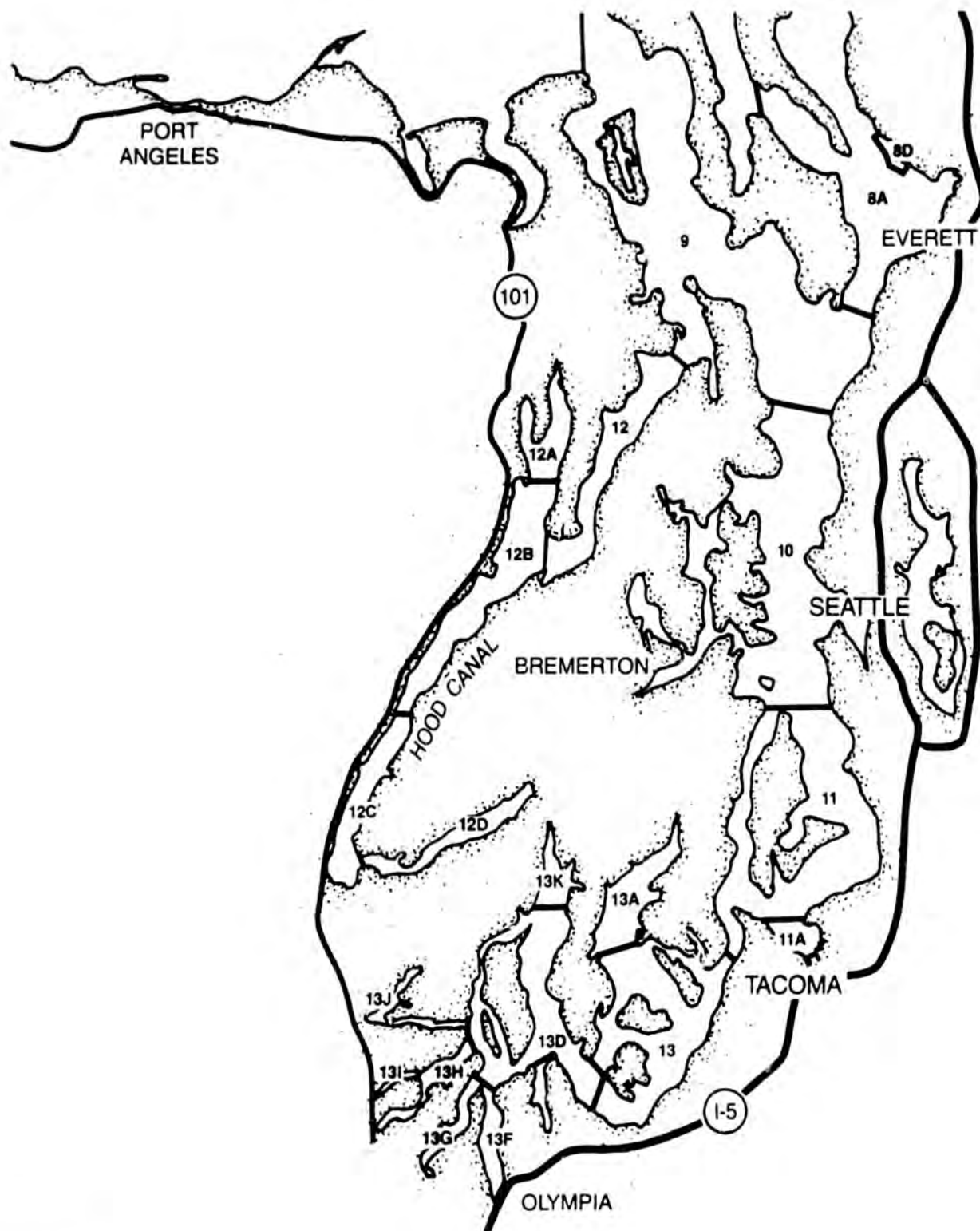
Set gillnets are vertically hung nets anchored in migration routes where fish will swim into the mesh of the net and become entangled. To help keep the net vertical in the water, it is supported at the surface by a series of floats and weighted at the bottom. Set gillnets can be attached to shore, dock, 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, that 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 (1800 ft) long, a small power skiff is used to hold the end of the net in place, during which time they drift with the current. When the school is completely surrounded by the net, the bottom is closed off and the fish are trapped. The seine boat will then retrieve the net from the water and harvest 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 then 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,



Source: WDF 1907



SCALE IN MILES

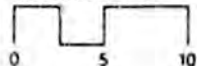


Figure 23.
Southern
Puget Sound Commercial
Salmon Management and
Catch Reporting Areas

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 (1800 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 weights 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. During the process of retrieving the net and harvesting the fish, the boat continues to drift.

b. Impacts on Commercial Fishing

Net pens are a physical obstruction in the water which, along with their anchor lines, pose a threat to commercial fishing like that described in Section II.B.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 net pens on commercial fishing is the potential for collision or entanglement of the fishing nets with the pen, resulting in a loss of available fishing area. The probability of such an occurrence depends upon the location of the net pens, and the type and intensity of fishing 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, by their numbers and by their limited maneuverability, the group potentially most affected by the placement of net pens. Placing a fixed object in the middle of a drift forces gillnetters to avoid the immediate area or to attempt to pull their nets near the pens and risk entanglement. Drift netters must also avoid natural and man-made obstacles as part of their fishing. These include island, points of land, rocks, docks, buoys, and bridge supports.

The potential conflict is increased because drift netters rely on currents to carry their nets while fishing. Similar current areas are also desirable for net pens which need moderate currents to flush the pens and to minimize sediment accumulations. The areas of greatest conflict, however, 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 will depend on many factors, especially the distance of the pen from shore. The further offshore the pens extend, the greater the area affected. Moving pens offshore 610 m

(2000 ft), as suggested to minimize aesthetic impacts (Section II.B.1, Aesthetics), maximizes the impacted area by extending the pens far into fishing channels, while also excluding the standard 550 m (1800 ft) net inshore of the pens. In intensely fished areas, such as the waters near the Hood Canal Bridge, the presence of a net-pen facility could result in intense conflicts with fishers and significant risk of collision and entanglement during the fishing season. In other areas, fishing is much less congested and a net pen would have proportionately less impact.

While the fishing area for gillnetters affected by net pens 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 pens, especially on the down current side. Trawlers could fish close to the pens, excluded only from the area occupied by the net pen 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 pens, there may actually be benefits to the fishers because of local enhancement or attraction of commercially desirable fish and shellfish to the area, especially crab. Migratory fish may also be concentrated as they navigate around the pens.

While the area actually occupied by 100 pens, as an extreme example, would only occupy 1000 to 2000 acres of bottom (0.3 percent of the Puget Sound Basin), if they were located in areas of highly concentrated, highly competitive fishing, accidents would be inevitable. Because they need to take advantage of areas open for a very short time, commercial fishers may risk collision or entanglement in these areas.

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 they have the opportunity to catch the same fish elsewhere, displacement of fishers from a particular site may not exclude those fishers from catching fish. This may be the case in situations where a relatively large area is open beyond the net-pen site.

In some cases, however, 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), then the non-tribal fishers may lose part of their court ordered allocation of salmon. This would disrupt the current salmon management plans and place the state in violation of these federal court orders.

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. This surplus to the needed number of spawners would represent an unnecessary loss to the fishing industry.

c. **Mitigation Measures**

The following are measures that could be implemented in siting of net pens to avoid or minimize displacement of existing tribal and non-tribal fishing. Appropriate measures will depend upon the extent of the potential conflict at the proposed site and the other impacts discussed in this PEIS (such as sedimentation, aesthetics, and navigation).

- Site net pens away from areas of intensive fishing. Such areas can be identified by consulting with commercial fishing organizations and WDF.
- Locate net pens near existing obstructions that must be avoided by drift net fishers.
- Notify all commercial fishing organizations of the location of net pens (for example, via the USCG Notice to Mariners) and provide schematic drawings showing the location of anchor lines.
- Locate pens near the shore and align the pen complex parallel to the shore.
- Locate pens away from WDF salmon management boundaries.

While not reducing the direct impact, salmon farmers and fishers suggest that some impact to fishers may be offset by net-pen farmers using available pen space to rear Pacific salmon for release. Final approval of such an action would be dependent upon approval by WDF and tribal biologists to assure that such releases were consistent with salmon management and enhancement objectives.

d. **Unavoidable Adverse Impacts**

It is unavoidable that some potential fishing area would be excluded from commercial harvest by the presence of a net pen. However, through appropriate mitigation significant adverse impacts on commercial fishing can be avoided.

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 pen-reared fish.

The objective of the mitigation measures in this section is to assure that no increased risk to human health shall result from net-pen activities.

a. **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 one of the most commonly occurring bacteria in the marine environment and include a diversity of species that are 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 in 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 net-pens sites in Puget Sound to those of shellfish from three comparable sites not near net pens. 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 net-pen 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 net-pen 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), Diphyllbothrium 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 Diphyllbothrium during their freshwater phase of development. Nanophyetus infects

fish by direct penetration of the cercarial stage of the worm, whereas fish become infected with Diphyllbothrium 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 Diphyllbothrium spp. occur frequently in wild Pacific salmon (Margolis 1982). In contrast, a survey of salmon from two net-pen farms in Washington revealed none of these parasites in 236 market-size fish (Deardorff and Kent, in press). Absence of anisakine worms was attributed to the fish feeding almost exclusively on pelleted feed through their grow-out phase in seawater. Nanophyetus and Diphyllbothrium infections were apparently prevented at the freshwater hatcheries before introduction to net pens.

b. 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 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 (in press) indicated that the pen-reared fish had no worms infectious to humans. This absence of parasites, the study concluded, occurs because pen-reared salmon live in a controlled environment during their freshwater development and are fed commercially prepared diets during seawater growth. However, further studies should be conducted

over a broader geographic range to determine whether these findings have general applicability.

c. Mitigation Measures

Siting aquaculture projects in areas that provide water quality compatible with good husbandry practices and productivity will ensure that farms are not placed in the warm rich embayments of Puget Sound susceptible to increased levels of V. parahaemolyticus in the summer and fall. The typical levels or significance of bacteria in fish feed is 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 research to determine bacteriological characteristics of fish feed would be desirable. Advisory notices to fish farmers on proper storage conditions for fish feed would also be desirable. These researchers did not find Salmonella in any oyster, sediment, or water samples collected from the same site as the feed or at any other sites.

Fish farming activities may increase the safety of eating raw salmon. Further research to validate the geographic distribution of lowered parasite loads in farmed fish would be desirable.

d. Unavoidable Adverse Impacts

No unavoidable adverse impacts were identified.

5. RECREATION

This section discusses the potential impact of aquaculture facilities on both aquatic and shoreline recreation.

The objective of the mitigation measures discussed below is to minimize any impacts on recreational opportunities in water or on beaches near net pens, including consumptive and non-consumptive use activities.

a. 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 of the average length of anchor line on recreational boats, most boats will anchor in water that is less than 15 meters deep (Boyce 1988).

Boaters also use embayments for temporary or overnight protected moorage during inclement weather. Wind direction, wave conditions, water depth, and currents, are factors boaters will consider when deciding which bays to pull into to wait out storms for safety.

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 the Puget Sound, but tends to concentrate in specific areas at certain times of year. The areas used intensively for recreational fishing at any particular time 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 Department of Natural Resources, the State Parks and Recreation Commission, the Department of Wildlife, the Department of Fisheries, the National Park Service, and the U.S. Fish and Wildlife Service. There are also a variety of county and local parks located on the Sound.

b. Impacts on Recreation

Floating net pens have the potential to impact recreational activities by obstructing access to shore or water areas traditionally used for recreation, or disrupting the intrinsic and aesthetic value of the area (see Section II.B.1, Aesthetics). Net pens may positively affect recreation by causing local increases in the numbers of crab and finfish near the pen site.

If net pens 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 II.B.2, Navigation). Recreational anglers could entangle their fishing lines on net-pen anchor lines. In general, net-pen anchors are placed at a distance away from the pens equal to about three times the water depth. Thus, trollers may risk entanglement within about 100 yards (91 m) of a net pen. Other fishers who are mooching, jigging, or trolling near the surface could fish closer to the pens or in between the anchor cables. Shoreline use could also be reduced by boat docks or other land-based installations associated with the net-pen facility. Odors and noise resulting from net-pen operations may also adversely impact recreational users (See Sections II.B.6 and 7, Noise and Odors). Net pens could also adversely affect the aesthetic value of an area (See Section II.B.1, Aesthetics) which may reduce the value of an area for recreational use.

Floating net pens can also have positive impacts on recreational activities. Personnel from net-pen facilities could provide assistance during boating emergencies, and the net pen structure itself could be used for temporary moorage during an emergency.

c. Mitigation Measures

Recreational activities within an area proposed for a net-pen facility will be dependent upon the nature of the area, its intrinsic value, presence of destination objectives, and its accessibility to the public. Efforts to avoid or minimize adverse impacts on recreation must, therefore, be based upon an evaluation of the specific nature of recreation in the area. Below is a list of some measures that could be used to reduce any impacts.

- Avoid the placement net pens in areas of high recreational use or value when the farm will adversely affect those values.
- Consult with resource agencies (especially WPRC and WDF), with the local planning department, and with local user groups (fishing clubs, dive clubs, yacht clubs) to identify current recreational uses and potential conflicts.
- Avoid areas of intense recreational use (such as fishing "holes", SCUBA dive sites, or destination moorage areas).
- Avoid areas where pens would adversely affect the intrinsic recreational value (for example, within 2000 feet (610 m) of state park beaches).
- In other areas, minimize adverse impacts on recreational use, including navigational, aesthetics, noise and odor. Specific mitigation measures are discussed in the appropriate sections of this PEIS.
- Provide public benefits to offset any adverse impacts to recreation. Specific activities will be project specific and would depend upon agreement between the net-pen proponent and interested parties. Such activities could include:
 - improving public access at access sites used for farm operations;
 - cooperative projects with fishing clubs, schools, tribes and the state to use available pen space to enhance wild fish stocks.

d. Unavoidable Adverse Impacts

With proper net-pen site selection, there will be no significant adverse impacts to recreational activities. Where lesser impacts are unavoidable, these can be minimized through the design, configuration, and placement of the pens at the site. In addition, activities can be undertaken in association with the net-pen operation to enhance recreational uses in the area.

6. NOISE

Sources of noise from aquaculture facilities include boats to service net pens, pumps and generators necessary for operation, and communication between workers. Concerns have been raised about the potential impact to nearby residences.

The objective of the mitigation measures discussed in this section is to prevent increases in the existing noise level that will adversely affect human activities near the net-pen site, especially increased noise to shoreline residents.

a. 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 equivalent constant sound level and is used to compare noise sources whose levels vary over time.

To help evaluate noise impacts, the EPA has developed a guideline to assess increases in ambient (existing) sound levels. If there is less than a 5 dBA increase, little or no impact is expected. Increases between 5 and 10 dBA may result in some impact, and increases greater than 10 dBA generally produce significant impacts. This guideline, known as the non-degradation guideline, is not a regulation and is not enforceable.

Noise is regulated by the Department of Ecology, which has established noise standards for various environments and activities (see below). Local government may adopt stricter noise standards or standards for nuisance noise. Most jurisdictions, however, have not adopted such standards and noise is regulated by the state standards.

Noise sources other than recreational watercraft are subject to Chapter 173-60 Washington Administrative Code (WAC), Maximum Environmental Noise Levels. 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. Table 6 shows the maximum allowable one-hour noise levels. Depending upon the categorization of net-pen 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.

Table 6. Maximum allowable one-hour environmental noise levels. (These levels are 10 dB lower during nighttime hours.)

<u>Activity at Source Property</u>	<u>Activity at Receiving Property</u>		
	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>
Residential	55 dBA	57 dBA	60 dBA
Commercial	57	60	65
Industrial	60	65	70

Source: WAC 173-60

The State also regulates noise created by waterborne activities. Chapter 173-62 WAC, Watercraft Noise Performance Standards, 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. Increases between 5 and 10 dBA have a significant impact, and increases 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).

b. Impacts of Noise

Potential noise impacts would primarily occur during daytime hours when net pen operations take place. Sources of noise from net pens would include boats servicing the pens, motors, and 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 summer-time 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 net-pen 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 feet [1.2 m]) was still detectable to the human ear at 158 m (520 feet), although the measured level was less than 5 dBA above existing levels. Noise from 5 to 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 net-pen facility may not be noticeable because of higher levels of surrounding activity.

An acoustical evaluation prepared for a proposed salmon net pen 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 (1600 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 net-pen facility would be less than 3 dBA. Depending on facility-receiver separations and the nature of equipment used in the net-pen operation, noise levels could vary from those just described. Noise-producing equipment such as generators, pumps, and boats are usually only in operation intermittently.

c. Mitigation Measures

In areas where noise from the pens would disturb shoreline residents and users, noise from net-pen facilities could be mitigated by several methods:

- Require the installation and proper maintenance of mufflers on all motorized equipment and enclose equipment to reduce noise.
- Limit activity on the facility to daytime hours.
- Require commercial boats serving net pens to meet the noise performance standards set for recreational watercraft.
- Require net-pen operations to meet the non-degradation guideline. This would prohibit an increase to existing sound levels on receiving properties of more than 10 dBA.
- Locate pens far enough away from residential properties to prevent disturbing noise levels.
- Use electric motors to operate pumps and compressors.
- Avoid siting of pens in small, populated, sheltered bays where low background noise levels would increase the impact of any noise emanating from the pens.

d. Unavoidable Adverse Impacts

Some increase in local noise levels would result from the operation of floating net-pen facilities. However, this increase is not expected to have significant impact on shoreline residents or other users of the adjacent water and shoreline. Where noise from the pens might adversely affect residential use of the adjacent shores, this noise could be reduced to acceptable levels by proper site selection and minimization of unnecessary noise.

7. ODORS

Concerns have been raised about the potential smell of aquaculture facilities. There is concern that odors will occur near the net pens from rotting dead fish, drying nets, and fish feed left out in the sun.

The objective of the mitigation measures identified in this section is to prevent odors emanating from the net pens from adversely affecting nearby residents.

a. 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 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. Another factor affecting how odors are perceived is 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).

b. Impacts of Odors

Because a large amount of organic matter is associated with marine facilities and with fish farming, net pens 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 pen 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 net-pen facility may be difficult, because other activities, man-made or natural, in the area may produce similar odors.

All odor impacts would be occasional and intermittent. The significance of net-pen odors on people in the area of the pens would depend upon the factors presented above, such as odors from other sources, the distance between the facility and the receiver, and weather. There is a potential for strong, unpleasant odors in the immediate vicinity of net pens if good management practices are not followed. These practices include removal of dead fish, cleanup of spilled feed, and general maintenance of the facility.

The placement of several net-pen facilities in a localized area could result in cumulative odor impacts. With an increased number of net pens 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.

c. Mitigation Measures

In situations where odors would affect users of the waters and shorelines, especially shoreline residents, measures to mitigate potential odor impacts include:

- Following best management practices and maintaining the general cleanliness of the facility. These practices include the immediate removal and disposal of dead fish and cleanup of spilled feed.
- Regular cleaning of nets or the use of nets that are less likely to become fouled, including the use of nets treated with approved antifoulants.
- Storage of feed in closed containers, storage of only essential amounts of opened food on the pens, and/or the use of dry feeds.
- Use of easily washable pens that have open walkways to allow spilled food and other matter to fall through into the water.
- In situations where odor may be a problem to nearby residents, sites can be selected to:
 - increase the distance between the facility and the shoreline receiver,

- place the pens downwind (prevailing distance, especially in summer) of the residences, or
- locate pens in areas already experiencing high levels of odor from other sources.

d. Unavoidable Adverse Impacts

Through site selection and management practices, significant effects of odor on human activities can be prevented. Occasional increases in local odors are an unavoidable adverse impact of net pens, but these can be further reduced through the mitigation measures presented above.

8. UPLAND AND SHORELINE USE

The issue in this section involves the potential displacement of existing and potential uses of shoreline and upland uses near an aquaculture facility.

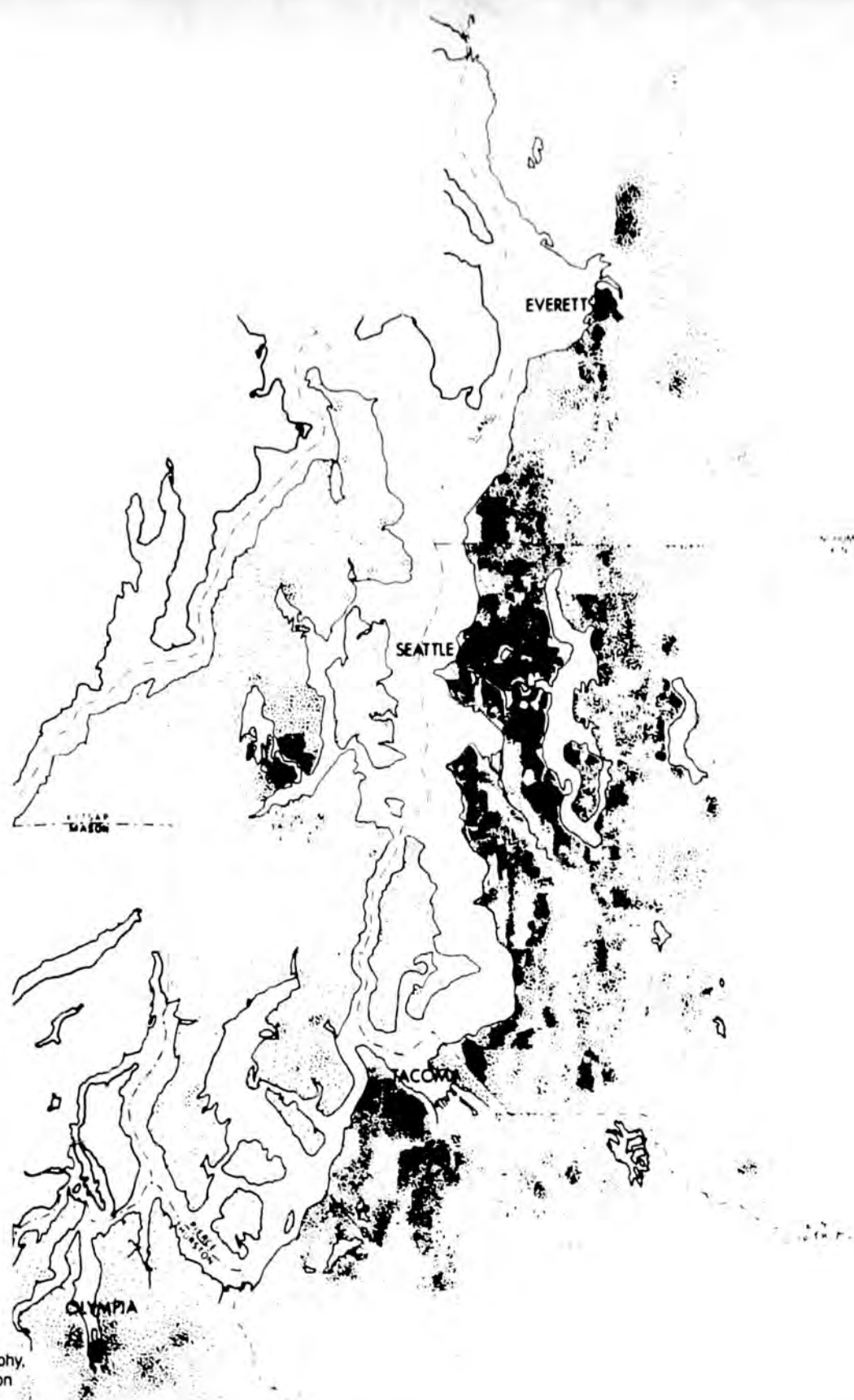
The objective of the mitigation measures described in this section is to minimize conflicts that may adversely affect current uses of the uplands and shorelines near net pen facilities.

a. Affected Environment

Over 2000 miles of shoreline wrap around the inland marine waters of Washington state. Twelve counties with a combined population of 2.9 million people share this shoreline. This corresponds to 65 percent of the state's population in only one-quarter of the state's land area. Figure 24 shows the spatial distribution of the population. The greatest concentration of people occur on the eastern coastal plains of Puget Sound, particularly in King, Pierce, and Snohomish counties. Figure 25 shows general land use patterns in the Puget Sound area.

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 percent of the statewide growth). In the next several decades, population in the Puget Sound region is expected to grow moderately, between 1.6 to 2.0 percent. 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. With this increasing development will come growing problems of water pollution from point sources (sewer and industrial discharges) and non-point runoff from uplands. In addition, the growing population will expect recreational 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



Source: Mary Stewart,
Department of Geography,
University of Washington
1987 Puget Sound
Water Quality Management Plan



SCALE IN MILES
0 5 10

Each Dot
Represents 100 Persons

Figure 24.
Population Distribution
in the Central Puget Sound Region

- place the pens downwind (prevailing distance, especially in summer) of the residences, or
- locate pens in areas already experiencing high levels of odor from other sources.

d. Unavoidable Adverse Impacts

Through site selection and management practices, significant effects of odor on human activities can be prevented. Occasional increases in local odors are an unavoidable adverse impact of net pens, but these can be further reduced through the mitigation measures presented above.

8. UPLAND AND SHORELINE USE

The issue in this section involves the potential displacement of existing and potential uses of shoreline and upland uses near an aquaculture facility.

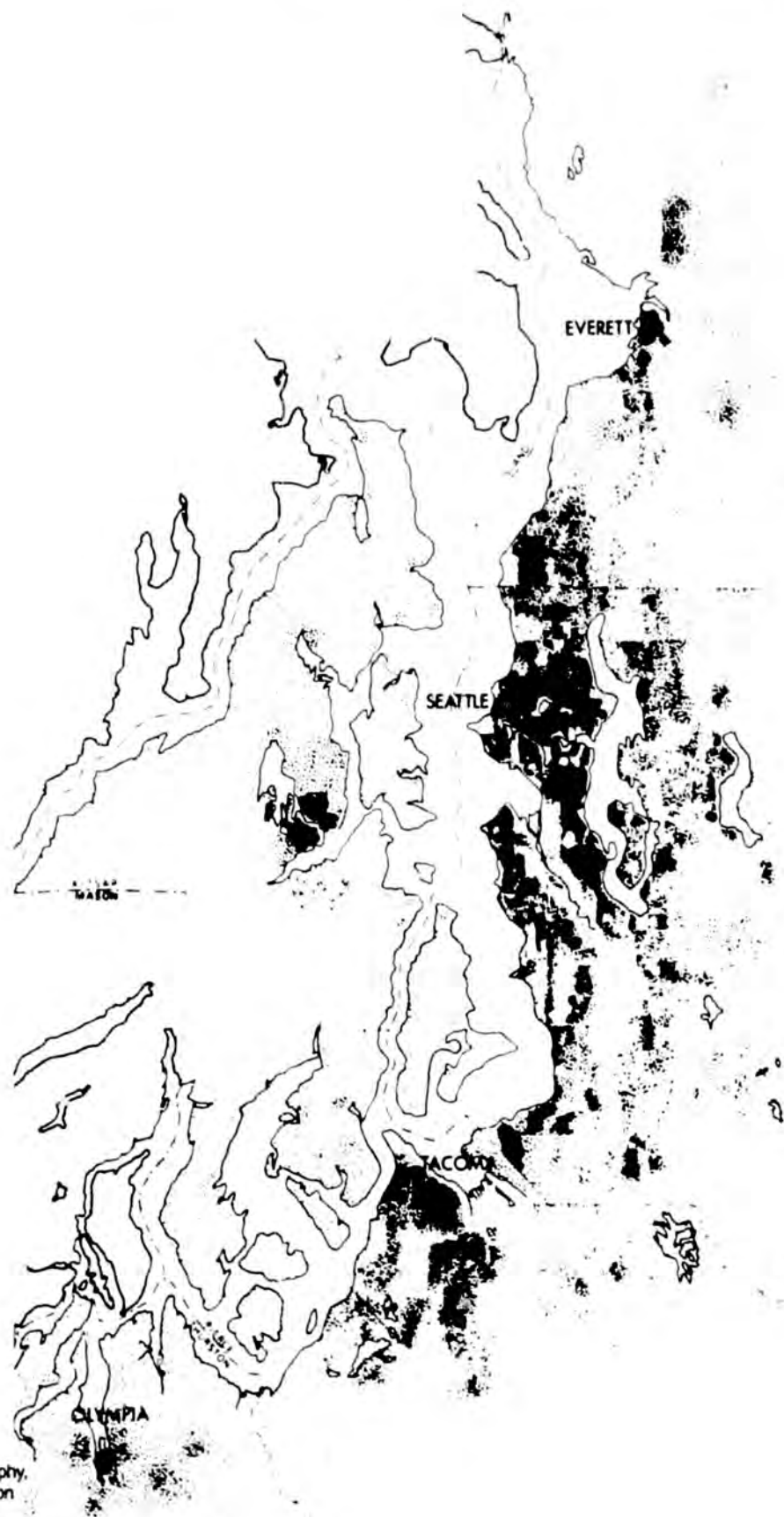
The objective of the mitigation measures described in this section is to minimize conflicts that may adversely affect current uses of the uplands and shorelines near net pen facilities.

a. Affected Environment

Over 2000 miles of shoreline wrap around the inland marine waters of Washington state. Twelve counties with a combined population of 2.9 million people share this shoreline. This corresponds to 65 percent of the state's population in only one-quarter of the state's land area. Figure 24 shows the spatial distribution of the population. The greatest concentration of people occur on the eastern coastal plains of Puget Sound, particularly in King, Pierce, and Snohomish counties. Figure 25 shows general land use patterns in the Puget Sound area.

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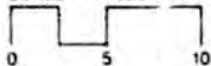
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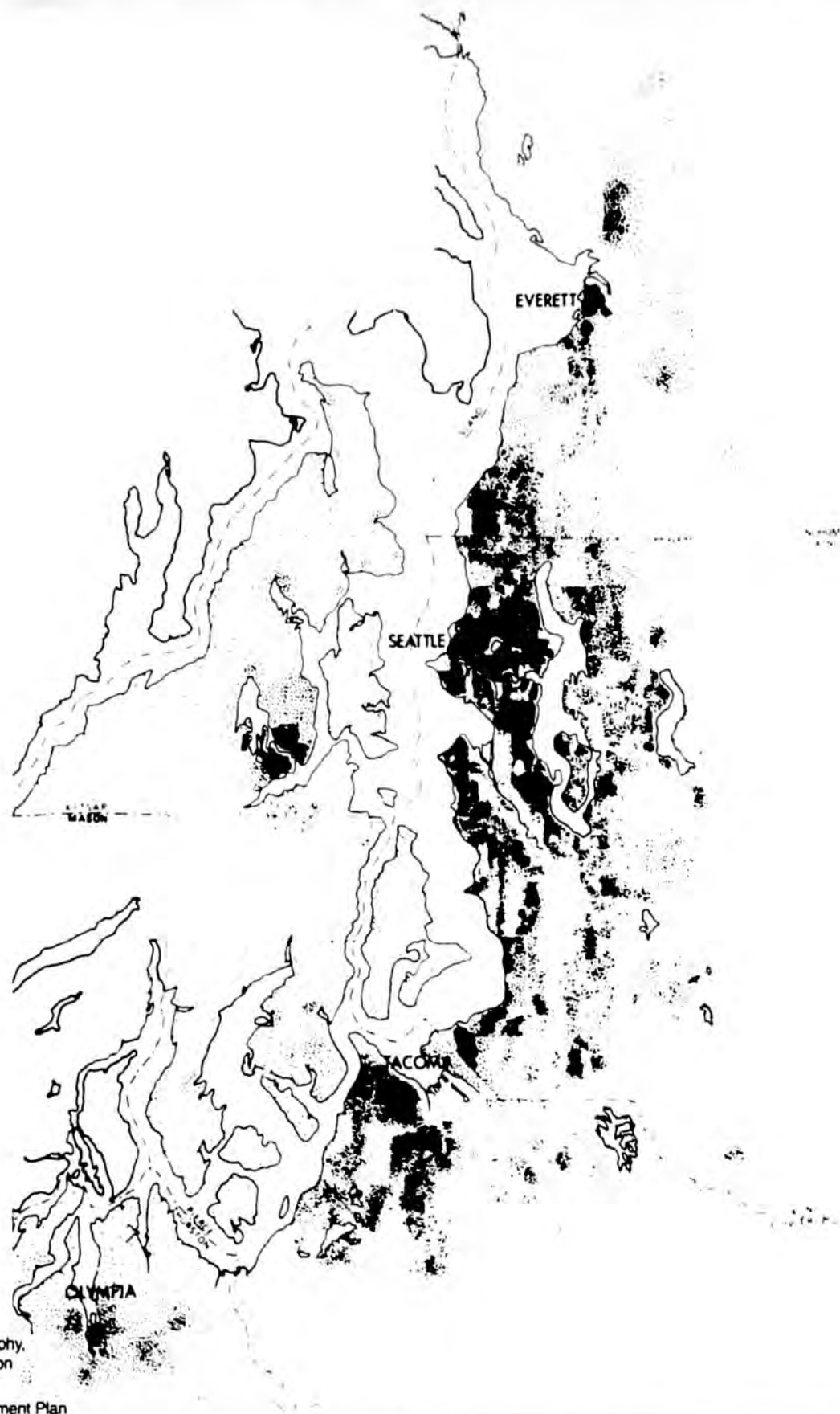
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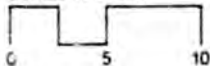
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Source: Mary Stewart,
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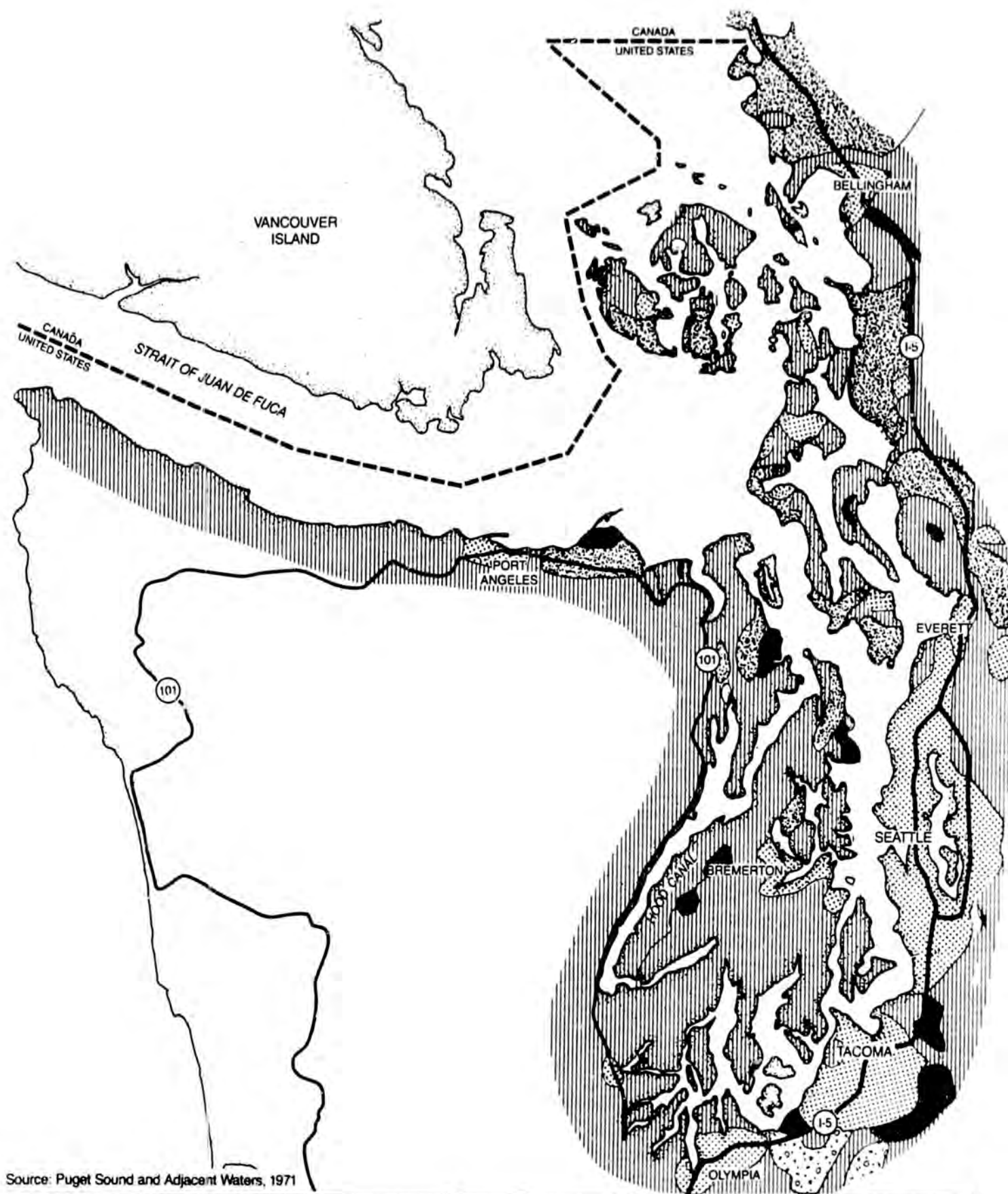


SCALE IN MILES



Each Dot
Represents 100 Persons

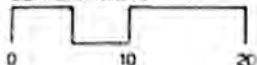
Figure 24.
Population Distribution
in the Central Puget Sound Region



Source: Puget Sound and Adjacent Waters, 1971



SCALE IN MILES



-  Built up Area (Urban/Suburban)
-  Forest
-  Rural Non-Farm

-  Cropland
-  Range
-  Grass, Brush, and Barrens

Figure 25.
Land Use in
the Planning Area

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.

b. Impacts of Alternatives

The potential impacts of floating net pens on these various activities have been discussed in Section II.B. An impact to land and shoreline use that is not discussed in other sections of this PEIS is the potential for net pens 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 net pens 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 net-pen facility is installed, it will highlight water quality concerns in the area. Therefore, greater attention may be brought to bear on activities that are not now 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.

c. Mitigation Measures

The possible highlighting of 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 net-pen facility 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 and needs no mitigation.

d. Unavoidable Adverse Impacts

None.

9. LOCAL SERVICES

The issue here is whether the presence of aquaculture facilities will impair the ability of governments and utilities to provide their services.

The objective of the mitigation measures discussed in this section is to minimize the requirements for additional services by local governmental agencies except where additional services are compensated for either directly or indirectly by the net pen operators.

a. 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. Police services are provided by county or municipal jurisdiction. Sewer and water service, 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.

b. Impacts on Local Services

The operation of floating net-pen facilities 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. Otherwise, bottled water would be used for drinking and a pump installed to wash down nets and walkways.

When located near shore, an electric cable can power electrically powered pumps, feeding mechanisms, and lights. When located a considerable distance offshore, sites use portable generators. In remote areas without available water or electricity, wells and electrical lines may have to be installed.

Net pens would not have a significant impact on other local services. Portable toilet units are used on the floating net-pen facilities. Net-pen facilities are not expected to have significant demands for police or emergency services. Use of existing boat ramps during net-pen operations may impact ramp facilities but the impact is not expected to be significant because net-pen operations involve only a few boat trips per day.

Increasing the number of net pens 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 net pen results in an insignificant demand on local services, the size of the cumulative impact of several pens would be minor.

c. Mitigation Measures

No significant impacts are anticipated. Costs incurred by service purveyors would be reimbursed through utility fees paid by facility owners.

d. Unavoidable Adverse Impacts

No unavoidable adverse impacts on local services are anticipated from any of the alternatives.

C. CUMULATIVE IMPACTS IN PUGET SOUND

Analysis of the impact of various levels of net-pen development on the entire Puget Sound is an exercise to estimate if there is an upper limit on the capacity of Puget Sound for net pens. This upper limit is the point beyond which additional net pens will reduce water quality in the Sound as a whole. The intent of such analysis is to show if projected levels of net pen development will adversely affect the Puget Sound by exceeding the assimilative capacity of the Sound. This analysis assumes that the net pens 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 net pen.

In addition, basin-wide analysis serves to put the inflow of nutrients and organics from net pens in perspective by comparing them to other sources of nutrients and organics, both man-made and natural. If the amount of nutrients from net pens 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 pen discussed in Section I.C, Background:

1. 13 farms, 4400 metric tons (10 million pounds) production
2. 25 farms, 8600 metric tons (19 million pounds) production
3. 50 farms, 16400 metric tons (38 million pounds) production
4. 100 farms, 34100 metric tons (75 million pounds) production

The first production level of 4400 metric tons is approximately equal to the estimated production from the 13 existing farms in Puget Sound. Production levels 2 through 4 are the upper limits of the production ranges given in Section I-D (Description of Alternatives). The production levels represent an approximately two-, four-, and eight-fold increase over current production. The 100-pen production level is considered by some to be in excess of the maximum number of pens 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 7. The values in the table were computed from loading analyses for Discovery Bay net pens (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 net-pen 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

Table 7. Loading of BOD, particulates (feed+feces), and dissolved nitrogen from different levels of fish production in net pens.

Number of farms	Production (MT/yr)	Total BOD (MT/day)	Feed+feces (MT/day)	Dissolved Nitrogen (MT/day)
13	4400	7.3	6.8	0.9
25	8600	14	13	1.8
50	16400	27	25	3.3
100	34100	55	52	6.8

treatment effluents from two Metro treatment plants and to one industrial source (Figure 26). In this comparison, 25 and 50 net-pen capacities are similar to a large wastewater treatment plant while 100 net pens is considerably larger than any single treatment plant on the Sound. However, the net pens represent a more diffuse source of BOD loading than a treatment plant.

For nitrogen loading, the net-pen 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-pen 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 net-pen 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 net-pen sources would remain unchanged.

The impact of net pens can on Puget Sound can also be evaluated by presenting the loading from net pens 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 lower low water to approximately 20 meters (66 ft), the total loading from the net pens would mix with 36 km³ 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 net pens 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.

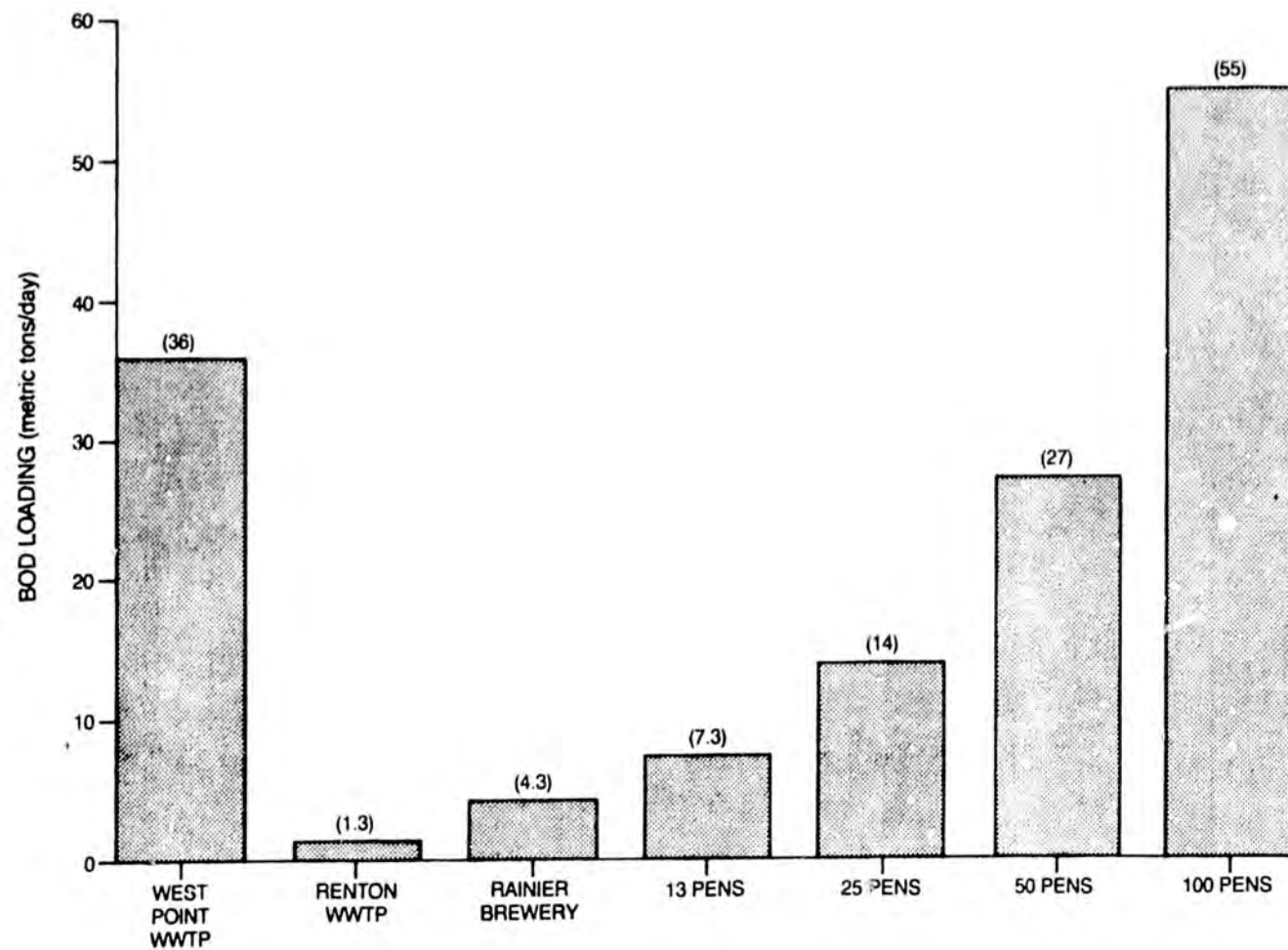


Figure 26.
BOD loading from West Point and Renton Wastewater Treatment Plants, Rainier Brewery, and different levels of net-pen development.

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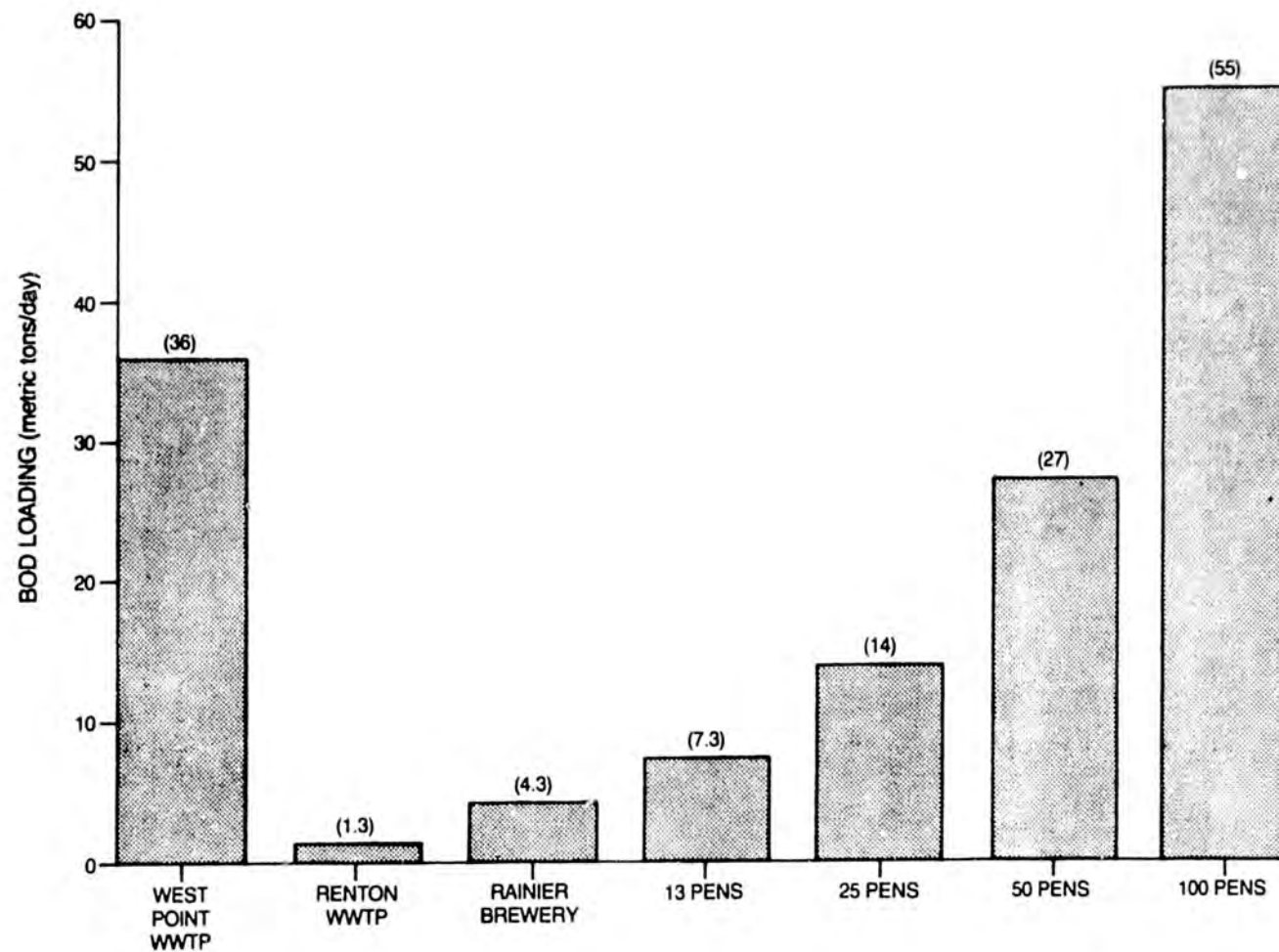


Figure 26.
BOD loading from West Point and Renton Wastewater Treatment
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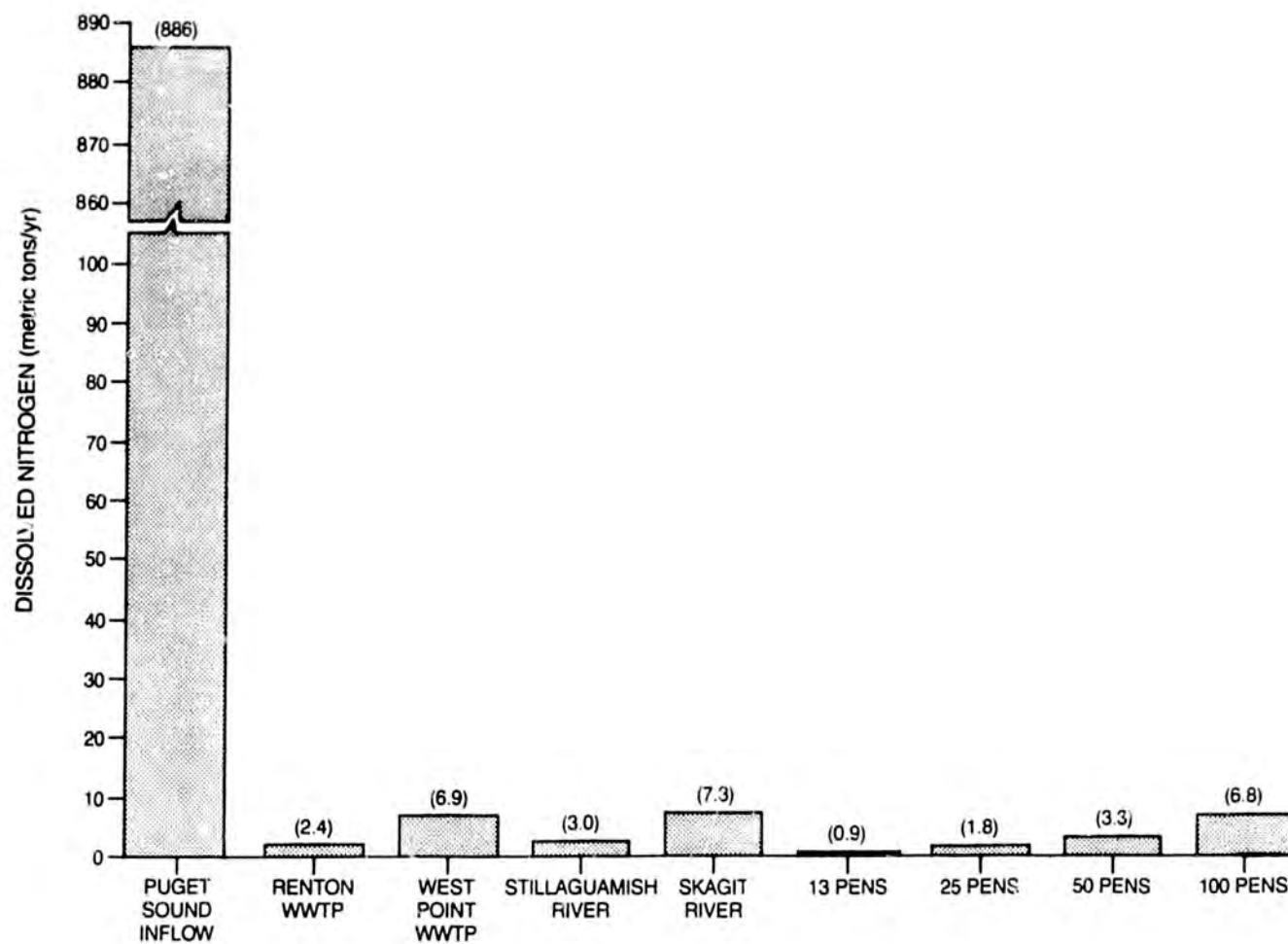


Figure 27.
Nitrogen loading from tidal and freshwater Inflow, Renton and West Point Wastewater Treatment Plants, Stillaguamish and Skagit River, and various levels of net-pen development.

In summary, the impact of 25, 50, or 100 net pens on the overall water quality of Puget Sound would be very weak and largely negligible. Consequently, the net-pen 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) may limit the number of farms to production levels well below the maximum production level considered here.

D. LAND-BASED TANK FARMS

A recent development in the culture of salmon is the rearing of fish on shore in large tanks. Sea water is continuously pumped through the tanks or raceways and discharged back into adjacent marine waters. Experimental culture of Atlantic salmon in Iceland has demonstrated the feasibility of this culture method. However, wide-scale commercial operations are just being initiated. Thus the method must be still considered experimental, but one which may provide an alternative method of fish culture in some areas and situations.

The primary advantage of tank farms to the fish grower is that he has much greater control over the water and the fish culture environment. By selecting the depth of the water source, the farmer can avoid noxious plankton, have limited control of temperature, salinity, and dissolved oxygen. He can also control flow rates through the tanks to provide optimal growing conditions, and may add supplemental oxygen or air to the water to allow higher stocking densities and lower disease risks. Other advantages include the ability to work in any weather, avoidance of many of the potential conflicts with other water users and avoidance of predator problems. Tank farms also provide the opportunity for treatment of the effluent in areas that may be sensitive to nutrient enrichment.

Disadvantages of tank farms are the higher construction and operating costs to pump water. Perhaps the greatest disadvantage is the limited availability of suitable sites, which must be flat, near water, and close to sea level to minimize pumping requirements.

The following discussion briefly describes tanks farms and the potential environmental impacts of this culture method which, in some situations, may provide an alternative method of fish culture to net pens.

The primary features of a land-based system include:

- An intake pipeline located subtidally to provide a constant supply of high quality water;
- A pump and delivery system to circulate water through the rearing tanks; and

- A series of upland rearing tanks and or raceways (circular tanks up to 20 meters [66 ft] in diameter and 3 m [10 ft] deep appear to be the preferred tank design).

Land-based sites low in elevation and near shoreline areas are preferred. Such locations reduce the length of the intake system and maintain pumping efficiency by limiting the pumping head (the vertical height water must be pumped to supply the rearing ponds). In addition, tank farms should be located in areas free of plankton blooms and near relatively deep water where water can be drawn from below any blooms.

The physiological requirements of salmon reared in tank farms are the same as those of salmon reared in net pens. However, because of different rearing conditions and economic considerations, there are notable differences in the two technologies in terms of rearing densities and operation and maintenance procedures. These differences are projected to have a significant effect on the quality of the discharge.

The most notable difference between the two technologies may be the amount of feed required for production of an equivalent amount of fish. Average food conversion ratio (FCR) in net-pen facilities may vary from 1.5 to 1 (Hardy 1988, personal communication) to 2.0 to 1 (Weston 1986). Recent work suggests that a FCR of 1.2 to 1.0 or less may be achieved (Asgard et al 1988). This ratio accounts for conversion of feed to fish flesh (dry pellets of 10 percent moisture compared to fish flesh of 70 percent moisture) as well as loss of feed (a 0-20 percent loss of the feed depending on the site location, type of feed, and rearing practices), loss of fish due to mortality, or other reasons. Since onshore tank farms use circular tanks with controlled flow and oxygen conditions, proponents claim that salmon are able to feed and convert fish feed more efficiently to flesh than in net pens that are subject to variations in water velocity and existing oxygen conditions. As the FCR improves (lower ratio), the amount of waste feed and total solids loss drops significantly.

Other positive aspects of land-based tank farming include the relatively high quality of waste water that is a result of dilution by the large volume of water flow necessary in the tanks. Since self-cleaning tanks may be designed, "shock loads" due to sudden discharges of large amounts of organic waste during cleaning may be avoided. Stocks of fish may be separated for disease isolation and treatment. Routine addition of oxygen may improve dissolved oxygen levels relative to existing source water conditions. This extra oxygen allows higher stocking densities and reduced incidence of disease.

Potential negative impacts of land-based tank farming include release of a more concentrated effluent than net pens. Because large volumes of flow are necessary for land-based tank farms, the concentration of pollutants such as ammonia in the effluent may be low, but not as low as that seen from net pens. The receiving waters must have active hydrodynamics to allow dispersion of the solid and dissolved wastes. This requirement is enforced through the National Pollution Discharge Elimination System (NPDES) permit system administered by the Washington Department of Ecology. Due to salt content, solids isolated from onshore tank farms are not readily disposable on

land as fertilizer or fill. Depending on its design and site, land-based tank farms may need to screen their intakes to prevent fish from being taken up in the intake.

In general, land-based rearing of fish allows for tighter control over all phases of outgrowing (growth to marketable size) compared to net pens. In a land-based system, water flow rates and dissolved oxygen concentrations (variables important to fish health) can be adjusted dependent upon the fish rearing requirements. In addition, fish reared in tanks are easily observed and sampled. This accessibility to the fish helps develop efficient feeding schedules, identify stress and disease, and aid in the treatment of fish if a fish disease or parasite is identified.

On the other hand, land-based tank farms are more costly to construct and operate than a net-pen system. Unlike net pens, tank farms need intake and outlet structures, as well as rearing ponds. Greater operational costs also occur with tank farms due to maintenance of the rearing facilities and the cost of pumping and circulating rearing water.

The successful operation of a land-based facility is, therefore, dependent upon efficient management and close control over the rearing process. Compared to net-pen operations, land-based facilities can potentially increase overall survival, improving harvest rates, as well as improving feed conversion ratios which result in decreased feed costs.

While there are no operating land-based tank farms in Puget Sound, upland systems have been proposed for Grays Harbor and Clallam counties, and other areas of the United States and Canada. Saltwater tank farms are successfully operating in western Europe and Iceland. Upland tank farms are a new technology and have yet to be fully proven economically. They appear, however, to offer an alternative means of growing fish which may complement net-pen farming and provide an alternative to net pens in situations where net pens would otherwise be impossible.

Land-based tank farms must comply with all local, state and federal regulations pertaining to net pens, with the possible exception of the Corps of Engineers permits concerning navigation (Section 10). In addition, tank farms as sources of point-source discharge, are subject to permitting requirements under the National Pollutant Discharge Elimination System.

The following discussion briefly summarizes the possible environmental impacts of upland tank farms for the purpose of comparison with net-pen culture.

1. SEDIMENTATION

Tank farms can introduce sediment into the marine environment through discharge pipes at an outfall. Unlike net pens, the fish farmer can regulate the effluent from the facility. Feces and excess feed frequently will settle to the bottom of the tanks where they can be removed, or be collected in settling ponds.

Any sediment which is discharged from a tank farm would affect the marine environment in a manner similar to the sediment deposited from a net-pen facility or similar discharges. Unlike net pens which by their size provide a vast area for dispersal, tankfarm discharges are a point source which would concentrate sediment impacts without adequate sediment removal or adequate dispersal of the discharged material.

A range of responses, similar to those described for net pens, will occur at the effluent outfall. Where effluent is rapidly and effectively dispersed, the effects will range from local enrichment of the bottom community to no noticeable change. If dispersion is minimal, the effects will be substantial with all three zones occurring as all of the sedimentation will occur in a concentrated area. Dispersion can be increased by placement of the discharge pipe in areas of high current flow and through the use of diffusers on the end of the pipe.

2. WATER QUALITY

The potential water quality impacts from land-based tank farms will be like those from floating net pens. Because of the relatively small volumes of water in tank farms relative to net pens, the dissolved oxygen concentration in the discharge water may be reduced. Data from 38 fresh water tank farms in Europe were used to calculate an average decrease in dissolved oxygen of 1.6 mg/l through the facilities (Alabaster 1982). As a worst-case approximation, a decrease of 2 mg/l through a land-based tank farm and an initial concentration of 6 mg/l would require a minimum dilution factor of about 10 to meet the state standard (5.8 mg/l in this case). A dilution factor of 10 would likely be achieved in close proximity to a land-based tank farm outfall. Tank farms also have the potential to aerate or oxygenate water entering and leaving the tanks. This can improve the culture environment for the fish as well as offset any oxygen demand from the fish or the discharged nutrients.

Land-based tank farms are subject to the same nutrient enrichment considerations as net-pen farms. That is, restricted embayments with nutrient sensitivity should be avoided for both the good of the cultured fish due to dinoflagellate blooms, and for the possible enrichment effect upon algae or phytoplankton in the discharge waters. The three onshore tank farms proposed or being built in Washington state are located in non-nutrient sensitive waters. As in net pens, about 70 percent of the nutrients are discharged in solution. Retention time of water within the tank farms will generally be less than two hours, and the water is actively moving in the tanks and pipes. Both the period of time and movement of the water are not conducive for the development of optimum algal growing conditions. Site characteristics, especially the physical oceanography, depth of intake and discharge, and the density of water at both intake and discharge depths will greatly influence the fate of discharged waste water.

Chemical usage in tank farms would generally be less than in net pens, again because the tank farm operator has much greater control over the culture environment. Antibiotic use would probably be less because the farmed fish will not be directly exposed to disease carrying wild fish, and the controlled culture environment reduces the probability of disease and permits easier control of any disease outbreaks. In addition,

it is likely that tank farms would not use large amounts of antifoulant materials. The use of any chemical in tank farms would have impacts on the aquatic environment like to those described in Section II.A.2.

3. FISH AND SHELLFISH

The primary impacts of net pens on fish and shellfish are the possible smothering of sessile (immobile) organisms below the pens, if the pens are located in shallow, poorly flushed areas, and the attraction of mobile fish and shellfish species to the site. Because tank farms would have a much more concentrated discharge, the area of bottom affected would be less than for net pens and the potential impact of sessile bottom-dwelling organisms would be reduced. Construction of the intake and outfall structures, however, could destroy shellfish beds in the construction area. Because shellfish populations usually occur in discrete beds, proper site selection can avoid significant impacts for clams, oysters, geoducks, etc.

In the absence of a significant structure in the water, the attraction of fish and shellfish to the site would be reduced or eliminated. Fish could be adversely affected if entrained in the intake pipe; therefore, proper screening of the intake will be necessary. It will also be necessary to avoid areas of intertidal herring and smelt spawning or important habitats for other fish species. Because the location of all these habitats is unknown, field observations will be necessary to determine what species use the area and if important habitats would be affected.

The potential for fish to escape into the wild from tank farms is relatively remote when compared to net pens. Even in the event of a major catastrophe, (for example, a tank ruptures during a large earthquake), most fish would be stranded on dry ground and die. If fish were to escape, the impacts to wild populations would be the same as for net-pens.

4. WILDLIFE

Construction of each land-based tank farm could result in the loss of several acres of upland habitat depending upon the previous use of that land.

Most of the habitat loss would be due to construction of the rearing tanks and support facilities such as operations buildings and new access roads. Clearing of vegetation would remove habitat and may result in losses or displacement of small vertebrates such as mice, snakes, and frogs. Larger animals such as river otter, deer, raccoon, beaver, and birds may temporarily avoid construction sites. Noise generated by net-pen construction and operation may temporarily displace or disturb nearby wildlife. Consultation with fish and wildlife agencies during permit review is required to avoid affecting the habitats of any threatened or endangered species. Stretching netting over the top of upland facilities is an effective technique for keeping predators away from the fish.

5. ODORS

Operation of a land-based tank farm facility would be less likely to produce odors than would a floating net-pen facility because nets and their associated fouling organisms would not be present and because the availability of enclosed storage areas for food. Minor odors could result from diesel engines used for emergency pumping during power outages, or from trucks servicing the facility. All odor impacts would be occasional and intermittent. As with floating net pens, dead fish could create unpleasant odors if not removed from the tanks and disposed of properly. Because tank farms are located on shore, they may be closer to residents than net pens. Consequently any odors produced may have a greater effect on these residents.

6. NOISE

Sources of noise at land-based tank farms would be similar for any small agricultural or commercial activity. Large pumps and compressors would be required for aeration and pumping. These would be electrically powered and enclosed in buildings or located below grade and would probably produce little detectable noise off the farm property.

Land-based tank farms would be required to meet the relevant local and state noise standards. In rural areas with low existing noise levels, noise levels meeting state standards may be disturbing. In such areas, additional mufflers, sound enclosures, or buffer zones could be used to minimize any disturbance of nearby residents.

7. UPLAND AND SHORELINE USE

Land-based tank farms have the same requirements for high quality water as floating operations and will provide ongoing monitoring of water quality. Other shoreline activities adversely affecting water quality would harm the fish culture operations. As in the review of any proposed activity, new projects near the tank farm would be evaluated for their effect on existing activities and their impacts on water quality and other elements of the environment.

Activity levels associated with an upland tank farm will be similar to those of a small farm or commercial facility. Increased vehicle traffic from employees travelling to and from work will occur and from deliveries of food and other supplies and shipment of harvested fish. In some cases, the farms may also attract visitors and tourists. The number of trips will depend upon the size of the facility and its proximity to suppliers. In addition, land-based tank farms may have other commercial elements such as fish processing which must be considered.

8. AESTHETICS

The extent of aesthetic impacts resulting from tank farms will vary depending on the site, especially the existing activities and structures in the area, and the visibility of the facility to outside observers. Highly visible tank farms may be perceived as visually

intrusive in rural or natural areas yet be unobtrusive at sites surrounded by industrial or commercial uses.

Aesthetic impacts in sensitive areas can be minimized by providing for adequate setbacks from adjoining properties and by providing landscaping to visually shield land-based facilities from nearby observers.

9. RECREATION

Recreational activities would not be impacted by land-based tank farms, except where the facility displaced existing shore-based use. If the beach is privately owned, recreational use by the public would be allowed only with the owner's permission. If the beach is publicly owned, intake and discharge pipes could be buried to avoid any conflict with existing use except during construction.

10. LOCAL SERVICES

The impacts of land-based tank farms on local services are expected to be similar to the impacts of floating net pens and would not be significant. Tank farms would have more demand on local services such as electricity, roads, and fire protection. They would also be subject to local property and other taxes which currently do not apply to net pens.

E. RELATIONSHIP TO LAND USE PLANS AND REGULATIONS

The geographical focus of this net pen PEIS 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. Lands covered by water are included within the boundaries of unincorporated or incorporated jurisdictions. However, these lands are also subject to both state and federal regulation.

Local Jurisdictions. Local jurisdictions have a variety of land use policies and regulations that affect the construction and operation of salmon-rearing facilities. These 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).

(a) Comprehensive Plans. The comprehensive plans of local jurisdictions generally contain goal statements and policies that seek to protect the environment and to 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.

(b) 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 cubic feet per second, and segments on lakes less than 20 acres in size. "Associated wetlands" include areas within 200 feet 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 the Washington Department of 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; and

- 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. RCW 15.85 declares that it is the policy of the state to encourage the development and expansion of aquaculture. 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-net pen operations 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.

A floating net-pen operation 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 the Department of 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, the Department of 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.

(c) Zoning and Other Regulations. Local jurisdictions would also regulate upland portions of a floating net-pen operation or tank farm through zoning regulations. Zoning regulations normally include limitations on the bulk of structures and also include 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 may be included in separate legislation. These regulations are discussed in appropriate sections of this document.

State and Federal Jurisdictions. Locating a floating net pen, in or adjacent to the marine waters of Puget Sound, would require leases and permit approval from several

Washington State agencies. In addition, the federal government has specific authorities over navigable waters and wetlands of the state. Appendix F is a list of the permits which may be required for a floating net-pen development. 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.

III. DISTRIBUTION LIST

Federal Agencies

U.S. Fish and Wildlife Service
U.S. Army Corps of Engineers
U.S. Coast Guard
U.S. Food and Drug Administration
National Marine Fisheries Service
National Park Service
Environmental Protection Agency
Bureau of Indian Affairs

Tribes and Tribal Organizations

Northwest Indian Fisheries Commission
Duwamish Tribal Office
Point No Point Treaty Council
Jamestown-Klallam Tribes
Klallam Tribe
Lower Elwha Tribal Council
Lummi Business Council
Makah Tribal Council
Muckleshoot Indian Tribe
Nisqually Indian Tribal Council
Northwest Indian Fisheries Commission
Port Gamble Business Committee
Puyallup Tribal Council
Sauk-Suaittle Indian Tribe
Skokomish Tribal Council
Small Tribes of Western Washington
Squaxin Island Tribal Council
Stillaguamish Tribal Council
Suquamish Tribal Council
Swinomish Tribal Council
Tulalip Board of Directors
Upper Skagit Tribal Council

State Agencies and Elected Officials

Office of Governor Booth Gardner
Senate Environment and Natural Resources Committee
House Environmental Affairs Committee
House Fisheries and Wildlife Committee
Office of the Attorney General
Department of Agriculture

Department of Community Development
Department of Ecology
Department of Natural Resources
Department of Parks and Recreation
Department of Social and Health Services
Department of Trade and Economic Development
Department of Wildlife
Washington Parks and Recreation Commission
Interagency Commission on Outdoor Recreation
Shorelines Hearings Board

County Governments

Washington State Association of Counties
Whatcom County
Skagit County
San Juan County
Island County
Snohomish County
King County
Pierce County
Mason County
Thurston County
Kitsap County
Jefferson County
Clallam County

Regional Agencies

Puget Sound Water Quality Authority
Thurston Regional Planning Council

Libraries

Copies of this EIS will be distributed to major libraries along the Puget Sound basin.

Organizations

Puget Sound Gillnetters Association
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
Trout Unlimited
Sierra Club
Northwest Towboat Association
Inner Sound Crab Association
Interclub Boating Association
Purse Seine Vessel Owners Association
Puget Sound Alliance
Seattle Aquarium
Washington Steelheaders Association
Save Our Shores

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