

ALASKA LEGISLATURE SPECIAL COMMITTEE/SUBJECT FILE 8672  
1910 SCOMM 75: MARICULTURE (FISH FARMING), 1987-1990

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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.<sup>3</sup>

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, tidlands  |           | 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 l   | 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 | Narroustone 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 | Narroustone 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 | Narroustone 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 | Narroustone 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 | Narroustone I.  | 0.86  | 100        | \$75,000  | \$750       | market     | l septic                              |           | 1     | Jefferson Co Realtor |
| Jefferson | Narroustone 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 | Narroustone 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 XSNMF6X                             |           | 0     | Kitsap Co Assessor   |
| Kitsap    | Eglon           | 0.56  | 60         | \$9,120   | \$152       | assessed   | h XSNMF6X                             |           | 0     | Kitsap Co Assessor   |
| Kitsap    | Colvos Passage  | 2.50  | 210        | \$42,000  | \$200       | assessed   | h GSNMF6E                             |           | 2     | Kitsap Co Assessor   |
| Kitsap    | Poulsbo         | 0.53  | 100        | \$30,000  | \$300       | assessed   | le GQPMF6X                            |           | 2     | Kitsap Co Assessor   |
| Kitsap    | Vinland         | 1.38  | 155        | \$108,810 | \$702       | assessed   | le BK(CPC)CAGX                        | 90860     | 5     | Kitsap Co Assessor   |
| Kitsap    | Vinland         | 0.79  | 120        | \$96,240  | \$802       | assessed   | le BK(CPC)CAGX                        | 65360     | 5     | Kitsap Co Assessor   |
| Kitsap    | Fletcher Bay    | 1.97  | 160        | \$92,090  | \$576       | assessed   | le BK(CPC)CFGE                        | 39220     | 5     | Kitsap Co Assessor   |
| Kitsap    | Colvos Passage  | 5.07  | 330        | \$50,160  | \$152       | assessed   | h B(CSD)PMF6X                         |           | 3     | Kitsap Co Assessor   |
| Kitsap    | Toku Pt.        | 5.97  | 425        | \$97,150  | \$221       | assessed   | h GSPCF6X                             |           | 2     | Kitsap Co Assessor   |
| Kitsap    | Vinland         | 2.36  |            | \$110,400 |             | assessed   | le BK(CPC)CAGX                        | 41430     | 5     | Kitsap Co Assessor   |
| Kitsap    | Poulsbo         | 1.77  | 205        | \$138,780 | \$677       | assessed   | le BK(CPC)CAGX                        | 34280     | 5     | Kitsap Co Assessor   |
| Kitsap    | Colvos Passage  | 5.08  | 142        | \$46,434  | \$327       | assessed   | le GQPMF6E                            |           | 2     | Kitsap Co Assessor   |
| Kitsap    | Vinland         | 3.94  | 200        | \$100,400 | \$502       | assessed   | le BK(CPC)CFGE                        | 44810     | 5     | Kitsap Co Assessor   |
| Kitsap    | Fletcher Bay    | 1.47  | 73         | \$53,020  | \$726       | assessed   | le BK(CPC)CFGE                        | 95230     | 6     | Kitsap Co Assessor   |
| Kitsap    | Eglon           | 1.88  | 100        | \$9,100   | \$91        | assessed   | h XSNMF6X                             |           | 0     | Kitsap Co Assessor   |
| Kitsap    | Eglon           | 2.02  | 170        | \$21,250  | \$125       | assessed   | le DQPMF6X                            |           | 1     | Kitsap Co Assessor   |
| Kitsap    | Fletcher Bay    | 3.80  | 210        | \$156,500 | \$745       | assessed   | h BS(CPC)PMF6X                        | 146150    | 5     | Kitsap Co Assessor   |
| Kitsap    | Fletcher Bay    | 2.61  | 150        | \$101,050 | \$674       | assessed   | le BK(CPC)XAGX                        |           | 4     | Kitsap Co Assessor   |
| Kitsap    | Vinland         | 0.86  | 100        | \$80,200  | \$802       | assessed   | le BQPMF6X                            | 113380    | 4     | Kitsap Co Assessor   |
| Kitsap    | Toku Pt.        | 8.49  | 300        | \$101,980 | \$340       | assessed   | le BK(CPC)CAGX                        | 182700    | 4     | Kitsap Co Assessor   |
| Kitsap    | Colvos Passage  | 3.26  | 200        | \$40,000  | \$200       | assessed   | h USNMF6E                             |           | 1     | Kitsap Co Assessor   |
| Kitsap    | Colvos Passage  | 8.18  | 220        | \$77,440  | \$352       | assessed   | le BK(CPC)CFGE                        |           | 4     | Kitsap Co Assessor   |
| Kitsap    | Eglon           | 2.38  | 260        | \$21,200  | \$120       | assessed   | h XSNMF6X                             |           | 0     | Kitsap Co Assessor   |

# A.1 Puget Sound Waterfront Property Survey

| FRONT    | SITE              | ACRES | FRONT FEET | PRICE     | PRICE FRONT | PRICE TYPE  | FRONT 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 | GNMFGN                     |          | 1     | Kitsap Co Assessor   |
| Kitsap   | Colvos Passage    | 6.09  | 285        | \$86,070  | \$302       | assessed h  | USMNGE                     |          | 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  | USMNGE                     |          | 1     | Kitsap Co Assessor   |
| Kitsap   | Egion             | 5.30  | 510        | \$73,500  | \$144       | assessed h  | XSMNGE                     |          | 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 | GNMFGN                     |          | 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     | 1                            | 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     | 1                            | 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     | 1                            | 0               | Island Computer Services |
| San Juan | San Juan I.        | 5.00  | 700        | \$75,000  | \$107       | market     | 1                            | 0               | Island Computer Services |
| San Juan | San Juan           | 79.25 | 360        | \$549,000 | \$1,525     | market     | n 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     | n 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   | \$651    | 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.

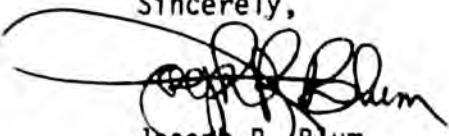
To facilitate public awareness, two public meetings have been scheduled to receive comments on the draft PEIS as follows:

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:klg

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<br>Sedimentation<br>Net-pen modeling<br>Water quality<br>Introduction of Atlantic salmon<br>Genetic impacts |

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# **CORRECTION**

**THIS DOCUMENT  
HAS BEEN REPHOTOGRAPHED  
TO ASSURE LEGIBILITY**

## 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).

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

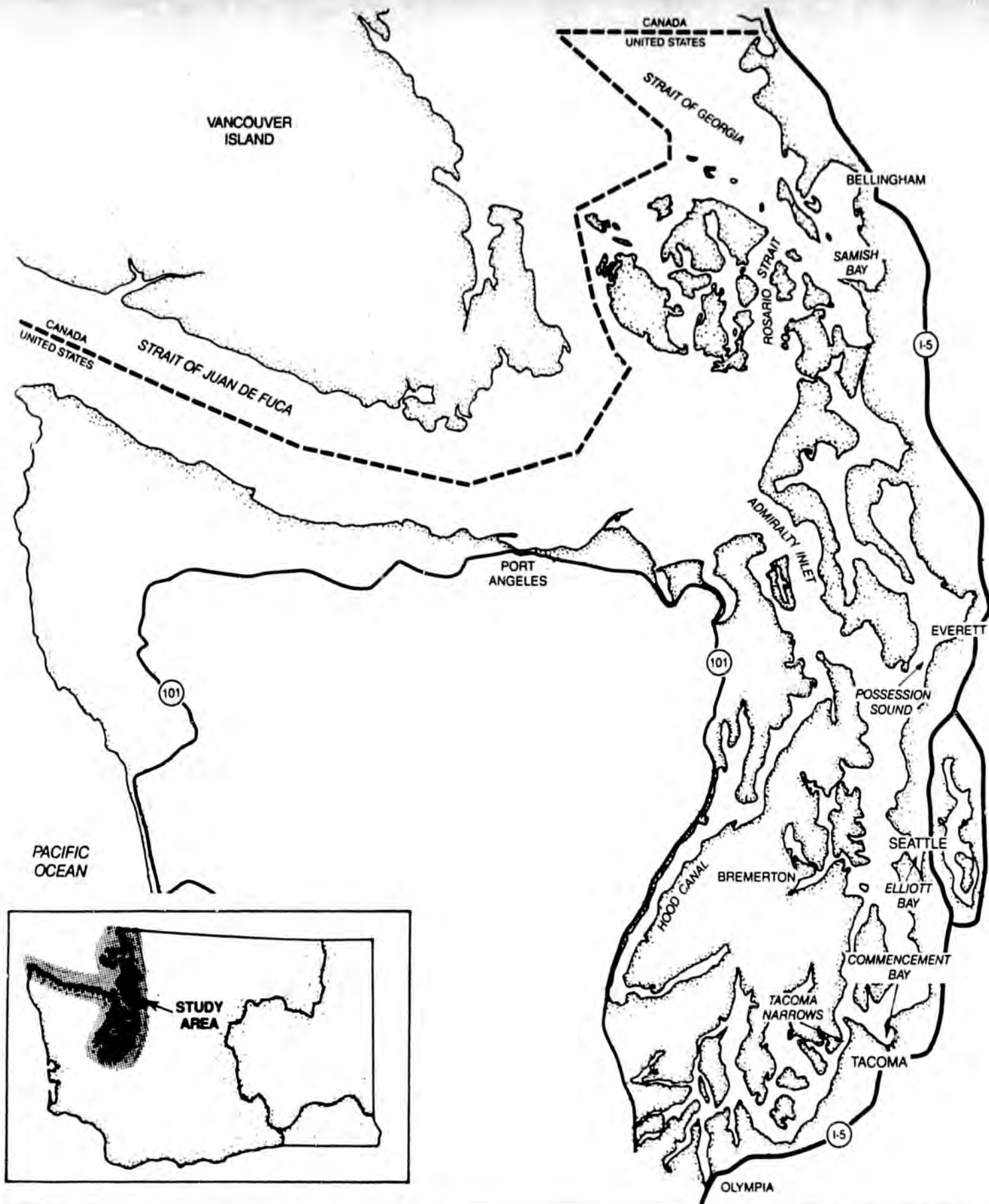
Written comments received in response to the scoping notice and audio tapes of the public meetings are on file with the Department of Fisheries in Olympia.

### 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.



SCALE IN MILES

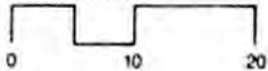


Figure 1.  
Vicinity Map

## 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 m<sup>2</sup>). 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

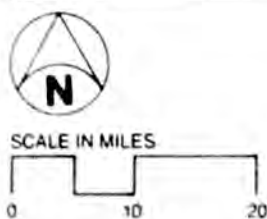
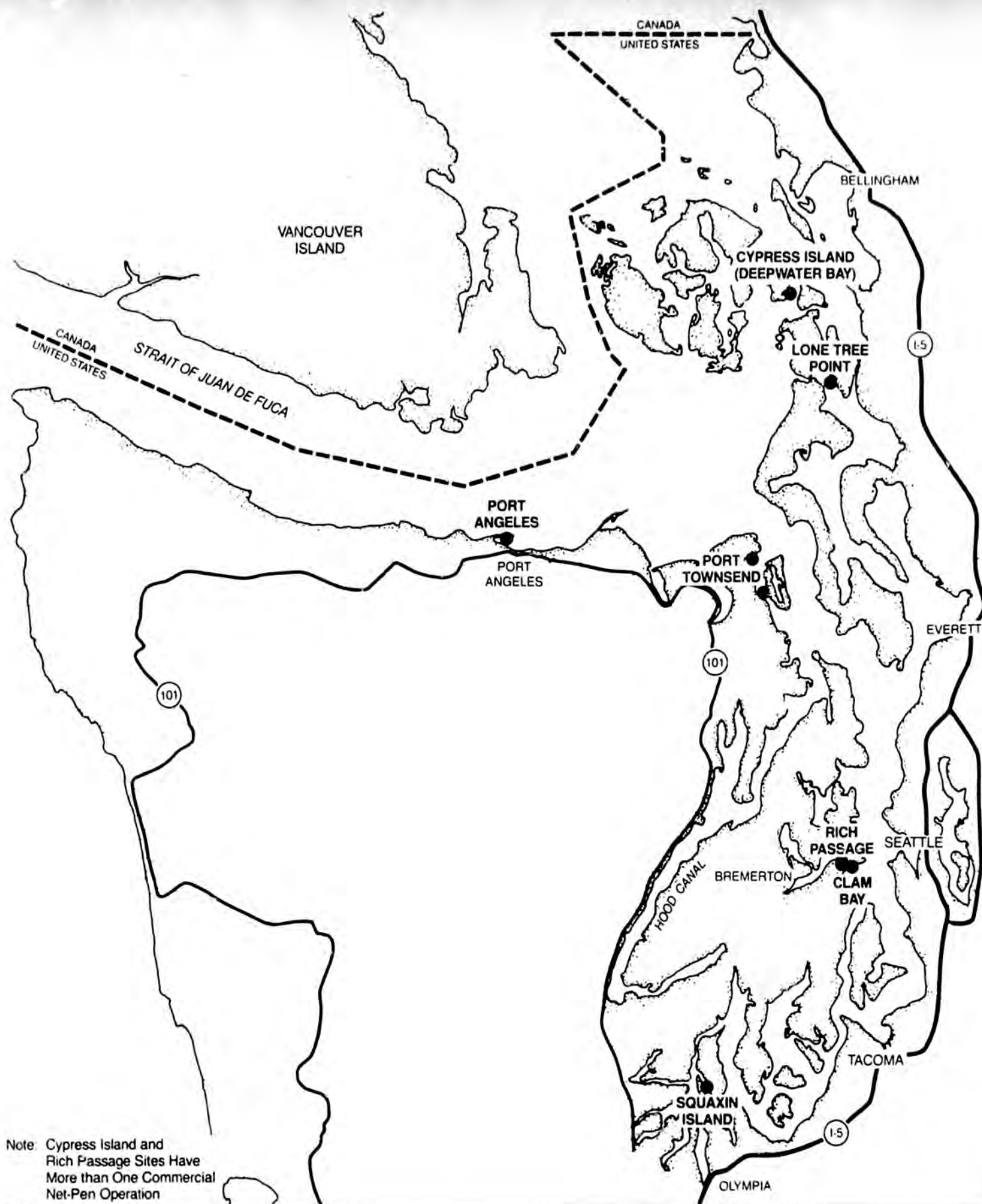
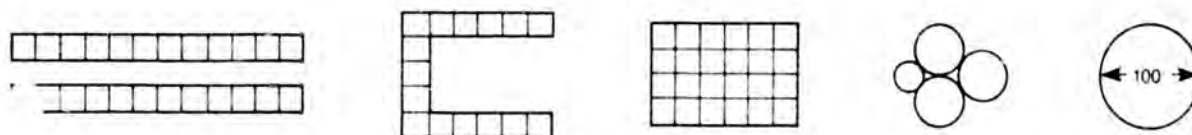
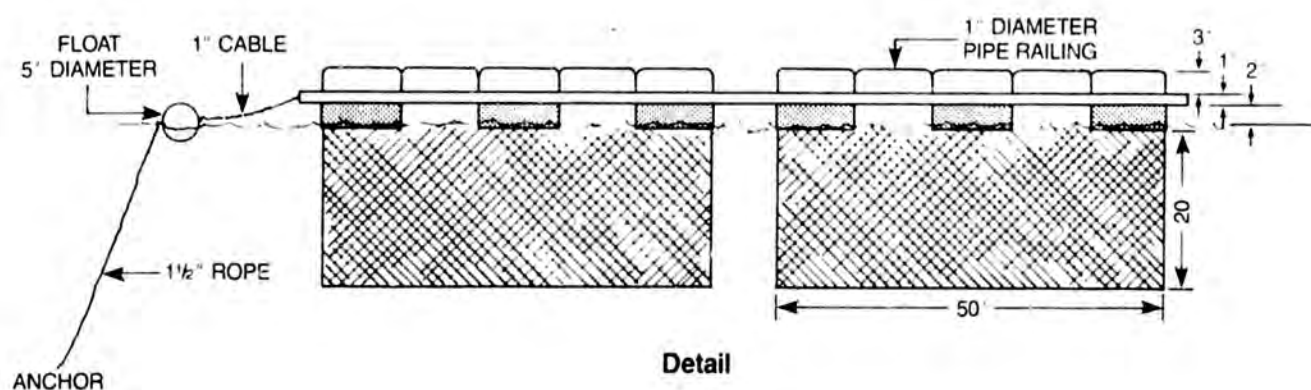
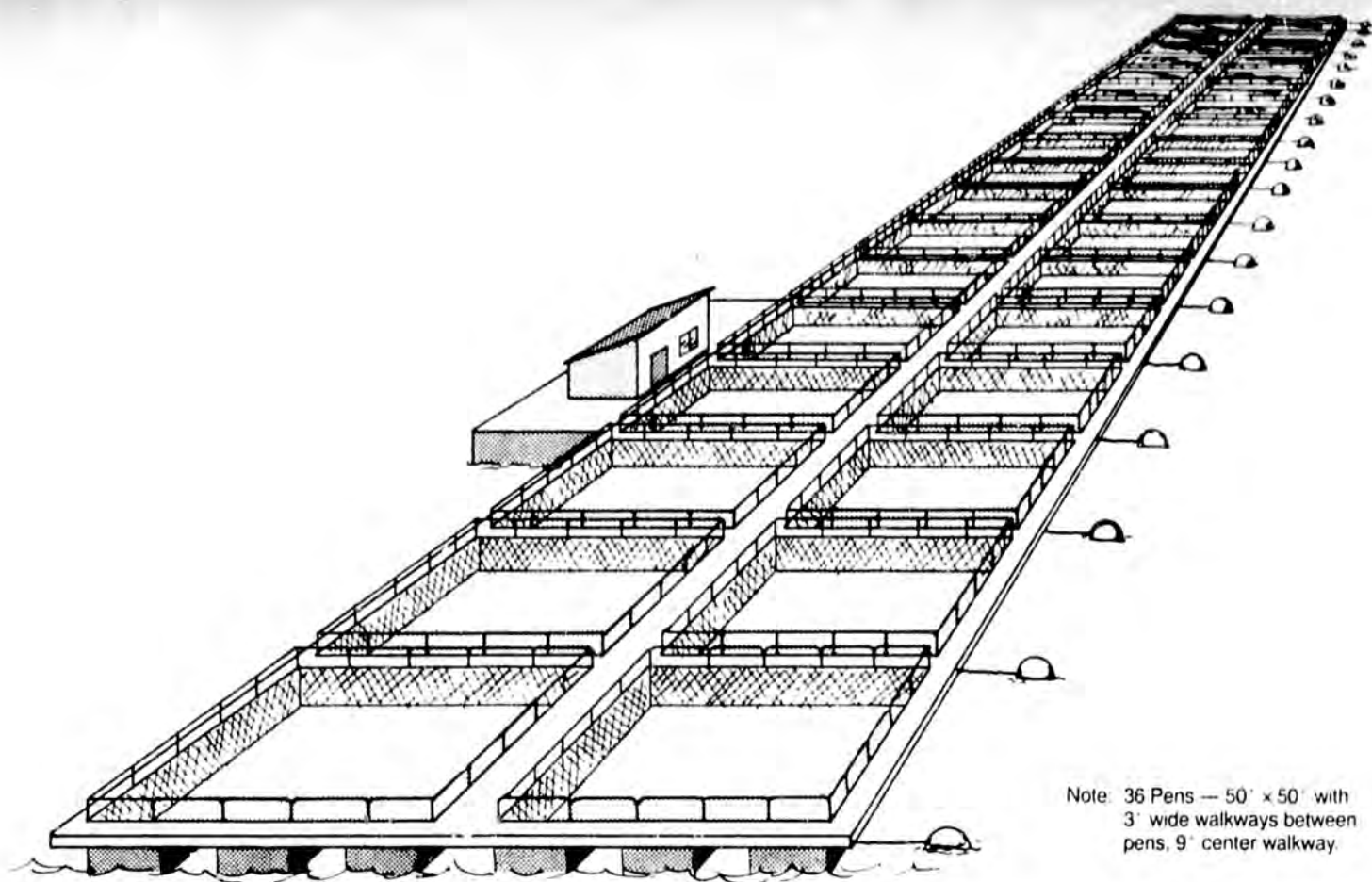


**Figure 2.**  
General Locations of  
Existing Commercial  
Net-Pen Operations



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 m<sup>2</sup> (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 m<sup>3</sup> 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 m<sup>3</sup> to encourage a small cottage industry, pens are stocked to maximal densities which may exceed 40 kg/m<sup>3</sup>. 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/m<sup>3</sup>. 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 ( $ml\ O_2/m^2/hr$ ).

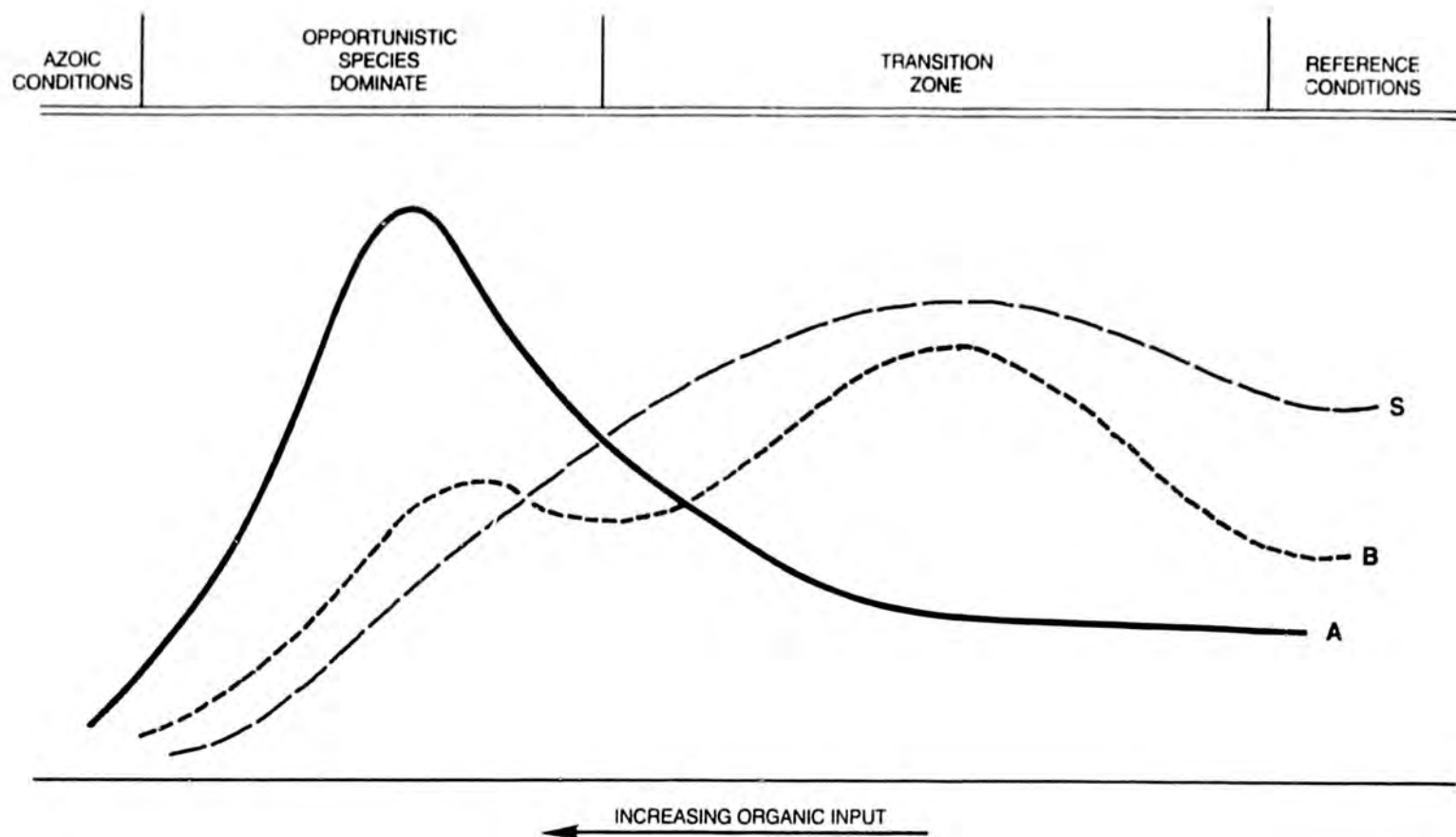
Another method for assessing the impact of organic deposition is the reduction oxidation (redox) potential. This measures sediment oxygen content at different depths to determine depth of the boundary between aerobic and anaerobic sediments. At this point (the redox potential discontinuity or RPD) oxygen 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/m<sup>2</sup>/day. It was estimated that the total area affected below this net pen (540 m<sup>2</sup>) was 6000 m<sup>2</sup>. Similar observations from studies of pulp mill and sewage treatment plant discharges reported an affected area of 5 to 23 km<sup>2</sup>.

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 H<sub>2</sub>S. 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/m<sup>2</sup>/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/m<sup>2</sup>/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-m<sup>2</sup> 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 m<sup>2</sup>) fish farms in Scotland showed good correlation between predicted and observed redox potentials at all six farms. Predictions correlated with species diversity in 4 of 5 farms. Weston and Gowen (1988) also tested this model at two farm sites in Puget Sound - a very large (14,560 m<sup>2</sup>) farm at Clam Bay, Kitsap County and a 1184 m<sup>2</sup> 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 km<sup>2</sup> (768 square nautical miles) at high tide with a volume of about 169 km<sup>3</sup> (26.5 cubic nautical miles).

Puget Sound is strongly affected by the force of tides, which provide most of the energy for movement of water in the Sound. Tidal exchanges, from low to high tide, can be as great as 5 m (16 ft) resulting in an average of about 3.25 km<sup>3</sup> 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.

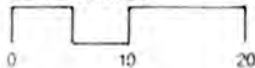


Source: Strickland 1983

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

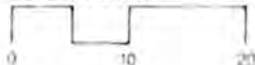
**Figure 6.**  
Generalized Surface Water  
Movement at Flood Tide  
in Puget Sound



Source: Puget Sound Water Quality Authority 1986

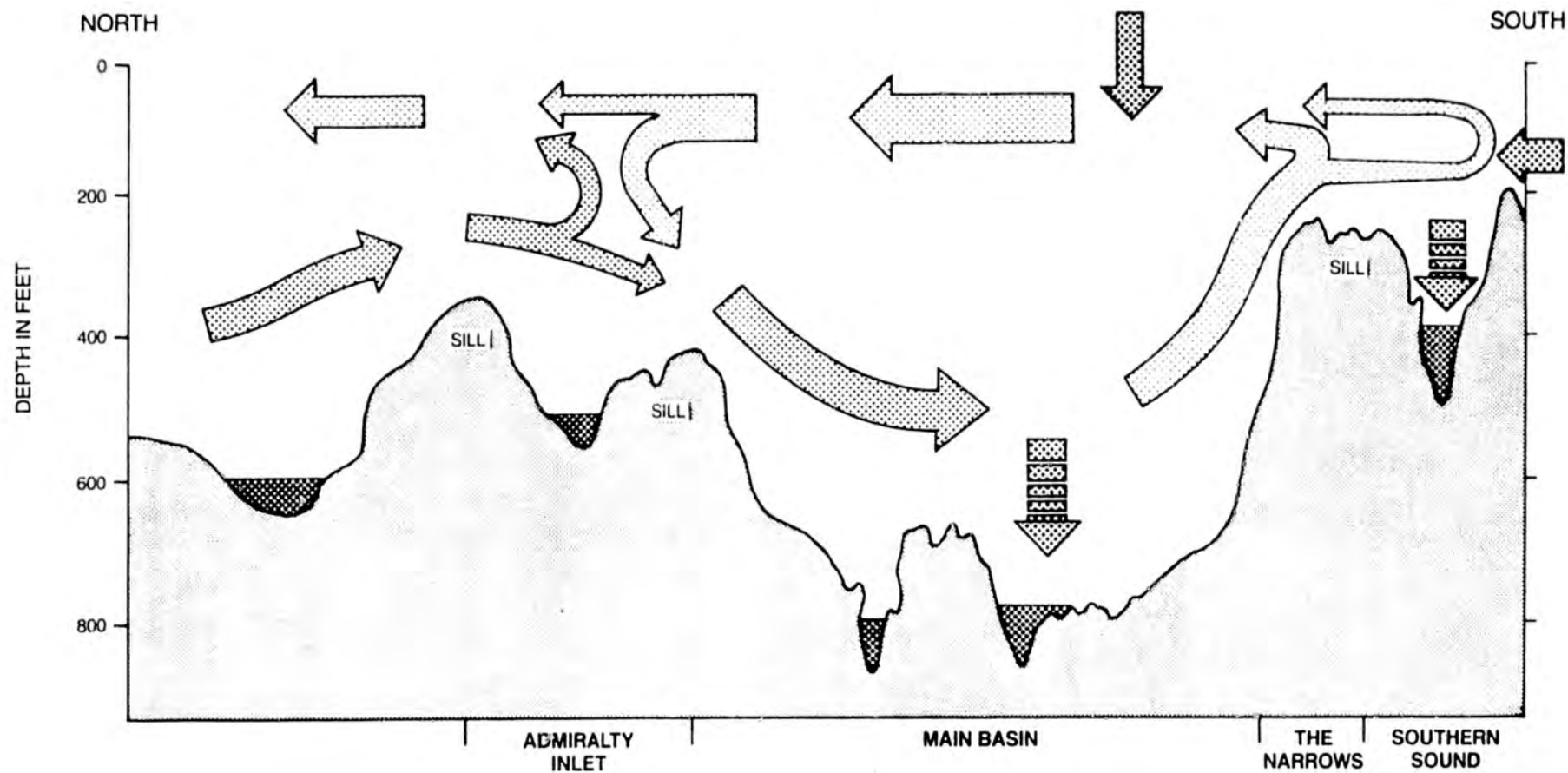


SCALE IN MILES



- 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**

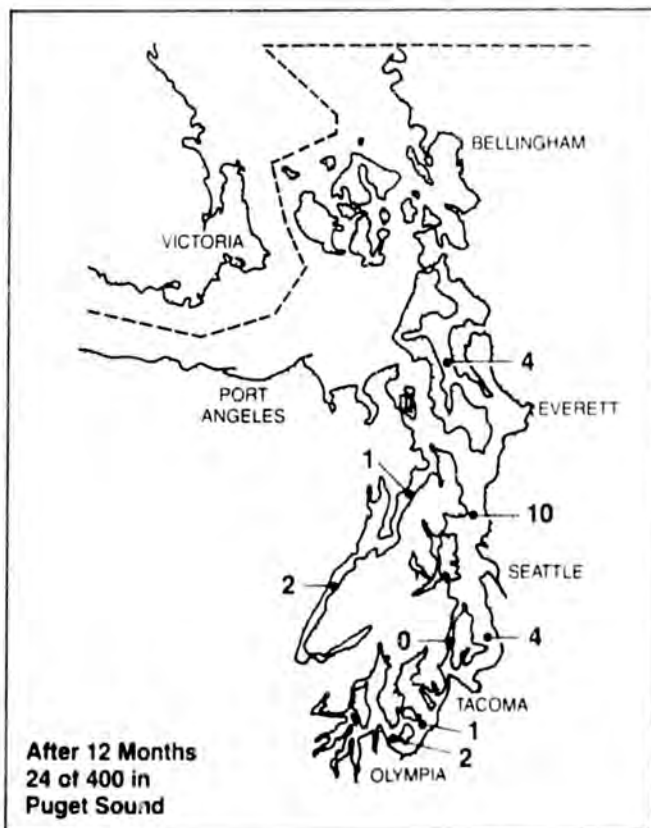
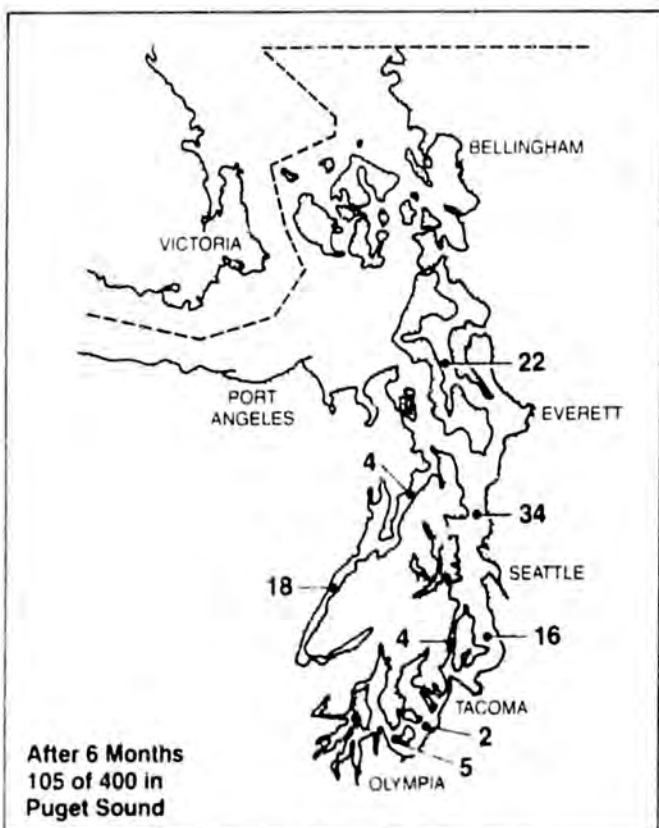
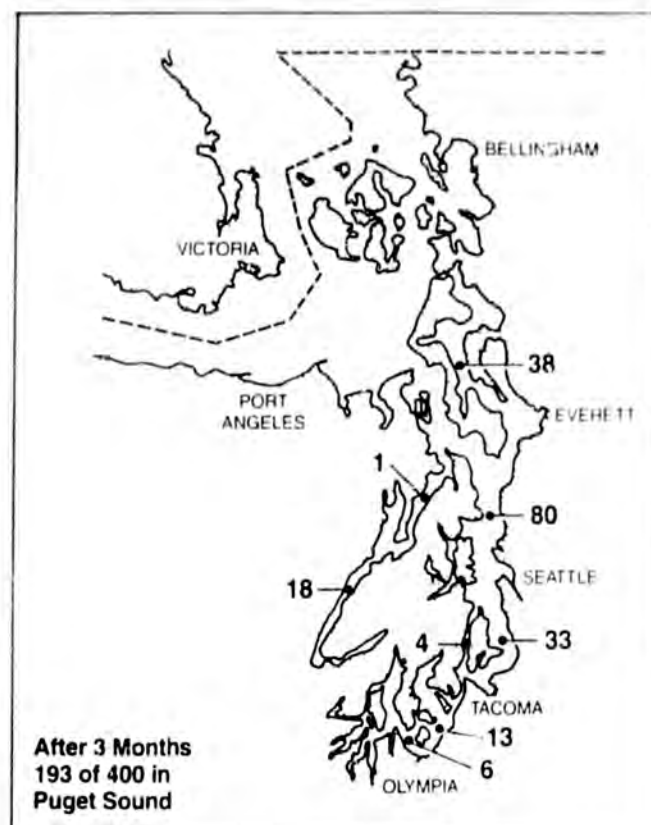
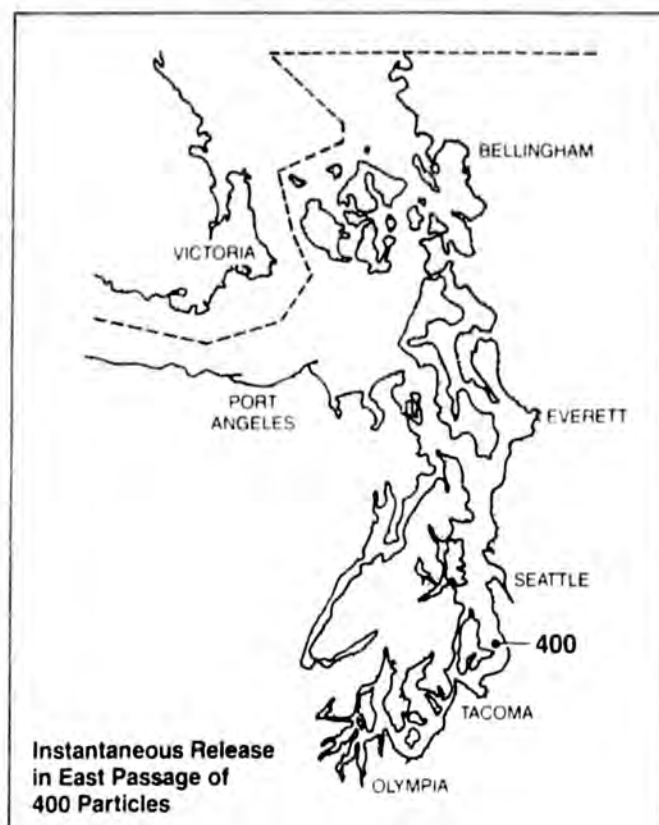
In addition to tidal driven water exchanges, meteorological conditions can cause large intrusions of saline, coastal water. According to Cannon (1983), "in the Strait of Juan de Fuca, the waterway connecting the Sound with the Pacific Ocean, winter storms with predominantly southerly winds along the 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 <sup>a</sup>  | -0.2                                                        | -0.2     | -0.2     | -0.2     |
| Temperature (°C)             |                                                             |          |          |          |
| upper limit                  | 13                                                          | 16       | 19       | 22       |
| increase limit <sup>b</sup>  | +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 <sup>c</sup> | +/-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. |          |          |          |

<sup>a</sup> decrease limit if background is less than lower limit

<sup>b</sup> increase limit if background is greater than upper limit (see Chapter 173-201 WAC for specific equations for increase limit)

<sup>c</sup> 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.

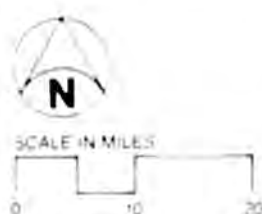
In summary, dissolved oxygen problems in Puget Sound most commonly occur in certain embayments that have poor circulation, such as southern Hood Canal, Budd Inlet, and Holmes Harbor. These problems typically occur during periods of low tidal exchange in late summer and autumn, and are related to phytoplankton 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 ( $\text{NH}_3$ ) 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 ( $\text{C-14}$  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  $16 \text{ cm sec}^{-1}$ ) 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  $1.7 \times 10^7 \text{ m}^2$  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-

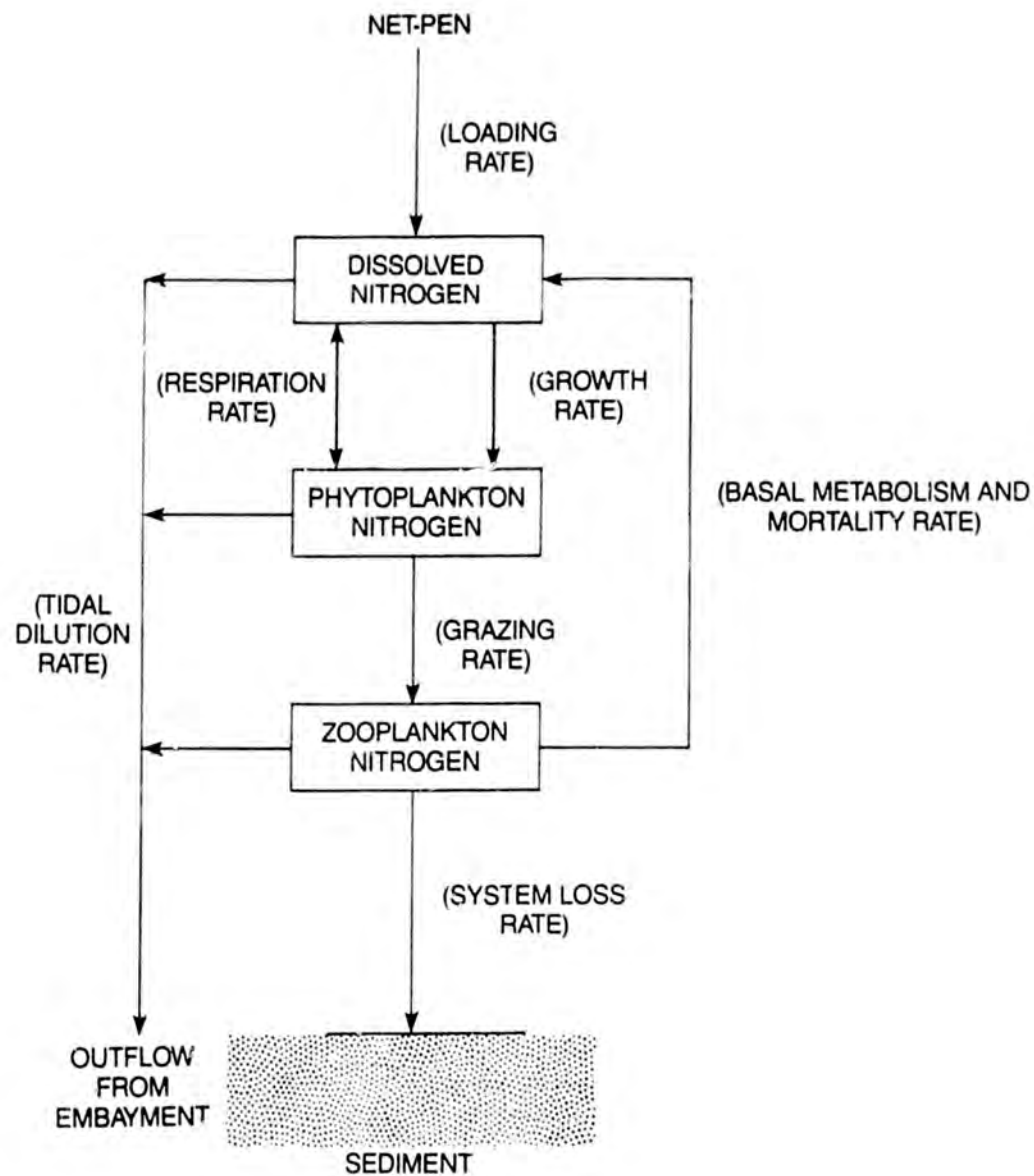


**Figure 11.**  
Schematic Representation of the  
Processes Simulated in the Keiffer  
and Atkinson Phytoplankton-Nutrient Model

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 ( $\delta N$ ) 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<sup>2</sup>)  
 Z<sub>m</sub> = mean depth or depth of the mixed layer (m)  
 D = dilution rate of the embayment by tidal exchange (day<sup>-1</sup>)

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><br>(mg/l) |          | <u>Phytoplankton</u><br>(mg/l) |          | <u>Zooplankton</u><br>(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