

ALASKA LEGISLATURE SPECIAL COMMITTEE/SUBJECT FILE 8672
1899 SCOMM 75: MARICULTURE (FISH FARMING), 1987-1990 1/6

TEMPERATURE*

	Good	Medium	Poor
Summer	10 - 15°C	16 - 21°C	> 21°C
Winter	> 7°C	5 - 7°C	< 4°C
	No short duration fluctuations in temperature.	Some short duration fluctuations in temperature.	Unpredictable & harmful fluctuations in temperature.
Fish Responses:			
	Good year round growth; sustained growth in winter.	Good growth but metabolic stress due to warm summer	Poor growth. Mortalities due to disease & thermal stress.

* Temperatures taken at 2m depth.

Interpretation

The optimal temperature range for culturing B.C. salmon species has yet to be determined, though it is believed that temperatures between 10 to 15°C for at least four months of the year give the best all round growth results (Kennedy, 1978). Year round ranges within 5 to 16°C are acceptable (Weston, 1986). At present, studies within the industry are being conducted to assess the merits of rearing fish in warmer water versus cooler water. Warm water temperatures (above 15°C) accelerate fish growth, decreasing the time and cost spent in getting fish to marketable size. At the same time, water temperatures approaching 21°C may cause thermal stress, and enhance incubation of disease organisms, resulting in mortalities that may greatly reduce the harvest biomass. Cool water rearing generally results in lower mortality rates, but also slower growing fish. Consequently more time and cost is involved in getting fish to the harvest stage. Fish are slowest growing in the colder winter months; 4 or 5°C being considered the minimum acceptable temperature. Temperatures below 4°C increase mortalities, and can be lethal to young fish (Kennedy, 1978).

Siting Opportunities

B.C. coastal waters provide a wide range of temperature regimes. Johnstone Strait provides cooler, well-mixed water to the areas north of Quadra Island, such as Okisollo Channel and Nodales Channel. Here,

summer surface temperatures usually average 10°C or less. Other areas such as Desolation Sound, Hoskyn Channel, and Jervis and Sechart Inlets have higher summer temperatures, which may rise above 21°C (Thomson, 1981). Sites should be selected that offer relatively uniform temperatures year round. Areas of extreme variations should be avoided: Poorly flushed, enclosed bays or inlets may suffer extreme summer temperatures; waters at the heads of fjords may undergo rapid drops in temperature due to glacial or snowmelt water discharge (see Hydrology).

Salmon have a low tolerance to temperature changes, and sites with small, predictable variations in water temperature are more preferable to areas that undergo rapid fluctuation (i.e. temperature changes greater than 5°C within a 12 hour period). Areas of rapid temperature flux may occur in warm water bays subjected to near-shore upwelling during offshore breezes (Thomson, 1981); for example, Nanoose Bay, Departure Bay, Kanish Bay and Tribune Bay. Other areas that may have rapid temperature changes are found at the mouths of inlets, where warm inlet water meets cooler channel water (e.g. Bute and Knight Inlets). Sills near the heads of some inlets may cause temperature fluctuations when cold, deep water is deflected to the surface.

Salmonid species vary in their range of temperature tolerance. Chinook salmon are the most sensitive to temperature fluctuations. Rainbow trout (steelhead) are the least sensitive to fluctuations and tolerate much greater temperature extremes. Another factor is the age of the fish: Generally, smolts and younger fish are more sensitive to temperature than older fish (Kennedy, 1978). When evaluating the temperature suitability of a site, the species to be reared should be considered.

Mitigation Opportunities

There are few methods for mitigating sudden changes in water temperature. Temperature increases can usually be dealt with by increasing the depth of the net pens so that fish can escape to the cooler water below. High water temperature can also be remedied by pumping deeper, cooler water into the seapens. To date, there do not appear to be any practical methods for warming water that is too cold.

DISSOLVED OXYGEN*

	Good	Medium	Poor
Minimum			
Oxygen			
Concentration:			
	8.1 mg/l (5.7 ml/l)	6.2 mg/l) (4.3 ml/l)	4.5 mg/l (3.2 ml/l)
Minimum			
Oxygen			
Saturation:			
	100%	79%	57%
Fish Response:			
	Few fish show symptoms of oxygen distress.	Some show symptoms of oxygen distress.	Large portion of population show symptoms of oxygen distress.
Risk to Operation:			
	No risk.	Some degree of risk if oxygen minima are prolonged beyond a few hours.	Substantial losses if oxygen minima are prolonged beyond a few hours.

*Concentration values determined at corresponding ratings for temperature and salinity (see text). saturation values derived from Davis, 1975.

Interpretation

Dissolved oxygen is the governing factor when assessing the suitability of marine sites for aquaculture. All oxygen-dependent organisms require particular minimal levels of oxygen to survive. Below these levels hypoxia and oxygen starvation occur, with concomitant ill-effects depending on the magnitude of the oxygen deficiency (Prosser and Brown, 1962).

The criteria for determining oxygen minima must take into account the nature of the exchange medium (environment), and factors that affect the availability of oxygen. For all animals, oxygen uptake is facilitated by an oxygen gradient between the blood of the organism and the surrounding medium. Oxygen requirements of aquatic animals are met by the amount of oxygen dissolved in the water. The gradient required to effect movement of oxygen into the blood is produced by a difference between the oxygen concentration in the animal's blood and the surrounding water. The degree of net movement is a function of the magnitude of the external concentration. When the concentration of dissolved oxygen in the surrounding water is greater than that of the fish's blood, oxygen enters the blood along a diffusion gradient. More oxygen diffuses into the blood per unit time when the external concentration is high (relative to the fish), and less as the external concentration decreases. At low oxygen concentrations, the fish must circulate more water over its gill membranes to obtain the oxygen it requires. The availability of oxygen in water is governed by temperature and dissolved solids (Hoar, 1975).

Dissolved oxygen concentration can be expressed in a variety of units, the most common being milligrams or millilitres of oxygen per litre of seawater (mg/l or ml/l), and percent saturation. In practice, it is preferable to express the oxygen concentration in mg/l because it is the actual amount of oxygen (mg), not its volume (ml), that is important to the fish (Hoar, 1975; Davis, 1975). The availability of oxygen in seawater is commonly analysed in terms of percent saturation (e.g. 100%). This is a function of the solubility of oxygen in water, which will vary depending on temperature and salinity. For example, at 10°C, freshwater is fully saturated (100%) when the oxygen concentration is about 11.3 mg/l. If the water were only 50% saturated it would have half the amount of oxygen [(5.6 mg/l); Davis, 1975]. Thus a body of water may be able to hold 11.3 mg of oxygen per litre, but only 5.6 mg/l are available because the water is 50% saturated.

Percent saturation is important because it reflects the magnitude of the oxygen gradient between the fish and the surrounding seawater. When water is 100% saturated with oxygen, the fish's blood can also be fully saturated. To some extent, fish can maintain their blood at 100% saturation even if the external saturation is somewhat lower due to the oxygen affinity of hemoglobin (Fry, 1957); however, there is a limit to this compensatory mechanism. Gradually, as saturation levels decrease the oxygen saturation of the blood decreases (Fry, 1957).

As temperature and salinity increase, the concentration of dissolved oxygen in seawater decreases (Davis, 1975). Of the two, temperature has the most profound affect on oxygen solubility (see Tables i-iii). Under most conditions, a 1°C change in temperature has almost 4 times the effect on oxygen solubility as a 10/00 change in salinity. A fish in warm water must pump more water over the gills than in cold water to obtain a given amount of oxygen per unit time, because of the reduced oxygen levels in warm water. Severe respiratory problems can result from

a combination of high temperature (low oxygen concentration) and low oxygen availability (water not fully saturated) (Davis, 1975).

Criteria for the minimal dissolved oxygen requirements for fish vary. One estimate gives a minimum range of 5 to 6 mg/l (Kennedy, 1978), while others report that 6 to 7 mg/l should be considered minimum acceptable levels (Weston, 1986). In both cases, the criteria were calculated on the basis of a fish's average metabolic needs, but do not establish lethal or sublethal limits. When establishing oxygen minima the lethal and sublethal effects of low oxygen (hypoxia) should be considered. Fish respond to hypoxia with a number of compensatory mechanisms and behaviours. These include increased ventilation rates, decreases in feeding and swimming behaviours, as well as biochemical changes. Over time, these responses cause stress that may manifest increased susceptibility to disease or reduction in growth (Davis, 1975). Therefore, low levels of oxygen that are above lethal levels may affect fish farm production by reducing growth rates and increasing mortalities.

The dissolved oxygen criteria given herein are based on those developed by Davis (1975) to include the levels at which sublethal effects of hypoxia occur. Davis argues that any level of oxygen that causes stress will eventually result in an increase in the mortality rate (Davis, 1975). Davis' criteria have been modified to take into account the crucial role temperature and salinity play in dissolved oxygen availability, and to more properly reflect conditions in the natural environment (Davis' criteria were established from laboratory tests under uniform conditions). Tables were constructed to calculate the availability of dissolved oxygen at various temperature and salinity regimes, using Davis' critical saturation values (see Tables i-iii). The dissolved oxygen values were determined at the corresponding ratings for temperature and salinity. For example, good temperature ratings are between 10 and 15°C in summer, and greater than 7°C in winter. Optimum salinity is above 24‰ and common salinity values for B.C. waters are about 28‰. From Table 1, the lowest value of dissolved oxygen within these ranges is 8.1 mg/l at 100% saturation. This occurs at 15°C and a salinity of 28‰. The oxygen concentration criteria given above thus account for sublethal effects, as well as reflecting the good to poor ranges of temperature and salinity. They represent minimum values for each rating, though it should be realized that actual dissolved oxygen concentrations in the environment may be higher.

As well as requiring certain amounts of oxygen, fish are extremely sensitive to changes in oxygen concentration. In general, fish are more affected by rapid, rather than gradual, changes in oxygen concentration. Fish in the wild can avoid adverse changes in dissolved oxygen simply by swimming away to more favourable areas. Fish in net pens are unable to avoid adverse oxygen conditions. Consequently, areas that are known to have sudden changes in dissolved oxygen should be avoided, unless adverse conditions can be mitigated (see below).

Dissolved oxygen levels can change dramatically as a result of plankton photosynthetic activity, upwelling of anoxic deep water, or a sudden shift in the biochemical oxygen demand (BOD) of an area (Weston, 1986). These changes can occur over relatively short periods of time. For example, a phytoplankton bloom can supersaturate an area with oxygen during the day, and severely undersaturate it at night when the organisms shift from photosynthetic to respiratory metabolism (Davis, 1975). Plankton bloom die-offs have been shown to seriously deplete available dissolved oxygen due to the increase in chemical oxygen demand (COD) associated with decay (Weston, 1986). The fish in the net pens and fouling organisms on the nets also affect the levels of dissolved oxygen. This could cause serious problems in areas where there is minimal oxygen replenishment due to poor flushing (Weston, 1986).

Salmonid species vary in their oxygen requirements. In general, salmon require higher levels of dissolved oxygen than other marine fish, probably a result of their pelagic habits (Davis, 1975). Chinook and Coho salmon have the highest requirements, and begin to show symptoms of oxygen stress when oxygen is below saturation, or less than 9 mg/l (Whitmore *et al.*, 1960). Atlantic salmon generally do not begin to exhibit symptoms of oxygen distress until the saturation drops to about 44%, or less than 4.5 mg/l (Kutty and Saunders, 1973). Steelhead require at least 64% saturation and 6 mg/l to avoid oxygen distress (Itazawa, 1970).

The age and size of the fish should also be taken into consideration. Smaller fish generally require more oxygen than larger fish to meet their higher metabolic demands (Hoar, 1975). Juvenile coho salmon appear to grow faster as oxygen levels increase: Herrmann (1958) found that juvenile coho at 20°C and 8 mg/l dissolved oxygen showed weight gains of 92%, as opposed to juveniles in 20°C and 4 mg/l dissolved oxygen, which showed only 52% gains in weight (Davis, 1975). Weight gains appear to decrease at levels above saturation (Davis, 1975), so there may be an upper limit of tolerance to dissolved oxygen.

There are a number of indications that fish can acclimate to lowered oxygen levels (Davis, 1975). Compensation, through acclimation and acclimatization, may alter the animal's critical oxygen demands (Hoar, 1975). An improved capacity to tolerate hypoxic environments has been demonstrated in a number of fish species. In general, there are two different levels at which compensation can occur; there are adjustments that enhance the supply of oxygen and adjustments that restrain its utilization (Hoar, 1975). Beamish (1964) noted that fish acclimated to 50% saturation levels performed better at this level than fish accustomed to full saturation levels. Compensation through metabolism is also well documented. Several species of fish have been shown to use more oxygen in the summer than they do in the winter, even though they are maintained at a constant temperature (Hoar, 1975). Davis (1975) considers that acclimation ability may be a built-in safety factor for species

encountering low oxygen conditions, but does not feel that there is sufficient evidence to warrant modification of oxygen criteria to include acclimatory ability (Davis, 1975). It should also be noted that acclimation occurs over days or weeks under constant conditions. The natural environment may not supply the uniform conditions necessary for acclimatization to develop.

All oxygen criteria should be considered with species-specific tolerances in mind. Most fish can tolerate short term, small magnitude changes in dissolved oxygen. When rating a site, the magnitude and duration of dissolved oxygen changes should be taken into account, as well as the species to be reared. A site that has medium year round oxygen levels may be more preferable than one at which good oxygen levels are only available for parts of the year. Also, a site with medium or poor oxygen levels may not be suitable for chinook or coho, but may be adequate for Atlantic salmon, which are more tolerant to low dissolved oxygen levels. Finally, a site poor in oxygen, but good in terms of salinity and temperature may be made suitable by aerating the water in the net pens. Oxygen criteria should not necessarily be viewed as absolute requirements, but as guidelines to choosing a site.

Siting Opportunities

Oxygen levels in coastal waters can be highly variable, both spatially and temporally. In general, tidal exchanges ensure adequate levels of dissolved oxygen to most coastal areas. Pickard (1961, 1963) provides a comprehensive study on the oceanographic characteristics for most of the inlets and channels of the mainland and Vancouver Island coasts. Large runoff inlets appear to show less variation in dissolved oxygen values along an inlet at any depth than do small runoff inlets (Davis, 1975). Supersaturation of upper layers is common and there is often an oxygen maximum at depths in which conventional fish farms operate. Small runoff inlets tend to have lowest oxygen values near the inlet head. Vancouver Island inlets show considerable variability in dissolved oxygen (Pickard, 1963). This probably relates to the high variation in temperature and salinity values recorded for these inlets.

Most coastal inlets have underwater sills at their mouths, and a few longer inlets have multiple sills throughout their length. Underwater sills change the flow characteristics of water as it enters or leaves the inlet. Combined with freshwater input, most inlets tend to show stratification of their inside waters, with dense, low oxygen water in the depths overlaid by warmer, high oxygen surface waters (Thomson, 1981). The depths at which low oxygen could become a problem vary, but for practical purposes are too deep to affect conventional fish farms, providing the strata remain stable. Problems occur when dense, low oxygen water mixes with water at the surface. This can occur in areas with active tidal flux, such as Johnstone Strait. In these areas, deep and

surface waters are well mixed, resulting in a uniform lowering of oxygen levels throughout the water column (Thomson, 1981).

Some inlets in B.C. experience seasonal fluxes in dissolved oxygen as a result of turnover. This is a common occurrence in winter, when poorly oxygenated deep water moves to the surface and displaces the well oxygenated upper layer. This phenomenon is mainly caused by differences in temperature (Thomson, 1981). During turnover, surface dissolved oxygen levels may decrease by 1 or 2 mg/l. In extreme conditions, anoxic bottom water may entirely replace oxygenated surface water causing high mortalities in some areas.

Phytoplankton can also drastically alter dissolved oxygen levels (see Phytoplankton). Recently, a plankton bloom occurred in the southern Johnstone Strait area that produced high mortalities at operating fish farms. The mortalities appeared to be caused by a sudden change in dissolved oxygen in this area (Aasen, pers. comm., 1987). Assessment of a site for aquaculture suitability should take into account the bloom history of the area.

Waste material from all sources that use the ocean for disposal, as well as the fish farms themselves, can deplete dissolved oxygen levels (see Pollution). The degree of such an effect is dependent on the frequency and magnitude of effluent discharges. Siting assessment should consider the proximity of pollution sources, including other farms in the area.

The importance of the oceanographic characteristics of an area should not be overlooked. Year round monitoring of dissolved oxygen levels should be conducted to ensure an adequate dissolved oxygen supply. Site selection should take into account the duration and magnitude of dissolved oxygen changes, as well as ensuring that oxygen minima can be maintained for most of the year.

Mitigation Opportunities

The application of good husbandry practices should mitigate short term small alterations in dissolved oxygen. The operator should ensure that net pens are not overcrowded, and the nets remain free of fouling organisms. Crowding and fouling organisms substantially increase the oxygen demands on an area. Decreasing stocking densities should be considered to overcome short term adverse conditions. Aeration by air stones or some other means can artificially elevate oxygen levels within the net pens. More drastic changes can be alleviated by pumping deeper, well oxygenated water to the surface during the summer, or by increasing the depth of the net pens to allow fish to escape from the high metabolic demand of warm, oxygen poor water. Pumping deeper water during times of plankton blooms, however, may artificially amplify the problem by supplying nutrients to the plankton. In extreme cases, it may be necessary to move the net pens to a more favourable area.

CONCENTRATION OF OXYGEN AT 100% SATURATION IN SEAWATER

(in milligrams/ litre, from normal atmosphere saturated with
with water vapour at a total pressure of 760 mm Hg)

TEMP.		SALINITY (‰)							
(C)	:	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00
4	:	11.93	11.85	11.77	11.70	11.62	11.54	11.47	11.39
5	:	11.63	11.56	11.48	11.41	11.33	11.26	11.18	11.11
6	:	11.35	11.27	11.20	11.13	11.05	10.98	10.91	10.84
7	:	11.07	11.00	10.93	10.86	10.79	10.72	10.65	10.58
8	:	10.81	10.74	10.67	10.60	10.54	10.47	10.40	10.33
9	:	10.56	10.49	10.43	10.36	10.29	10.23	10.16	10.10
10	:	10.32	10.25	10.19	10.12	10.06	10.00	9.93	9.87
11	:	10.09	10.02	9.96	9.90	9.83	9.77	9.71	9.65
12	:	9.86	9.80	9.74	9.68	9.62	9.56	9.50	9.44
13	:	9.65	9.59	9.53	9.47	9.41	9.35	9.30	9.24
14	:	9.44	9.38	9.33	9.27	9.21	9.16	9.10	9.04
15	:	9.24	9.19	9.13	9.08	9.02	8.97	8.91	8.86
16	:	9.05	9.00	8.94	8.89	8.84	8.78	8.73	8.68
17	:	8.87	8.82	8.76	8.71	8.66	8.61	8.55	8.50
18	:	8.69	8.64	8.59	8.54	8.49	8.44	8.39	8.34
19	:	8.52	8.47	8.42	8.37	8.32	8.27	8.22	8.17
20	:	8.36	8.31	8.26	8.21	8.16	8.11	8.07	8.02
21	:	8.20	8.15	8.10	8.05	8.01	7.96	7.91	7.87
TEMP.									
(C)	:	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00
4	:	11.32	11.24	11.17	11.09	11.02	10.95	10.87	10.80
5	:	11.04	10.96	10.89	10.82	10.75	10.68	10.61	10.54
6	:	10.77	10.70	10.63	10.56	10.49	10.42	10.35	10.29
7	:	10.51	10.45	10.38	10.31	10.24	10.18	10.11	10.05
8	:	10.27	10.20	10.14	10.07	10.01	9.94	9.88	9.81
9	:	10.03	9.97	9.90	9.84	9.78	9.72	9.65	9.59
10	:	9.81	9.74	9.68	9.62	9.56	9.50	9.44	9.38
11	:	9.59	9.53	9.47	9.41	9.35	9.29	9.23	9.18
12	:	9.38	9.32	9.26	9.21	9.15	9.09	9.04	8.98
13	:	9.18	9.12	9.07	9.01	8.96	8.90	8.84	8.79
14	:	8.99	8.93	8.88	8.82	8.77	8.71	8.66	8.61
15	:	8.80	8.75	8.70	8.64	8.59	8.54	8.48	8.43
16	:	8.62	8.57	8.52	8.47	8.42	8.37	8.31	8.26
17	:	8.45	8.40	8.35	8.30	8.25	8.20	8.15	8.10
18	:	8.29	8.24	8.19	8.14	8.09	8.04	7.99	7.95
19	:	8.13	8.08	8.03	7.98	7.93	7.89	7.84	7.79
20	:	7.97	7.92	7.88	7.83	7.78	7.74	7.69	7.65
21	:	7.82	7.78	7.73	7.69	7.64	7.60	7.55	7.51

CONCENTRATION OF OXYGEN AT 79% SATURATION IN SEAWATER

(in milligrams/ litre, from normal atmosphere saturated with
with water vapour at a total pressure of 760 mm Hg)

TEMP.		SALINITY (/oo)							
(C)		14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00
4	:	9.43	9.36	9.30	9.24	9.18	9.12	9.06	9.00
5	:	9.19	9.13	9.07	9.01	8.95	8.89	8.83	8.78
6	:	8.96	8.91	8.85	8.79	8.73	8.68	8.62	8.56
7	:	8.75	8.69	8.64	8.58	8.52	8.47	8.41	8.36
8	:	8.54	8.49	8.43	8.38	8.32	8.27	8.22	8.16
9	:	8.34	8.29	8.24	8.18	8.13	8.08	8.03	7.98
10	:	8.15	8.10	8.05	8.00	7.95	7.90	7.85	7.80
11	:	7.97	7.92	7.87	7.82	7.77	7.72	7.67	7.62
12	:	7.79	7.74	7.69	7.65	7.60	7.55	7.50	7.46
13	:	7.62	7.58	7.53	7.48	7.44	7.39	7.34	7.30
14	:	7.46	7.41	7.37	7.32	7.28	7.23	7.19	7.14
15	:	7.30	7.26	7.21	7.17	7.13	7.08	7.04	7.00
16	:	7.15	7.11	7.07	7.02	6.98	6.94	6.90	6.85
17	:	7.01	6.96	6.92	6.88	6.84	6.80	6.76	6.72
18	:	6.87	6.83	6.78	6.74	6.70	6.66	6.62	6.58
19	:	6.73	6.69	6.65	6.61	6.57	6.53	6.50	6.46
20	:	6.60	6.56	6.52	6.49	6.45	6.41	6.37	6.33
21	:	6.48	6.44	6.40	6.36	6.33	6.29	6.25	6.22

TEMP									
(C)		22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00
4		8.94	8.88	8.82	8.76	8.71	8.65	8.59	8.53
5		8.72	8.66	8.60	8.55	8.49	8.44	8.38	8.33
6		8.51	8.45	8.40	8.34	8.29	8.23	8.18	8.13
7		8.31	8.25	8.20	8.15	8.09	8.04	7.99	7.94
8		8.11	8.06	8.01	7.96	7.91	7.85	7.80	7.75
9		7.93	7.88	7.82	7.77	7.73	7.68	7.63	7.58
10		7.75	7.70	7.65	7.60	7.55	7.50	7.46	7.41
11		7.58	7.53	7.48	7.43	7.39	7.34	7.29	7.25
12		7.41	7.36	7.32	7.27	7.23	7.18	7.14	7.09
13		7.25	7.21	7.16	7.12	7.07	7.03	6.99	6.94
14		7.10	7.06	7.01	6.97	6.93	6.88	6.84	6.80
15		6.95	6.91	6.87	6.83	6.79	6.74	6.70	6.66
16		6.81	6.77	6.73	6.69	6.65	6.61	6.57	6.53
17		6.68	6.64	6.60	6.56	6.52	6.48	6.44	6.40
18		6.55	6.51	6.47	6.43	6.39	6.35	6.31	6.28
19		6.42	6.38	6.34	6.31	6.27	6.23	6.19	6.16
20		6.30	6.26	6.22	6.19	6.15	6.11	6.08	6.04
21		6.18	6.14	6.11	6.07	6.04	6.00	5.97	5.93

CONCENTRATION OF OXYGEN AT 57% SATURATION IN SEAWATER

(in milligrams/ litre, from normal atmosphere saturated with
with water vapour at a total pressure of 760 mm Hg)

TEMP.		SALINITY (‰)							
(C)	:	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00
4	:	6.80	6.76	6.71	6.67	6.62	6.58	6.54	6.49
5	:	6.63	6.59	6.54	6.50	6.46	6.42	6.37	6.33
6	:	6.47	6.43	6.38	6.34	6.30	6.26	6.22	6.18
7	:	6.31	6.27	6.23	6.19	6.15	6.11	6.07	6.03
8	:	6.16	6.12	6.08	6.04	6.01	5.97	5.93	5.89
9	:	6.02	5.98	5.94	5.90	5.87	5.83	5.79	5.76
10	:	5.88	5.84	5.81	5.77	5.73	5.70	5.66	5.63
11	:	5.75	5.71	5.68	5.64	5.61	5.57	5.54	5.50
12	:	5.62	5.59	5.55	5.52	5.48	5.45	5.41	5.38
13	:	5.50	5.47	5.43	5.40	5.36	5.33	5.30	5.27
14	:	5.38	5.35	5.32	5.28	5.25	5.22	5.19	5.15
15	:	5.27	5.24	5.21	5.17	5.14	5.11	5.08	5.05
16	:	5.16	5.13	5.10	5.07	5.04	5.01	4.98	4.95
17	:	5.06	5.03	4.99	4.96	4.93	4.91	4.88	4.85
18	:	4.95	4.92	4.90	4.87	4.84	4.81	4.78	4.75
19	:	4.86	4.83	4.80	4.77	4.74	4.71	4.69	4.66
20	:	4.76	4.74	4.71	4.68	4.65	4.62	4.60	4.57
21	:	4.67	4.65	4.62	4.59	4.56	4.54	4.51	4.48
TEMP.		SALINITY (‰)							
(C)	:	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00
4	:	6.45	6.41	6.36	6.32	6.28	6.24	6.20	6.16
5	:	6.29	6.25	6.21	6.17	6.13	6.09	6.05	6.01
6	:	6.14	6.10	6.06	6.02	5.98	5.94	5.90	5.86
7	:	5.99	5.95	5.92	5.88	5.84	5.80	5.76	5.73
8	:	5.85	5.82	5.78	5.74	5.70	5.67	5.63	5.59
9	:	5.72	5.68	5.65	5.61	5.57	5.54	5.50	5.47
10	:	5.59	5.55	5.52	5.48	5.45	5.41	5.38	5.35
11	:	5.47	5.43	5.40	5.36	5.33	5.30	5.26	5.23
12	:	5.35	5.31	5.28	5.25	5.21	5.18	5.15	5.12
13	:	5.23	5.20	5.17	5.14	5.10	5.07	5.04	5.01
14	:	5.12	5.09	5.06	5.03	5.00	4.97	4.94	4.91
15	:	5.02	4.99	4.96	4.93	4.90	4.87	4.84	4.81
16	:	4.92	4.89	4.86	4.83	4.80	4.77	4.74	4.71
17	:	4.82	4.79	4.76	4.73	4.70	4.67	4.65	4.62
18	:	4.72	4.69	4.67	4.64	4.61	4.58	4.56	4.53
19	:	4.63	4.60	4.58	4.55	4.52	4.50	4.47	4.44
20	:	4.54	4.52	4.49	4.46	4.44	4.41	4.39	4.36
21	:	4.46	4.43	4.41	4.38	4.36	4.33	4.30	4.28

SALINITY*

Good	Medium	Poor
Long Term		
Salinity:		
>24 ⁰ /oo	15 - 24 ⁰ /oo	<15 ⁰ /oo
Short Term		
Fluctuations (within 12 hr.):		
<3 ⁰ /oo change	3 - 5 ⁰ /oo change	>5 ⁰ /oo change
Fish Response:		
Little or no osmotic stress.	Subthreshold osmotic stress due to short term fluctuations.	Incomplete smolting. Poor growth. Possible sublethal osmotic stress due to short term fluctuations.

* Salinities measured at 4m depth.

Interpretation

There are no generally accepted standards for salinity in net pen culture (Weston, 1986). All five Pacific salmonid species and Atlantic salmon have been reared to maturity in both freshwater and seawater, although seawater rearing is the preferred method (Kennedy, 1978). Consequently, it is difficult to determine the optimum salinity range for rearing net pen fish. A reasonable assumption should be that after the fish undergo smoltification, salinity optima for net pen rearing would be those approaching oceanic salinity values (28 - 30⁰/oo).

Responses to salinity vary with species and age. There is growing evidence that salinity may affect growth rates as well as survivorship in some species. Presmolt and juvenile fish generally prefer brackish water (i.e. <20⁰/oo) for the first year of development, after which higher salinities are preferred as the fish age. Young coho apparently do not adapt to seawater as well as chinook or sockeye, and all species appear to grow faster in salinities between 5 and 17⁰/oo during the first year

(Clarke et al., 1981). Young Rainbow trout (steelhead) exhibit marked reductions in growth rates at salinities above $10^0/00$ during the first year, and a salinity $>20^0/00$ is detrimental to survivorship in this species (McKay & Gjerde, 1985). On the other hand, low salinities ($<17^0/00$) have been shown to decrease resistance to toxic substances in young coho, and increase susceptibility to *Vibrio* infections in Atlantic salmon (Alderdice, 1981; Gjerdrem & Aulstad, 1974). A husbandry practice that is becoming more prevalent in the industry involves "hardening" smolts for up to 1 year in brackish water. Juvenile fish are reared in areas where freshwater runoff produces a natural freshwater lens. As the fish mature, they are gradually acclimatized to more saline water, either by moving the net pens away from the lens, or by transferring the fish to another site. This technique apparently results in hardier fish that more readily adapt to saltwater (Furby, pers. comm., 1987).

The salinity of the open ocean is generally greater than $30^0/00$. Coastal waters vary in salinity due to freshwater input from rivers and rainfall runoff. The average salinity for B.C. coastal waters is about $28^0/00$, but this will vary from region to region, and is dependent on the amount of freshwater input (Thomson, 1981).

Freshwater input creates a brackish layer that overlies the denser seawater. Brackish layers are common to most of the fiords and inlets of the B.C. coast. Such layers usually extend to about 3m depth, and vary in salinity from 1 or $2^0/00$ near the heads of inlets, to $20^0/00$ at the mouths (Gilmarten, 1958). In times of high freshwater input, such as spring snowmelts or winter rainfall, the brackish layer can extend to 10m deep or more (Thomson, 1981). Brackish layer salinities vary with the volume and frequency of freshwater input, and with the amount of saline entrainment from deeper seawater. Consequently, salinity values for coastal waters are highly variable and subject to rapid change over short periods of time.

Salinity and temperature affect the level of dissolved oxygen in the water. Oxygen is less soluble in salt water than in fresh, so the brackish layers arising from river runoff tend to be rich in oxygen while saline oceanic waters are oxygen poor. When choosing a site, the extent of mixing between brackish water and oceanic water is of prime consideration (see Dissolved Oxygen).

Siting Opportunities

The Johnstone Strait and Discovery Passage areas are seasonally influenced by oceanic waters from the Pacific. Salinities in these regions tend to approach oceanic values between 28 and $32^0/00$. Waters from the Strait of Georgia are more variable, owing to the large freshwater input from the Fraser River. Strait of Georgia salinity values are generally within the 10 to $28^0/00$ range, but these are highly variable with depth and with the season (Thomson, 1981).

Most of the major inlets undergo estuarine circulation, in which a brackish layer resulting from river and rainfall runoffs is constantly moving seaward, independent of tidal cycles (Pickard, 1961). Inlets can be classified on the basis of how much freshwater input they receive: High runoff inlets, such as Knight, Bute, Toba and Howe Sound, generally receive annual freshwater discharge rates over 200 m³/s, and vary in surface salinities between 0.1 to 20‰. These inlets are subject to annual reductions in salinity during May to September. Low runoff inlets, such as Sechart, Jervis, and Seymour, typically have runoff rates below 200 m³/s annually. Their salinities range from 1 to 29‰. Major changes in salinity occur between April and July, and during October to January (Pickard, 1961).

Mitigation Opportunities

For most sites that experience shallow brackish layers, increasing the depth of the net pens often provides adequate refuge for fish that prefer higher salinity. Where the brackish layers are extensive, pumping of deeper, more saline water can be undertaken, though some method for aeration may be required if the water is low in oxygen. Areas of freshwater lensing, such as near river mouths, may be ideal for underyearling fish.

PLANKTON

Ratings:	Good	Medium	Poor
Description:	Production of phytoplankton low. No recorded blooms (large growths) of plankton harmful to fish.	Potentially harmful levels of phytoplankton production. Infrequent reports of plankton blooms but no direct severe losses to farmed fish due to harmful plankton or due to oxygen depletion.	High risk of losses due to plankton production. Frequent lethal blooms recorded involving severe fish loss due to direct harm or to oxygen depletion.
Fish Response:	None, or minor irritation from plankton.	Some irritation and stress due to direct harm from plankton or decreased dissolved oxygen.	Irritation and stress to fish resulting in direct kills or sub-lethal effects--disease, poor growth or maturation.
Farm Operation:	Little or no effect on farm operation.	Occasional curtailment of some activities such as feeding and net changes during plankton blooms, and increase in net cleaning to reduce fouling.	Mitigative measures, if possible, are required to prevent severe fish losses. Frequent net cleaning required.

Interpretation

Organisms which are unable to maintain their distribution against the movement of water masses are called "plankton". This group includes bacteria, plants (phytoplankton), and animals (zooplankton). Generally, with a few exceptions, all plankton are small and often microscopic. Some phytoplankton and zooplankton can move themselves through the water, but movement is weak in comparison with the prevailing water movement (Parsons, Takahashi, and Hargrave, 1977).

The component of primary concern to salmon farmers is the phytoplankton. These microscopic cells (about 1/50 millimetre) use carbon dioxide and the energy of sunlight in order to grow and reproduce just as land plants do. They produce (photosynthesize) more oxygen than they use (respire)

in the daytime, but are net consumers of oxygen at night. Like land plants in temperate areas, the phytoplankton respond to the increasing spring daylight with increased productivity (spring bloom). In some cases this results in an increase of abundance coloring the water brownish green or red. A marked discoloration can also occur in the fall, but in winter lower production results in greater water clarity. Blooms intense enough to color the water surface are called red tides. In addition to light availability several other factors, including nutrients, temperature, and zooplankton abundance control the abundance of phytoplankton.

Very little is known about British Columbia phytoplankton, especially north of Vancouver Island; many of the species found appear to be similar to those located off Norway, western Japan, Chile, western South Africa, and eastern Canada (Gaines and Taylor, 1986). Generally, the phytoplankton are composed of: non-swimmers suspended in the water, the most important of which are the diatoms; and swimmers, called flagellates, the most important of which are the dinoflagellates.

Diatoms are surrounded by silica shells, often containing spiny projections. Most of the year they dominate the phytoplankton, especially in the spring when cool temperatures, high nutrient levels, and well-mixed water favour them over other groups. Consequently, the spring bloom consists almost entirely of diatoms.

While most diatoms are beneficial, the chain-forming Chaetoceros convolutus damages fish gills. This organism, often effecting lethal damage because of its spines, is found nearly everywhere in British Columbia waters, with the possible exception of protected bays and inlets where it tends to settle out of the water column. The concentration necessary for damage appears to be approximately 5 cells/millilitre (ml). This species, like other diatoms, tends to favour well-mixed nutrient-rich water (Gaines and Taylor, 1986).

Flagellates swim by means of propulsion with one or more whip-like extensions (flagella). Consequently, they can travel between well-lighted surface waters and nutrient-rich deeper water, and as a result usually dominate over non-swimmers in calm protected areas.

The flagellate of primary concern to salmon farmers is Heterosigma akashiwo which is probably found in all temperate areas of the world. Although the mechanism is unknown, Heterosigma blooms have been linked to the deaths of caged fish in a number of areas. It is a small (15-20 micrometers) potato-shaped organism with two flagella, and many mucus-producing vesicles. Closely related to well-known toxic flagellates that have killed millions of fish in Japan, Heterosigma is usually found in the upper 5-10 meters of water. It tends to bloom between May and July after the diatoms have declined, commonly causing red water in restricted areas, but less often throughout the southern Strait of Georgia.

Heterosigma can tolerate an unusually wide range of salinity (2 to 50‰), preferring a range of 15 to 20‰. Although preferring higher temperatures, it has been known to reach concentration of hundreds of millions of cells per litre below 15°C and can adapt well to low and high light intensities.

There are also a number of other phytoplankton species of concern which may prove to be a problem in the future, but have not yet been implicated in any fish kills in British Columbia (Gaines and Taylor, 1986).

Summary of Fish Impacts

There are three main types of negative impact on farmed fish from phytoplankton blooms.

1. Chaetoceros blooms can directly harm fish by damaging their gills.
2. Heterosigma blooms also can directly harm fish, possibly through toxicity, as well as causing susceptibility to disease; Rainbow trout appear to be the fish species most susceptible to harm from Heterosigma.
3. Nighttime respiration by blooms of any phytoplankton species can cause mortality or stress on fish by depleting dissolved oxygen levels. When dying off at depth due to poor conditions (such as low light), these organisms can also deplete oxygen in the water as they decompose. This latter form of oxygen reduction usually occurs at a depth where the cells reach a state of neutral buoyancy (10-30m) and remain suspended in the water column (Herlinveaux, Fisheries and Oceans Canada, Institute of Ocean Sciences, Pers. Comm. 1987).

Weston (1986) reports that salmon farms may contribute to plankton blooms by releasing nutrients into the water column.

Siting Opportunities

Because of the environmental requirements of diatoms and flagellates, there are many areas in British Columbia where problems may occur. Consequently, site choice is largely a matter of risk assessment.

In some cases this is relatively simple, because there have been reports of bloom for certain areas. For instance, harmful Chaetoceros blooms have been reported for Porlier Pass on Vancouver Island, Nanaimo, Hoskyn Channel, Calm Channel, and Agamemnon Channel/Sechelt Inlet). Heterosigma blooms have been reported for Nanoose Bay and Barkley Sound. This organism has also bloomed regularly in areas influenced by the Fraser

River northwards on the east side of the Strait of Georgia (e.g. English Bay/Howe Sound and Sechelt Inlet) with occasional spread to the west side of the Strait (e.g. Sansum Narrows). Frequency of blooms is an important consideration here. Because so many factors affect blooms, a bloom may occur in one area, and yet the likelihood of future blooms may remain very low. Only areas where blooms tend to occur repeatedly should be considered high risk areas.

In some cases, biological oceanographic literature can be of great assistance. For instance, Parsons *et al.*, (1981 and 1984) report the existence of major biological fronts, or zones of high phytoplankton production at the north end of Georgia Strait in the Hoskyn, Lewis, and Sutil Channel areas. They also report high production zones at the southern end of the Strait in the Fraser Estuary areas. These frontal boundaries of high production move with the tidal cycles as well as being influenced by the circulation.

High production is inferred in these cases from data on chlorophyll-*a*, the photosynthetic pigment found in phytoplankton. The weight of chlorophyll-*a* per unit volume or area has been correlated with standing biomass stock of phytoplankton. For instance, Harrison *et al.*, (1983) report bloom conditions in the Strait of Georgia being reflected by chlorophyll-*a* values of up to 15 mg/m³.

In the absence of written or verbal reports or biological data, it may be necessary to look at an area in terms of circulation, mixing, temperature, salinity and nutrient availability to assess the risk of bloom conditions. Smaller fronts, more localized than those described above, may occur where deep nutrient-rich water wells up within the zone of light penetration. Such areas could include turbulent passages between islands such as Active Pass, Porlier Pass and other areas in the Gulf Islands (Parsons *et al.*, 1981), shallow sills such as Skookumchuk Narrows, and upwelling areas in bays, such as Nanoose Bay.

Where mixing and flushing are low in stratified bays and inlets, phytoplankton production may be reduced or not sustained because of rapid nutrient depletion (assuming no significant source of nutrients such as sewage discharge, landwater runoff, or other fish farms).

Unfortunately, prolonged stratification may result in other conditions undesirable for fish farming such as stagnation and oxygen depletion at depth, and subsequent oxygen depletion of the surface.

Mitigation Opportunities

Mitigation measures must be geared to the agent causing bloom conditions as well as to the nature of the harm being done. Unfortunately, it is not always possible to determine the cause at all or in time to reduce

the impact. For instance, the mechanism by which Heterosigma causes damage is not clearly known.

In many cases, husbandry practices can significantly contribute to the degree of damage caused, or how much damage is avoided. It is not uncommon for a bloom to occur in an area, with significantly different losses being encountered among different farms in the same area.

The first step of problem solution is to notice the problem before it causes much damage. The best way to accomplish this is routine monitoring of water conditions. Daily secchi disc readings give some idea of decreased light penetration caused by plankton blooms. However, these readings are of light penetration only and therefore can be confusing if affected by other factors such as increased water turbidity due to spring freshet and increased landwater runoff.

A more certain way of monitoring phytoplankton is to take water samples and do microscopic examinations and cell counts on a routine basis. A good frequency would be biweekly between early March and mid-September, with daily sampling and analysis if secchi readings begin to decrease. This is especially necessary to detect Chaetoceros which can form blooms within a week (Gaines and Taylor, 1986).

Several general practices can help reduce the damage caused by blooms. These include maintaining low stocking densities, and keeping the nets clear of fouling material. During a recent Chaetoceros bloom, farms stocking at 4 kg/m³ experienced significantly fewer losses than other farms stocking at 12 kg/m³. Also, it appears that if the nets are fouled, the oxygen demand of the fouling material coupled with the reduced flow through the nets makes oxygen depletion worse.

Deep nets may be effective in areas where Heterosigma blooms are likely, since these organisms generally favour the upper 5-10 m of water. However, there have been cases where Heterosigma blooms are distributed to quite deep levels, such as in the Agamemnon Channel in 1986. Where Chaetoceros blooms are likely, increasing net depth will probably not be effective because of the deeper nature of these blooms in well-mixed waters.

Pumping water into the nets from very deep levels has been considered as one mitigative tool to flush the pens. However, this can cause additional problems when the deeper water is low in oxygen. Further, deeper waters might also be high in nutrients and as a result increase or prolong the plankton bloom.

Ware(pers.comm.,1987) reports successfully dealing with a Chaetoceros bloom by pumping fresh water onto the surface of new smolts pens, while wrapping the pens with a tarpaulin. This technique may help control Heterosigma

blooms, although the organism's salinity tolerance should be taken into account. Of course, this approach necessitates a ready supply of fresh water.

POLLUTION

ings:	Good	Medium	Poor
cription:	Area is outside the environmental influence ¹ of industrial, municipal or local sources of pollution. Debris absent or rarely present.	Area is within the environmental influence ¹ of low continuous levels or rare periodic discharges of pollution. Sporadic debris (major storms).	Area is within the environmental influence ¹ of severe pollution (significant change in background levels of water quality characteristic). Areas within 100 m of outfall or diffuser are unacceptable ² . Prolific presence of debris on almost daily basis.
Fish Response:	None.	No known or measurable harm.	Mortalities; tainting of flesh; sub-lethal effects such as abnormal growth; accumulation of toxic materials; higher incidence of infection.
Farm Operation:	None.	Minor cleaning of equipment and nets. No mitigation of fish impacts required.	Continuous maintenance problems. Mitigative action required.

¹ Influence means there is a measurable change in ambient water quality caused by the pollution.

² Policy of B.C. Waste Management Branch is that areas 100 m downstream or within a 100 m radius of a municipal/industrial outfall or diffuser are considered dilution zones. Discharges must meet ambient water quality objectives by the end of this dilution zone.

Interpretation

The main types of pollution which can affect salmon farms are:

1. toxic, which has a poisoning effect on fish;
2. organic, which can deplete water column oxygen;
3. nutrient, which stimulates growth of algae (these can deplete water column oxygen, and some species harm fish);
4. acid, which changes ambient pH and affects toxicity of some pollutants;
5. sediment, which may clog or harm fish gills;
6. thermal, which alters the temperature of the ambient environment; and
7. debris, which clogs or damages nets and farm structures, and can exert a biochemical oxygen demand of the water column or sediments.

Pollution sources include: industrial and municipal effluents; discharges from anchored and passing boats; debris from logged watersheds or log-handling areas and log-towing operations; accidental spills from transport vessels (e.g. oil tankers); upland runoff contaminated with sediment or toxic substances (pesticides, oils, solvents, wood preservatives, cleaners, fertilizers); and cumulative impacts from other fish farms.

The negative impact might range from rapid mortality to long-term sub-lethal (lower resistance to disease, abnormal growth and maturation) in addition to tainting of fish flesh, and accumulation of chemicals and metals hazardous to humans.

Many of these discharges comprise several kinds of pollution. For instance, a municipal sewage discharge might contain the toxic, organic, and nutrient pollution, whereas a mine discharge may contain toxic, acid, nutrient, and sediment pollution.

There can also be negative effects on farm operation in terms of increased attached growth on nets (sliming) due to nutrient loading from a variety of sources, damage of nets or walkways by floating debris, or reduced visibility in water due to sediment or phytoplankton.

Most direct industrial and municipal discharges (point sources) such as sewage, mine, and pulp mill effluent are documented and, whether continuous or intermittent, must be permitted by the Provincial Government. The Waste management permits specify waste quality standards to be met by the permittee, as well as objectives for environmental quality which must be maintained. Information on discharges under permit

is available from the Regional Waste Management Offices (Ministry of Environment and Parks [MEP]). The Environmental Protection Service (EPS) (Environment Canada) has the regulatory responsibility for ocean dumping. All the existing dumping sites have been documented.

Diffuse (non-point) discharges such as landfill leachate, sewage from marinas and boats, toxic spills, and upland runoff may be intermittent or continuous and may not be documented. Careful examination of various activities such as solid waste disposal, logging, boat transportation, and marina location will be necessary to assess the risk of non-point discharges and concomitant pollution occurring in an area. Federal fishery officers and Provincial conservation officers can provide useful information on coastal activities in this context.

A new potential source of pollution in British Columbia is the marine fish farm itself. Unused food and faecal wastes can contribute significant amounts of nitrogen compounds to the water, possibly enhancing plankton production at the site, and also organic carbon to the sediments which can cause oxygen depletion problems (Weston, 1986). Sediment anoxia can result in production of hydrogen sulfide gas which is toxic to fish. This impact is usually specific to fish located at the site.

A coastal system may have the capacity to assimilate waste loadings because of tidal dispersal and current mixing. Also, in time, sediments at a site will return to normal once the waste loading ceases. Nevertheless, cumulative impacts might occur where several large-scale farms are located in poorly exchanged waters such as some coastal inlets, channels and bays. The Ministry of Agriculture and Fisheries (MAF) can provide assistance with regard to calculating waste loadings from various sizes of farms.

Fish farms can also cause a form of aesthetic/fish health pollution. Every farm experiences mortality of a variable percentage of its salmon stock ranging from about 10 to 40%. If these fish are disposed of by throwing them into the water outside the pens, they can wash up on shore creating undesirable sight and smell, in addition to being a means of disease transmission to wild or other domestic salmon stock. Burial of the dead fish in a lime pit or incineration will avoid such problems, and the complaints which accompany them (contact MEP or MAF regarding this).

Siting Opportunities

Over 70% of British Columbia's population resides on or near the coast of the Strait of Georgia. This strait serves as a receiving water for many of the Province's industrial and domestic liquid waste discharges. Also, because of upstream waste loadings, the Fraser River is a major contributor of various pollutants. Fortunately, except for localized areas, water quality in Georgia Strait is fairly good, because of the

degree of renewal with water from the open ocean via Juan De Fuca Strait (Thomson, 1981).

To date, most farm sites have been located in remote, relatively pollution-free regions of Georgia and Johnstone Straits as well as other areas such as Sechelt Inlet and Barclay Sound. These areas are removed from the major estuaries, such as Squamish, Fraser, Nanaimo, and Cowichan where the majority of the Province's industries are located, and which are generally not suitable for salmon farming because of depth, salinity or current not being acceptable.

Inlets on the east side of the Strait of Georgia, such as Howe Sound and Burrard Inlet, that receive direct industrial or municipal discharges may, at certain times of the year, have poor localized water quality. These areas should be generally avoided. Of course, there may be a few isolated locations within these areas which are acceptable. On the west side of Georgia/Johnstone Straits, several major discharge plumes from pulp mills at Crofton, Nanaimo, and Campbell River should also be avoided. Pulp mill discharge areas at Port Mellon in Howe Sound, and also at Powell River, should be avoided. The nature and extent of these zones are generally well-documented by environmental agencies (EPS, MEP).

Some other areas, such as Rupert Inlet and Alice Arm, are the sites of mine waste disposal. While the effects of these wastes on pelagic Biota are uncertain (Waldichuk and Buchanan, 1980) caution is advised with regard to siting salmon farms within tailings plumes.

Also, throughout B.C. coastal waters, one should be careful in considering abandoned log-handling sites. These areas may have been disturbed recently enough to result in release of toxic wood waste components or sulfur dioxide gas from thick deposits of decaying wood bark. A dive survey can assist in an assessment of substrate conditions.

Locating a farm in the vicinity of marinas increases the likelihood of harm from cleaning bilges, dumping cleaning solutions, gas and oil discharges, spills, or contamination by antifoulant paints.

When assessing the suitability of a site in the vicinity of a community or population, care should be taken to avoid locations of both point and non-point sewage discharges, such as outfalls or malfunctioning sewage disposal systems. Local Public Health Inspectors (Ministry of Health) can provide information on areas prone to malfunctioning systems.

Assistance in assessing the potential impacts of various wastes on a potential fish farm can be obtained from EPS, Fisheries Branch (MEP) and the Aquaculture and Commercial Fisheries Branch (Ministry of Agriculture and Fisheries). In many cases, the information available has been obtained from reports on experiments using salmonids under controlled conditions in the presence of various pollutants.

Important considerations in siting salmon farms are water quality criteria and objectives -- the definition of "criterion" used by the Water Management Branch (MEP) is as follows:

"A maximum and/or a minimum value for a physical, chemical, or biological characteristic of water, sediment, or biota, applicable province-wide, which must not be exceeded to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions."

The MEP is currently developing general water quality criteria on a province-wide basis. These criteria will form the basis for water quality assessments, or the preparation of site-specific objectives. At present, general marine criteria exist for cyanide and nitrogen for British Columbia, and no objectives (site-specific ranges) exist. Until B.C. criteria and objectives for salmon exist, the prospective farmer is advised to consult U.S. EPA when investigating an area which may be subject to the influence of a particular type of pollution. Advice on what water quality data are available for a specific area, and how to compare those data with water quality criteria can be obtained from the Resource Quality Section of the Water Management Branch (MEP).

A convenient rule of thumb one can use in the absence of water quality criteria is to avoid areas upon which shellfish closures have been imposed by Fisheries and Oceans Canada because of pollution (Waldichuk, Fisheries and Oceans Canada, Pers. Comm., 1987).

Siting pens in areas of good current helps to distribute farm-produced organic waste over a larger area. This decreases chances of overloading the natural ability of bottom animals to break the waste down to a stable form with a low oxygen demand. Areas with high flushing potential such as open bays have a greater potential for diluting and removal of any nutrients. Consequently, such areas are less prone to increased plankton blooms than enclosed low-flush areas such as the heads of inlets (Gowen et al., 1985).

Mitigation Opportunities

Impermeable skirts around seapens can be used to avoid the effect of accidental surface contamination from a toxic chemical or an oil spill. Pumping of deep, clean water into the seapen would also help disperse pollutants. For prevention purposes, it is worthwhile to inform boaters encountered of the sensitivity of farmed fish to bilge waters, cleaning solutions, oil, and gas. These measures are directed more to accidental or spontaneous pollution occurrences. The best way to avoid continuous pollution is to select a site in a better location.

The employment of a feed fine recovery system will reduce organic and

nutrient loading from the farm to the environment. Fine removal will also help avoid the decrease of dissolved oxygen in the pens frequently noticed after feeding (Weston, 1986). Pen movement can be used to spread waste accumulation over a greater area and allows time for biological degradation of the organic sediments in those areas from which the pens have been moved (fallow areas). Orienting the pens so that the largest surface area is exposed to the current will also distribute the organic material over a wider area.

CURRENTS*

	Good	Medium	Poor
At Slack Water:			
	10 - 15 cm/s	10 - 2 cm/s	<2 cm/s
At Peak Flows:			
	10 - 15 cm/s	50 - 100 cm/s	100 - 200 cm/s
Current Regime:			
	Even currents throughout tidal cycle.	Short periods of slack water during tidal cycle.	High variability in current speeds during tidal cycle.
Fish Response:			
	No adverse symptoms.	Greater effort required to capture feed and maintain position during peak flows.	Stress from fast currents at peak flows, and oxygen distress during slack water.
Effect on Operation:			
	No adverse effects.	Alteration of feeding schedule during peak flows. Minor reduction in usable volume of net pens.	High feed losses. Frequent net cleaning. Reduction of usable net volume. Anchoring problems.

*Measurements at 5m depth.

Interpretation

Currents play an important role in fish farming. Adequate currents are required to exchange water through the net pens, and to disperse waste feed and fecal material (Weston, 1986). In general, a flow of at least 10 cm/s outside of the net pens is desirable throughout most of the tidal cycle (Kennedy, 1978). Although occasional and short-term decreases in current speeds are acceptable, sites with consistently low flows should be avoided (Weston, 1986).

On the other end of the scale, excessive current flows will distort the sides of the net pens, reducing the usable volume and causing stress to both the fish and the anchoring system (Weston, 1986). Some authors suggest that maximum current flows in the range of 50 to 100 cm/s should be avoided (Kennedy, 1978), while many in the industry feel that speeds above 200 cm/s are the maximum range.

When choosing a site, the effect that the net pen facilities on current flow must be taken into account. Net pens will produce a wake, which will alter the current patterns and speeds in the vicinity of the facility. Within the net pens themselves, reductions in current speeds to 35 - 81% of the upcurrent velocity have been reported (Weston, 1986). The degree of current flow reduction depends on the configuration of the facility, the amount of fouling on the nets, and the number of fish stocked.

Reduction of current speeds could potentially promote sedimentation of suspended particulate matter or enhance degradation of water quality as a result of poor flushing. This could become significant under certain conditions, such as a high density of units in a bay with very restricted natural circulation (Weston, 1986). Reduction of current speeds could prevent adequate supplies of oxygenated water and inhibit removal of metabolic wastes. One study found that chinook salmon experienced heavy mortalities when fouling of the net prevented adequate water exchange. Dissolved oxygen concentrations dropped as low as 2 mg/l inside the pens, while concentrations outside the pens were 6.5 to 9 mg/l (Weston, 1986).

Siting Opportunities

Coastal currents are caused by tides, winds, freshwater runoff and wave induced transport (Landless and Edwards, 1976). Wave action (except for the effects of swell) is probably the least important factor in current generation. Tides have the most predominant and persistent effect on current speeds. A general picture of expected tidal currents can be obtained from navigational charts of the area, tide and current tables, and current atlases. In practice, considerable variability is found near irregular topographic features. Eddies occur in the lee of points, in bays, and over irregular bottoms; because of this variability, atlas information should always be supplemented with a site survey (Landless and Edwards, 1976).

The range in tide heights for the B.C. coast averages 3 to 5 m, with greatest amplitudes occurring during June and December and lowest amplitudes in March and September (Canadian Hydrographic Service, 1987). These changes in the height of water generate tidally induced currents, the magnitudes of which vary with the change in tide height, and the geomorphology of a particular area (Thomson, 1981). Measured speeds vary from 52 cm/s in the open ocean to maxima of 800 cm/s (16 knots) at Natwakto Rapids in Seymour Inlet (Thomson, 1981).

Currents along the B.C. coast are also affected by freshwater runoff; this is particularly true of large runoff inlets such as Howe Sound. In these inlets a surface layer of low salinity water, fed by rivers, covers the deeper, more saline water. This upper layer has a net movement seaward. The magnitude of the surface current depends on the rainfall and consequent runoff; the seaward flow always augments the ebb tide and diminishes the flood, and can on occasion be so marked as to reverse the surface flood, in which case surface water shows a constant ebb (Landless and Edwards, 1976).

Wind also exerts stress on surface layers. Surface current speed can be 1 to 5% of windspeed (Landless and Edwards, 1976). This could pose problems to fish farmers, especially in areas where the water is stratified and there is poor tidal mixing. In summer, warm surface water could be wind-driven by onshore breezes onto fish farms.

On site current measurement by the use of current meters or drogues is a prudent step in site selection. Measurements should be taken throughout a tidal cycle to account for the different current rates at spring and neap tides. The measurements should also be taken at various depths to determine the extent of countercurrent velocities in areas of high stratification. Most current measurement should be taken at about one-half the total depth of the net pens, or about 5 m. The direction, as well as its speed, should be determined.

Mitigating Opportunities

Operators can take several measures to minimize the effect of the facility on water circulation. In strong currents, multiple pen arrangements should be oriented parallel to the direction of water flow. This would minimize alteration of water circulation and simplify anchoring requirements under weak current regimes, the facilities would be better arranged perpendicular to the current flow to increase the waste disposal area and ensure maximum water exchange in the net pens (Weston, 1986). Regular cleaning of nets will alleviate drag and deformation of the net pens in high current flows, while ensuring adequate replenishment of oxygenated water. Increasing the mesh size can also enhance water circulation. A 5 cm mesh size has been shown to decrease the current velocity inside net pens by up to 60%, while a 2 cm mesh reduced the current flow by 70% (Weston, 1986). These measurements were made before appreciable fouling organisms had built up. Stocking density is also a factor, as the number of fish per pen will have a profound effect on current flow.

During times of fast current flow (i.e. between 50 and 100 cm/s) the feeding regime will have to be adjusted to reduce feed losses. Feeding could also be curtailed during prolonged periods of slackwater to minimize sedimentation of waste feed.

Natural circulation in areas of low current flow may be enhanced by artificial means. The use of large, underwater propellers to increase current velocities at net pens is currently being investigated in Norway (Litaca, pers. comm., 1986).

SITE PHYSIOGRAPHY
(Water Depth (metres), Geomorphology and Substrate)

Ratings:	Good	Medium	Poor
Chart Depth (at low tide):	50 - 100 m	20 - 49 (seapens) 100 - 150 (anchorage)	10 - 19 (seapens) >150 (anchorage) (less than 10 m is unacceptable unless the current is very strong)
Geomor- phology/	Bedrock or boulder inter- tidal zone at steep (>30°) slope; can use stiff legs on- shore; boulder, gravel or sand sub-tidal sub- strate at gentle slope (<30°), good for use of anchors.	More gently sloping Gentler (15-30°) bedrock or boulder intertidal zone, with sand or mixed rocks; stiff legs not feasible.	Very gently sloping (<15°) gravel on mud intertidal zone; sub-tidal zone of mud and/or organic ooze; stiff legs not feasible.
Farm Operation:	Anchoring close to shore with- out having to anchor farther out in exposed water to reach a desirable depth; no bottom accumu- lation of or- ganic wastes; no likelihood of damage due to slope failure.	Extra anchoring required because of unstable substrates. Pens must be located farther from shore for suitable depths; some organic waste accumulation on bottom; small prob- ability of damage from slope failure.	Difficulty in anchoring. Excessive waste accumulation. Fallow area for dispersal of wastes required; high probability of damage from slope failure.
Geomor- phology/ Shoreline Stability:	No shoreline instability above or below water; no signs of slumping, rockfalls, avalanches, or debris flows.	Isolated evidence of instability, above or below water; some slumping, rockfalls, avalanche zones or debris flows.	Shoreline known to be unstable above or below water; surface slumping, deltas, rockfalls, avalanche zones or debris flows abun- dantly evident.

Note: Chart depths less than 10 metres are not considered acceptable. ratings based on assumed tidal current of 5 cm/s and farm production of 100 tonnes (maximum biomass on site). Slower currents and/or higher production require greater depth.

Interpretation

Water depth is considered important for two purposes:

1. Sufficient depth is necessary for satisfactory dispersal of waste food and faecal material, as well as isolation of this material from the fish in the pens (see: Pollution); and,
2. The farm must be located in an area which is not too deep for suitable anchorage at an acceptable cost.

Greater depths improve natural biological degradation as feed and faecal particles slowly sink to the bottom. However, less depth is required if tidal currents are sufficient to disperse wastes. About 5m less depth is required for every 10 cm/s increase in mean current velocity up to a velocity of about 50 cm/s (Science Applications International Corporation [SAIC], 1986). At any velocity greater than this, the depth should be at least 20 m for a site of medium suitability. The above depth ratings were based on experience with the salmon farming industry as well as a review of SAIC (1986).

Geomorphology of an area is important from the perspective of flushing and removal of nutrients from an area, as well as anchorage and farm safety. It is also important for understanding oceanography of an area primarily in terms of dissolved oxygen concentrations, but also from the perspectives of temperature and salinity.

Shallow sills have a tendency to restrict inflow of seawater from outside to deeper levels of inlets. The result can be poor renewal at depth, in some cases for a major portion of the year, resulting in stagnation and deoxygenation. In winter, smaller inlets reach uniform temperature from top to bottom, and then circulation and mixing of deeper, poorly oxygenated water causes surface dissolved oxygen levels to plummet. An example of this is the Saanich Inlet (Thomson, 1981). In larger inlets, dense, cold, deep water from outside the inlet can well up over the sill in winter, sink and then force stagnant, deep inlet water to surface at the head. An example of this is the Sechelt Inlet (Lazier, 1962). There are also special cases such as the Rupert/Holberg Inlet system which experiences seasonally low dissolved oxygen levels in late summer/early fall. This occurs because a rapid density current dives down the inside of the sill, and actively mixes poorly oxygenated water throughout the water column (Truscott, 1987). The result in all these cases is an environment with lower dissolved oxygen levels than are desirable for salmon farming.

The criterion for sill depth used for the ratings above is based on a review of sill depths and the thickness of the brackish surface layer in inlets which experience estuarine-type circulation. If the depth of the sill is equal to or less than the thickness of the brackish surface

layer, stagnant conditions result, with a marked restriction in the flushing of the fjord (Gilmartin, 1962).

Enclosed bays or inlets also experience decreased flushing by the tide. This is because in most deep estuaries, high and low tides occur virtually simultaneously throughout the length of the fjord, suggesting that tides act primarily as a pulse at the mouth. Indian Arm provides a good example of this kind of pulse effect (Gilmartin, 1962).

- Unstable upland slopes are common along the B.C. Coast, given its rugged physiography. A variety of factors affect the stability of slopes (Sharpe, 1938) including:

- slope angle;
- geological processes operating in an area (glaciation, vulcanism, earthquake activity, springs, snow and rainfall, wind, movement of crustal plates, and waves);
- presence or lack of vegetation;
- human activities such as deforestation, railroad and road building, and mining;
- natural agents such as tides, thunder, fires, heating, cooling and drying.

With the abundance of unstable slopes comes the likelihood of damage or destruction to a farm, if located in an area prone to mass wasting (land/mud slides), avalanches, slumping, or debris flows down creeks or slopes. Upon failure, unstable submarine slopes can cause loss of anchorage or submergence of the farm if the anchors are heavy enough and move far enough downslope. Slope failures can occur slowly or often very rapidly leaving little or no time for escape.

Siting Opportunities

Due to past glacial activity and the rugged nature of the British Columbia Coast, there are many potential sites with sufficient depths for salmon farming within a few hundred metres of the shoreline. The majority of sites under application reflect this potential. Even in very deep fjords and channels, siting in water of adequate depth is possible through use of stifflegs attached directly to a rocky, convoluted shore.

Mouths of streams and rivers where marine deltas are present, such as at the heads of inlets, tend to offer depths in the "poor" category. These areas also tend to be poor for other reasons such as upwelling of low dissolved oxygen-containing water, low temperature, and decreased salinity.

Quite a lot of information has been documented on causes of slope failure, and also terrain mapping for British Columbia. From the foregoing

discussion it will be obvious that the potential salmon farmer should become aware of possible slope stability problems in an area under investigation, and simply avoid problem areas. Terrain and soil-land form maps are available from Maps B.C., Ministry of Environment and Parks (MEP), Victoria, B.C., V8V 1X5. All published maps and reports are listed in the Division Catalogue available at the same location. An excellent and essential booklet for interpreting these maps was prepared by Ryder and Howes (1984), also available at the above location. Information on slope stability assessment can be obtained from MEP, Fisheries Branch, Habitat Management Unit, Victoria (above water) and Energy, Mines and Resources Canada, Pacific Geosciences Center, Sidney, B.C. (marine).

When planning or assessing a farm site, area bathymetry, slope, and stability should be studied in order to determine anchoring specifications and cost. This can avoid problems such as anchors rolling or sliding down a steep or unstable slope.

Mitigation Opportunities

Other than choosing a better location, the only practical way of dealing with insufficient depths is to use shallower net pens, thereby increasing the depth below the pens. Unfortunately, this can create a new set of problems such as eliminating potential deep water refuge for the fish from high temperatures or reduced surface salinities.

Because of the magnitude of potential problems where unstable slopes are found, there is virtually no way to mitigate such problems.

HYDROLOGY (Study of Freshwater Flow)

Ratings:	Good	Medium	Poor
Description:	A small source of freshwater which will not rapidly alter salinity or water quality. A small source (stream or well) is present for potable water.	Seasonal run-off or freshets that rapidly change salinity or water quality to a limited extent (5 to 10 cubic metres per second [m^3/sec] stream discharge)	Flash flooding accompanied by silt or debris. Rapid change in salinity to a large extent.
Fish Response:	No stress to fish.	No or minor short-term stress to fish.	Severe stress to fish and impacts to farm structures.
Depth of Freshwater Lens:	< 1 metre	1 - 4 metres	> 4 metres
Change in salinity > 50/00, or in temperature > 5°C within:	24 hours	24-12 hours	< 12 hours

Interpretation

The above ratings pertain primarily to rapid and significant changes in salinity, dissolved oxygen, and temperature due to local freshwater runoff events such as freshets and severe storms. These criteria were based on actual stream discharge data from three different sources and their effect on the marine environment in terms of depth and areal extent of the freshwater lens.

Discharges from streams in British Columbia are quite variable. Many small streams exist, discharging maximum volumes of less than $5 \text{ m}^3/\text{second}$ at any time, and may in fact run dry during part of the year. Some streams, while dry at times, experience sudden large peak flows during storm events which would be undesirable from a salmon farming perspective. At the upper end of the range are major rivers, the largest of which is the Fraser. In an average year the Fraser discharges a peak

flow of about 10,000 m³/sec. (Wyman, B.C. Ministry of Environment and Parks [MEP], Pers. Comm., 1987). The Squamish River, although smaller, still has a substantial discharge with a normal peak flow of 760 m³/sec in the early summer, and abnormal peaks in the order of 2100 m³/sec (Thomson, 1981).

From a hydrological perspective, farm sites are most suitably located in areas of low relief, well away from mountainous areas that are subject to a high degree of precipitation, or outside the influence of runoff from large watersheds. Some areas of steep relief are subject to a lot of precipitation, such as the west coast of the Queen Charlotte Islands. The result is sudden storm events, runoff peaks, and slope failures -- especially in heavily logged areas (Poulin, 1986). Runoff in these areas is above average in the winter and spring, and below average in the July - September period, following the coastal rainfall pattern. Areas with large watersheds, such as Knight, Bute, and Rivers Inlets, experience large runoff due to snowmelt in the May - July period with a secondary maximum in October (Pickard, 1961).

High runoff areas release large amounts of fresh water to either a localized area (small watershed, steep terrain situation) or over a large area (large watershed situation). Because freshwater is less dense than seawater, it tends to float on the saltwater, mixing with it only very slowly. Consequently, a brackish layer may exist to a depth of several meters over a large geographical area such as occurs in Howe Sound due to runoff from the Squamish River (Thomson, 1981). Another instance would be Knight Inlet runoff, which is noticeable as far down the coast as Calm and Sutil Channels (Pickard, 1961).

Often, silt and debris are associated with runoff from sudden storm events. This adversely affects water quality, in addition to causing rapid changes in salinity. Temperature can also drop dramatically if the runoff is from melting glaciers and snowpack. These effects are most noticeable close to the discharge point, and because of gradual dilution due to entrained seawater, become less pronounced farther away. The larger the runoff is, the more noticeable and widespread the effects will be.

Coastal inlets with small watersheds, such as Seymour, Belize, and Sechart tend to be less of a problem due to lower runoff (Pickard, 1961).

Generally, salmonids are more tolerant to sustained salinity and temperature regimes than to rapid changes in those variables. Immediate fish mortality may not occur from sudden changes, but sub-lethal, latent effects may manifest as disease outbreaks, reduced growth, and incomplete smoltification.

A moderate source of freshwater can be used to advantage to facilitate smoltification (see: "hardening" in Salinity). This is accomplished by

pumping freshwater into a seapen wrapped with a tarpaulin. The resulting salinity gradient allows the fish a choice of salinity. Such an approach has also been used recently to avoid fish mortalities from Chaetoceros blooms (see: Plankton).

Siting Opportunities

In assessing the suitability of a site for salmon farming, the prospective farmer should examine available long-term data from streams and rivers in the area, as well as salinity/temperature profiles at the proposed site over a one-year period to determine seasonal changes in marine surface-water caused by regional runoff. One can estimate average discharges from streams by calculating the size of drainage basins on maps and by determining volume per unit area of precipitation in the area. The likelihood of extreme events cannot be assessed using this method. Discharge data from some areas are available from Environment Canada - Water Survey of Canada. Precipitation data can be obtained from Environment Canada - Atmospheric Environment Service. The Surveys and Resource Mapping Branch (MEP) sells topographic maps of the province. Actual stream discharge data are preferable because such measurements give more accurate estimates of hydraulic loading than are available from precipitation data.

Mitigation

Where sites have only 1-2 metres of freshwater on the surface, use of deep nets will provide some refuge for the fish, providing there is no dissolved oxygen depletion problem at depth. Sites which experience rapid temperature and salinity changes to depths greater than 3 or 4 metres offer no effective means to avoid impacts on fish. Where changes are moderate, selection of more tolerant species of fish such as rainbow trout is advisable. Damage to the farm from debris can be avoided by constructing booms and debris nets.

PREDATORS

Ratings:	Good	Medium	Poor
	No indigenous predators; rare migrants; minor protection measures needed.	No indigenous predators, but indigenous population close enough for them to be in the area frequently (within 80km.). Readily manageable.	Predator colony/ population lives very near the site; site on migration route; common presence of predators and predation problems; protection measures and constant vigilance required to prevent serious fish loss.

Interpretation/Siting Opportunities

A variety of animals which prey upon salmonids are found in B.C. coastal waters. These include seals (Harbour, Fur), sea lions (Steller, California), dogfish, heron, kingfisher, seagulls, otter, and mink. It is virtually impossible to find an area without the presence of one or more of these predators. However, it is not advisable to locate near a colony, such as a sea lion haulout (i.e. within 5 km).

Seals and sea lions can be a major problem by pushing poorly hung predator nets against the sides of a salmon pen, and biting through the mesh. The B.C. Provincial Museum can provide information on seal concentrations and haulouts. Bigg (1985) provides information on rookeries (mating areas), haulouts and winter sites (rocks) and rafting sites (transitory floating accommodation) for Steller and California sea lions.

Dogfish are also bothersome predators. If predator nets are not used, or are carried close to the pens, by the current, dogfish can bite fish through the meshes of the pen. Federal Fisheries Officers for the various regions can provide information on dogfish concentrations.

River otters, which are common throughout B.C. coastal waters, have a tendency to get into the growout pens and bite the fish. In addition to direct mortalities, this can create extra stress for the fish. The Wildlife Branch (MEP) has information on their distribution.

Water birds (e.g. heron, kingfishers, and seagulls), waterfowl (e.g. mergansers, cormorants), and birds of prey (e.g. eagles, hawks, ospreys)

also cause other mortalities and damage to fish by capturing them or pecking at them.

Both grizzly and black bear can threaten the farmer as well as the farm operation. Disposal of dead fish on land can aggravate this threat since bears' keen sense of smell will often enable them to locate fish carcasses. With a potential continuing supply of food, bears will be motivated to frequent the fish farm area.

The regional conservation officers (MEP) can provide advice on proper disposal procedures, fencing of both the disposal site and the farm, and bear distribution. Grizzlies are common at the heads of inlets and in stream areas, particularly during salmon migration. Black bears are common to most wild areas along the coast, including islands.

There is no current evidence that killer whales are likely to be a problem to salmon farmers, despite the fact that salmon is a preferred food item. Neither has there been any account of killer whales interfering with commercial seine fishing operations in the Johnstone Strait area, which is a whale migration route.

Mitigation Opportunities

The best mitigative measure is to avoid siting in areas rated as poor. Destruction of wildlife is legal only when authorized under the Wildlife Act or the Migratory Birds Convention Act. If a predation problem results, it is the policy of the B.C. Ministry of Environment and Parks to issue permits to destroy wildlife only when the farmer has made all reasonable efforts to minimize the attraction of the animals.

Marine animals, such as seals and sea lions, fall within the jurisdiction of the Federal Department of Fisheries and Oceans. Section 21 of the British Columbia Fishery (General) Regulations prohibits the killing of any marine animal except under licence.

The following guidelines will help to ensure that aquaculture operations are predator proof.

1. Waterbirds, Waterfowl, and Birds of Prey

Aquaculture operations should be covered with netting that:

- i) has a mesh size small enough to prevent the birds from penetrating it, and
- ii) is made of a gauge heavy enough to be clearly visible to the birds and to prevent them from becoming entangled in it.

These apply to nets used for both above water and under water protection. Spaced white string over nets can deter birds as well.

2. Furbearers

Aquaculture operations should be designed and managed to minimize the attraction of furbearers. This could take the form of netting that:

- i) is of a size that will not permit animal entrance, and
- ii) is made of a gauge or material that cannot be chewed or clawed apart.

To prevent passage of furbearers to floats, sheet metal collars should be erected on cables, boom sticks or stiff-legs which are attached to shore. Guard dogs and electric fences are also deterrents to the furbearers such as mink and otters.

3. Bears

A waste management permit (MEP) is currently required for disposal of all waste. Garbage should be kept to a minimum and incinerated daily. Waste Management Regulations relative to salmon farms are under revision at present.

Disposal of fish by-products and carcasses should be done in a manner to minimize the attraction of bears and to prevent the spread of fish disease.

4. Marine Animals

Heavy gauge nets should be used to prevent seals from gaining access to aquaculture operations. An enclosure within an enclosure may be the most effective way to prevent direct access by sea lions and other marine animals, such as dogfish. Routine removal of dead fish also helps alleviate dogfish predation.

MARINE PLANTS AND FOULING ORGANISMS

Good	Medium	Poor
Fouling organisms in low abundance. No nearby kelp beds or other macrophytes.	Seasonal increases in fouling organisms. Nearby kelp or macrophyte beds.	High year round abundance of fouling organisms. Kelp or macrophyte beds on site.

Fish Response:

No symptoms attributable to net fouling.	Short term seasonal fouling may cause symptoms of oxygen distress.	Severe stress due to chronic fouling, low oxygen levels.
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Effect on Operation:

Only require routine net maintenance.	Regular net maintenance. Increased cleaning required during seasonal fouling.	Frequent net cleaning and replacement required. Increase in net damage resulting in escapements.
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Interpretation

Most large marine plants (macrophytes) grow in less than 10 meters of water. Kelp species are among the largest marine plants on the B.C. coast. They anchor to rocky substrates, usually in areas of high current flow or wave action. Kelp beds constitute a nuisance to navigation, and can impede boat passage and entangle propellers. At certain times of the year, they may make a site inaccessible by boat. Kelp beds can also foul fish farm sites when fronds and other debris break off during storms. Some species of kelp undergo an annual die-off in winter, freeing large masses of drifting plant material that can inundate a site. In some areas, kelp beds act as natural breakwaters, altering wave action and attenuating currents. Sudden die-offs could have a profound affect on a site's current and wave regime.

The best time of the year to assess a site for potential kelp problems is between June and September, during the summer growth period. Kelp surveys conducted by the Marine Resources Section of the Ministry of Agriculture and Fisheries provide valuable information on the location and abundance of kelp at many areas on the coast.

Other macrophytes form habitats for a number of marine species. Eelgrass beds are among the most important because they provide refuge for outmigrating salmon, and offer a substrate for herring spawn. The proximity of a proposed site to an eelgrass bed may preclude its acceptance for fish farming because of the possible impact on natural wild stocks. The Department of Fisheries and Oceans of Environment Canada should be consulted in this regard.

Net fouling organisms consist primarily of algae, invertebrate larvae such as mussels and barnacles, and small plants (microphytes). The effects of fouling occur as soon as the nets are immersed in water. Microscopic plants and animals attach themselves to the nets and, as they grow, entangle larger particles of debris. The rate at which marine fouling builds up increases as water temperature increases (Kennedy, 1978) and as circulating currents decrease. In general, the longer the nets remain in the water, the greater the fouling load will be. Without routine cleaning, fouling will eventually build to the point of restricting water flow through the net pens. Fish have died at an experimental fish farm because of the lack of oxygen attributable to a heavy build up of marine fouling that restricted water circulation (Kennedy, 1978).

Another source of fouling may occur when net pens are located too close to natural herring spawning areas. Herring may deposit large numbers of eggs on the nets over a very short time. The result has serious consequences both in terms of restricted water circulation, and environmental impact. In some cases, operators may not be permitted, by law, to remove their net pens from the water until after the eggs have hatched. Without the opportunity to clean the nets an operation could lose an entire year class. Close proximity to herring spawning areas should be avoided.

Siting Opportunities

In general, sites with cool water and rapid current flow will have a slower rate of marine fouling than warm water, low flow sites. Water temperature has a direct effect on primary productivity, while current flows physically limit a fouling organism's ability to settle on nets or other objects. Fouling rates in Johnstone Strait waters would be lower than the Strait of Georgia for the above reasons.

Sites that experience high levels of freshwater runoff, such as Howe Sound, generally have less problems with fouling near the surface. However, these areas are usually unsuitable for fish farming because of the lower salinities encountered.

Mitigating Opportunities

Fouling of fish farming gear, or any other gear placed in seawater, is a

fact of life. Good maintenance practices carried out at regular intervals have no substitutes when dealing with fouling. Kennedy (1978) recommends that net pens should be changed at least every 3 weeks during the summer, every 3 months during the winter, and at intermediate intervals during intermediate temperatures (Kennedy, 1978). Regular inspection of net pens and their supporting structures is desirable. Mussel and barnacle accumulations must be avoided by changing the nets as soon as build up appears. Proper net pen spacing will slow marine fouling by ensuring adequate circulation throughout the site. The use of antifoulant chemicals to inhibit growth of marine organisms on nets should be approached with care, since many antifoulant chemicals are toxic, and may affect the fish and surrounding environment. Information on antifoulants and their impacts can be provided by the Ministry of Agriculture and Fisheries.

Debris from kelp beds and other flotsam encountered in the marine environment may be controlled by log or tire boom breakwaters. In areas that suffer high amounts of debris, nets suspended from these booms may also be required to protect the submerged portion of the net pen assemblies. These debris nets will require routine cleaning and clearing.

MISCELLANEOUS (SNOW, ICE, WIND AND WAVES)

Snowfall/Freeze

Good	Medium	Poor
<30 cm snowfall; no freezing of water surface	30-60 cm snowfall short duration freezes with ice <5 cm in thickness.	>60 cm snowfall; Ice >5 cm thick, lasting for days.

Interpretation

It is obvious that ice and snow can interfere with farm operation. Snow makes working conditions hazardous and inconvenient. Ice interferes with feeding of the fish, farm maintenance, such as cleaning nets, and can damage net pens.

Siting Opportunities

Northern areas of the coast are more prone to ice and snow conditions. Inlets with restricted entrance and large freshwater input may also be more prone to freezing because of reduced water movement or reduced surface salinities. The heads of some inlets, such as Salmon and Narrows Inlets, are also likely to freeze. Contact Environment Canada, Atmospheric and Environment Service for regional climatic information.

Mitigation Opportunities

Little opportunity exists to mitigate snow and ice problems if they are in the "poor" category. Thin ice can be broken, and moderate amounts of snow can be swept or shovelled.

Wind and Waves

Good	Medium	Poor
Site is not exposed to polar outflows; sheltered from the prevailing wind couplet of SE and NW winds; short fetch, with waves <60 cm.	Partial exposure to some polar outflow; exposed to either SE or NW winds; moderate fetch with waves 60-120 cm.	Complete exposure to the main thrust of a polar outflow; exposed to both prevailing SE and NW winds; long fetch with waves >120 cm.

NB Wave height criterion based on cage design.

Internal Waves

<u>Good</u>	<u>Medium</u>	<u>Poor</u>
None present.	Only artificially induced or very deep (no influence in upper 15-20 m).	Shallow, naturally induced.

Interpretation

Many locations would expose a farm to severe wind and waves if there is a long fetch and prevailing SE and NW winds. Such factors can negatively affect farm operation by causing rough water. Both high winds and rough water can cause physical damage to a farm in addition to making working conditions and water travel hazardous.

Also, wind can cause a standing wave phenomenon (Seiche), where surface water is blown to one end of an inlet or fjord. Where there are marked temperature (thermocline) and salinity (halocline) gradients, a farm may be subjected to sudden shifts in temperature and salinity. One end (usually the blind end of the channel/inlet) would receive a thick layer of surface water which may be very warm or cold, depending on the season, and may possess low salinity if there is a freshwater lens present. The other end of the channel would experience a surfacing of deep water which may be much colder than surface water in summer and much higher in salinity. An example of this is the south end of the Sechelt Inlet. Reduced salinities at deep levels and rapid temperature changes can stress fish.

Rough water can also cause stress to fish if the wave surges penetrate deep into the net pens. There have even been reports of seasickness in fish, although no scientific documentation of such a phenomenon has been located at this writing.

Also, during times when water is very rough, the farmer may have to discontinue feeding the fish, possibly for several days.

Internal or gravity waves can also occur within the interior of a body of water, provided its density increases with depth (Thomson, 1981). They are generated by some influence such as tidal movement against sills or other bottom features which disturbs the equilibrium level between the upper, less dense layer and the deeper, denser layer. Gravity waves cannot exist in water of homogeneous density.

Unlike surface gravity waves, which possess maximum vertical water displacements of the surface, but decreasing vertical displacements with depth, internal gravity waves produce maximum vertical displacements

within the water column and negligible distortion of the water surface. In other words, the waves are only within the interior of the water body. Typical internal wave lengths in the Strait of Georgia are 25 to 100 m with wave heights of 5-10 m and propagation speeds of about 0.5 m/s (1 km).

Bute Inlet is an area known to possess internal waves throughout the water column, whereas Jervis Inlet possesses them at deep levels. Boundary Passage and Active Pass, as well as the Knight Inlet shallow sill, are vigorous sources for these waves which move slowly into the strait of Georgia or Knight Inlet (on the flood). In Johnstone Strait, strong internal tidal motions appear to be generated by swift tidal currents surging over the partial sill at Kelsey Bay, distorting tidal flow for about 10 km west of the sill. Knight Inlet wave crests are 70-100 m apart and possess an up-inlet speed of about 50 cm/s (1 km) (Thomson, 1981).

The main impact of such waves can be a series of horizontal current reversals, causing rapid sequential changes in temperature and salinity values in stratified waters over short periods of time. This can place even more stress on fish than waves caused by seiches, because of the frequency of the oscillations, and because they tend to be a regular occurrence when tidally induced. Other sources for such waves exist, such as atmospheric pressure fluctuations, ship propellers, the mutual interaction of waves in a sea, or a swell. These sources, however, tend to be less regular or frequent.

Siting Opportunities

Exposed areas with long fetches should generally be avoided, especially where the prevailing couplet of NW and SE winds can affect a farm. Also, areas subject to polar outflows, such as Howe Sound, and Knight, Bute and Toba Inlets should be generally avoided. These are areas where long channels and valleys penetrate into the province interior and receive cold polar outflows which can howl down channels with gale force winds for several days at a time (Thomson, 1981).

There may be isolated sheltered spots in some of these locations. However, there may be problems with transportation to and from sites due to rough water in the vicinity. Environment Canada, Atmospheric and Environment Service can provide some information on prevailing winds.

Areas subject to internal waves such as locations close to sills should be avoided.

Mitigation Opportunities

The wave criteria stated above are based on a standard cage design net

pen for an average farm (15 X 15 X 12 metres). From a farm and fish safety perspective, one can, of course, design for winds and waves which would receive a poor rating; it is simply a matter of deciding how much capital one is willing to invest in a farm.

Cages can be built deeper to allow the fish to escape the surface wave surges. Booms and pens of heavier construction can be placed on site. Stiff legs, if feasible, can also add to the security of a site.

At certain times of the year, however, a farmer located in a poorly rated, isolated site will have to be resigned to being stranded for days at a time.

There are no known mitigation methods for internal waves.

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MARCH 20, 1988



ALMON

are industry

Editor's Notes

By GEORGE BRYSON

We come to our cover story on the burgeoning salmon-farming industry this week (burgeoning, that is, just about everywhere but Alaska) with a few biases.

We admit at the start our particular love for salmon. We love to fish for them. And after we have caught them, we love to eat them. Beyond that, there's a special respect here for the thousands of Alaskans who make their living as commercial salmon fishermen.

The point is, we openly admire these people who make their living in the honest, time-honored method of "Those that go down to the sea in ships." Fortunately, commercial fishing is flourishing in Alaska now as never before.

Which brings us around, in a manner, to fish-farming, or mariculture — which is just starting to flourish as well, though only in other places. The harvesting of Pacific salmon in pen farms in Alaska's tidal waters is opposed by leaders of the United Fishermen of Alaska. The group representing 12,000 Alaska fishermen is concerned about the competitive aspects posed by fish-farming, as well as its environmental risks. Its leaders say that farm-raised salmon could spread disease to wild salmon stocks.

Supporters of mariculture, on the other hand, say fish-farming poses no greater risk of disease to wild salmon than do salmon hatchery operations, which have enhanced natural fish stocks in Alaska for years.

While the debate isn't likely to subside any time soon, our magazine doesn't plan to join it this week. Instead, this issue focuses on the nature of fish farming, both here and abroad. We do so hoping that when the debate rises in Juneau once more, we might know something of what they're talking about. ♀

This Week

FUTURE STOCK? A federal research center on Baranof Island is studying salmon farming — otherwise forbidden in Alaska. The technology is promising, but commercial fishermen's fears are likely to put aquaculture on hold in Alaska. By Hal Bernton. Page 6.

COVER: Photo of king salmon fry by Michael Penn.



Roy Martin, project supervisor at the Osprey Bay fish farm in Southeastern Alaska, opens a shed that holds fish feed.

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We Alaskans

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General Delivery

March weather teases the jogger dreaming of spring

By BARBARA TAYLOR
 Wasilla — Winter 1988

Fickle March weather. Now the guessing game begins. Jogging along at 20 degrees, I'll be just right in my sweats and a cotton blouse. Mitts, a sweatband around my ears and sport socks in my running shoes will do.

But is a breeze gusting down the road? Chilling wind cuts through my sweatshirt and pants. Maybe add my windbreaker and long johns under my sweat pants, a wool hat to shield my forehead.

The general rule: Dress for 10 degrees warmer than the actual temperature. If it's 15 degrees, act like it's 25, because body heat from exercise will keep you comfortable — not too hot, not too cool.

Tomorrow's forecast says minus 5 degrees. Put on wool socks, a cotton turtle-neck under a wool ski sweater and pull the hat down low.

Outside, it is crunchy cold as I begin a slow jog down our long driveway. My cheeks, chin and nose quickly begin to sting. Drawing off my mitt to rub my face

with one hand, I know I'll soon be warmer as my body puts out more heat.

What a good run. My body flows easily with the rhythm of my legs. Breathing is steady and slow. As the miles slip by I can feel the cleansing sweat and heat evaporate through my clothes; my tensions and frustrations evaporate as well.

Now I pause to watch. The pale Chugach Range parades pinks and purples like a pastel display of the aurora borealis. But chill quickly seeps through my damp clothing. Time to go back.

Halfway home, the sound of a snapping stick brings me to a halt. A huge paddle-eared moose blends softly into the trees, her brown coat muted by the early morning shadows of the spruce and birch, her long legs mimicking the slender trunks. "Hi there, girl," I speak softly. We stare at each other, and I walk slowly by, not wanting to disturb.

How is it that one day the cold drills into my fingers like sharp immunization needles, and the next day — a warm thaw?

A chinook? Shed the hat, long johns and

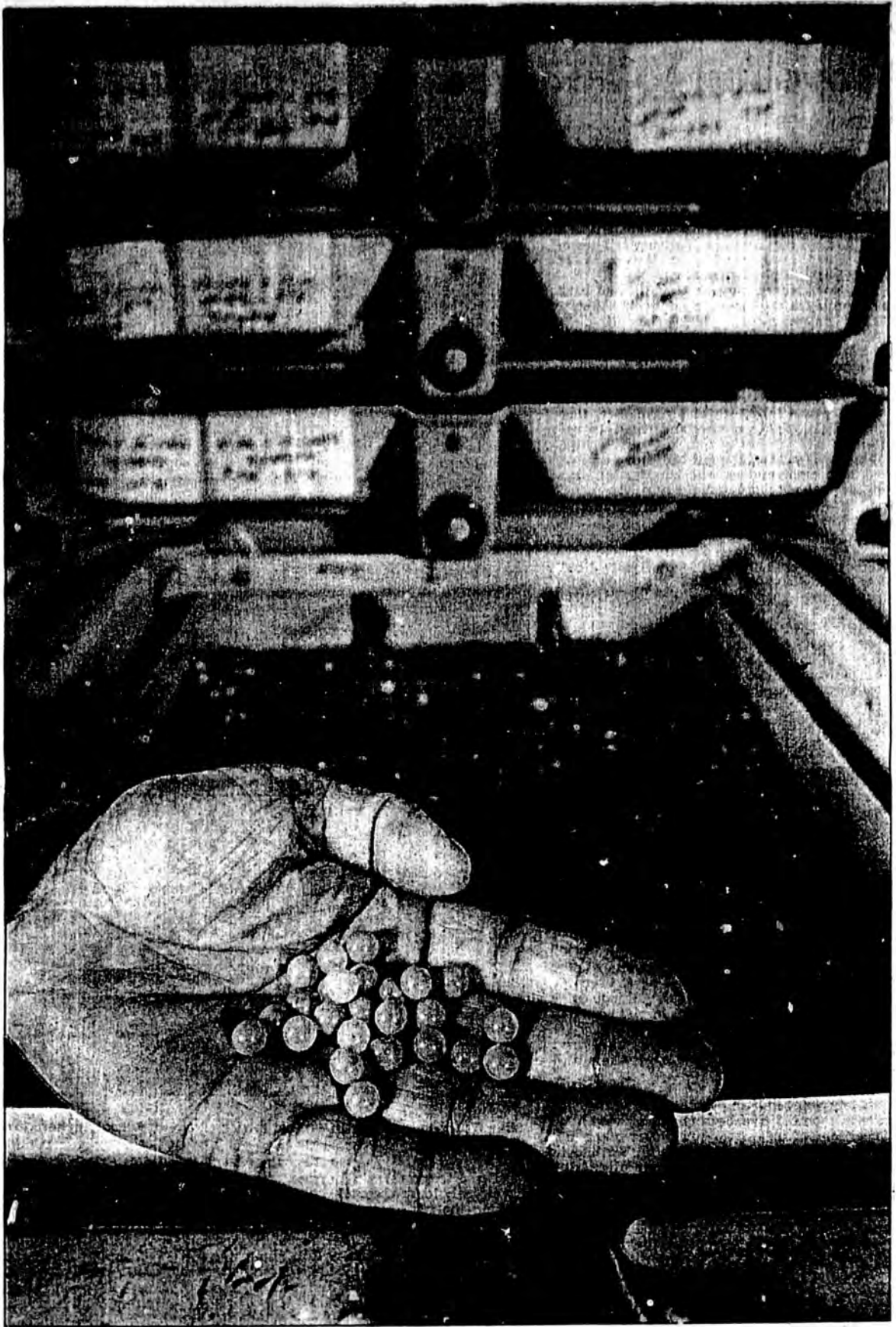
wool socks, even the sweatband. Back to sweats for 40 degrees. I feel light as a sheared lamb. This time I tread along with balmy breezes ruffling my hair. As the miles slip by, all of me responds to the measured beat of my body harmonizing with the measured cadence of the Earth. I fit. My senses are tuned to the mood of nature and I am confident.

Oh, shoot. Rain. No slicker for me. I slog through the slush, droplets coursing down my hair, spurling in a miniature waterfall off my nose, leaking into my eyes and ears. Soggy sweats cling to my skin like stubborn Saran Wrap as I quicken my pace.

Wet birch bark turns a rich brown, reminding me of spring. On I slosh. Ah yes, spring. Budding green leaves...

When I slip in the slush I'm jerked back to March, but those tantalizing memories of sweet scented air, little flowers and warm, long days haunt my thoughts.

Fun? Well, yes, if you're part chameleon and can change clothes just as fast. Bless the season of shorts, a top, shoes and socks for three whole months. ♀



King salmon eggs in front of their incubator at the Little Port Walter research station on Baranof Island.

FUTURE STOCK

Researchers know how to run efficient salmon farms, but commercial fishermen's fears may sink mariculture

By HAL BERNTON
Photos by MICHAEL PENN

On the southern edge of southeastern Alaska's Baranof Island, a federal research station is experimenting with a technology now forbidden in the rest of Alaska — the farming of salmon.

National Marine Fisheries Service biologists at Little Port Walters hatch king salmon eggs in incubators and nurture the smolt in the fresh water of an estuary. Then they raise them to sizes of up to 25 pounds in salt-water pens a few miles away at Osprey Bay.

The project is supported by the state Commerce and Fish and Game departments. In Norway, Canada, Chile, Japan and a dozen other

nations, this technology has created a major industry that now produces more than 280 million pounds of

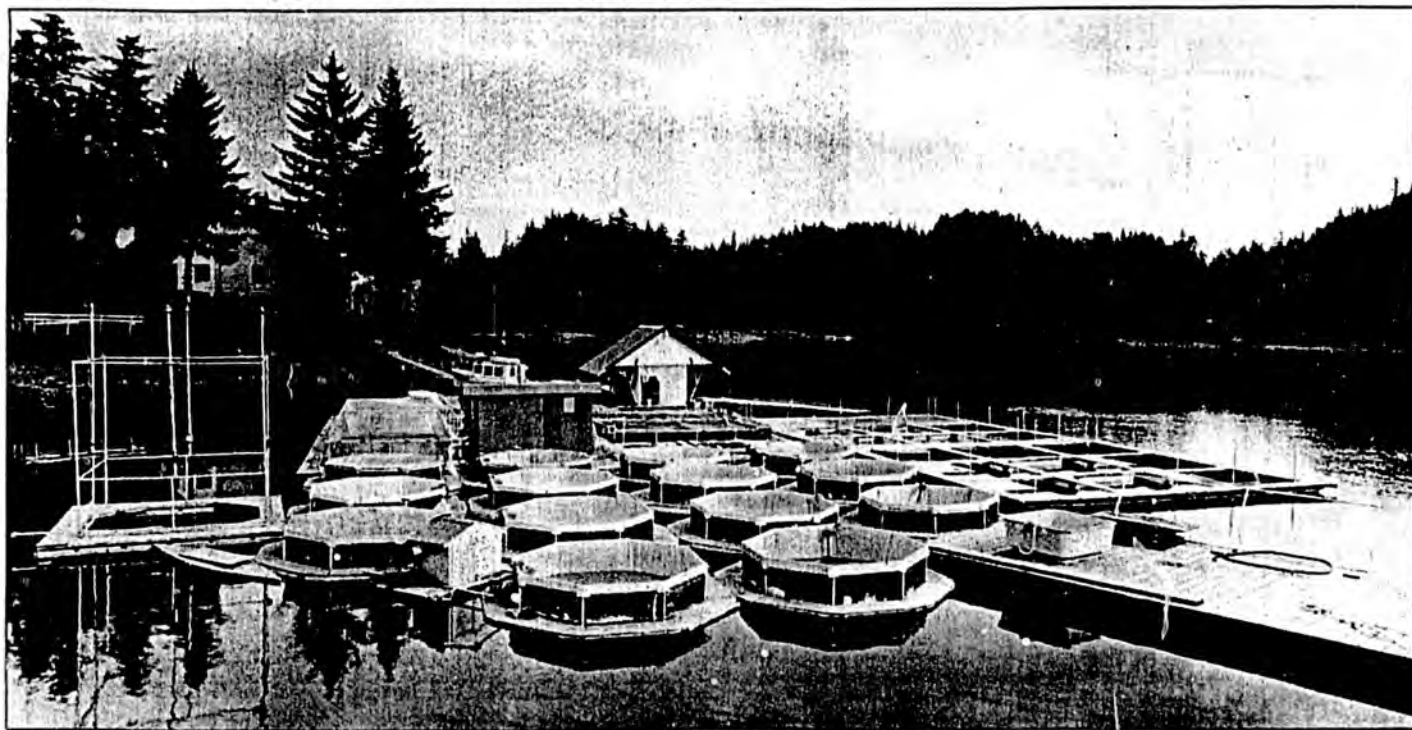
fresh salmon each year for international seafood markets. Some entrepreneurs would like

to lease state tidal waters to establish the industry in Alaska, but many fishermen vigorously oppose the idea. They fear both the competition that farm-reared salmon might pose to sales of wild salmon, and possible harmful environmental effects of salmon farming.

In Juneau, 150 miles north of Little Port Walters, the legislature is determining the industry's fate in Alaska amid an intense lobbying campaign by both advocates and opponents. More than a half-dozen bills addressing the future of salmon farming have been submitted to House and Senate committees. They range from an outright ban on the industry to a gradual leasing of state tidal waters to a new generation of Alaska fish farmers.



An aerial view of the Osprey Bay fish farm.



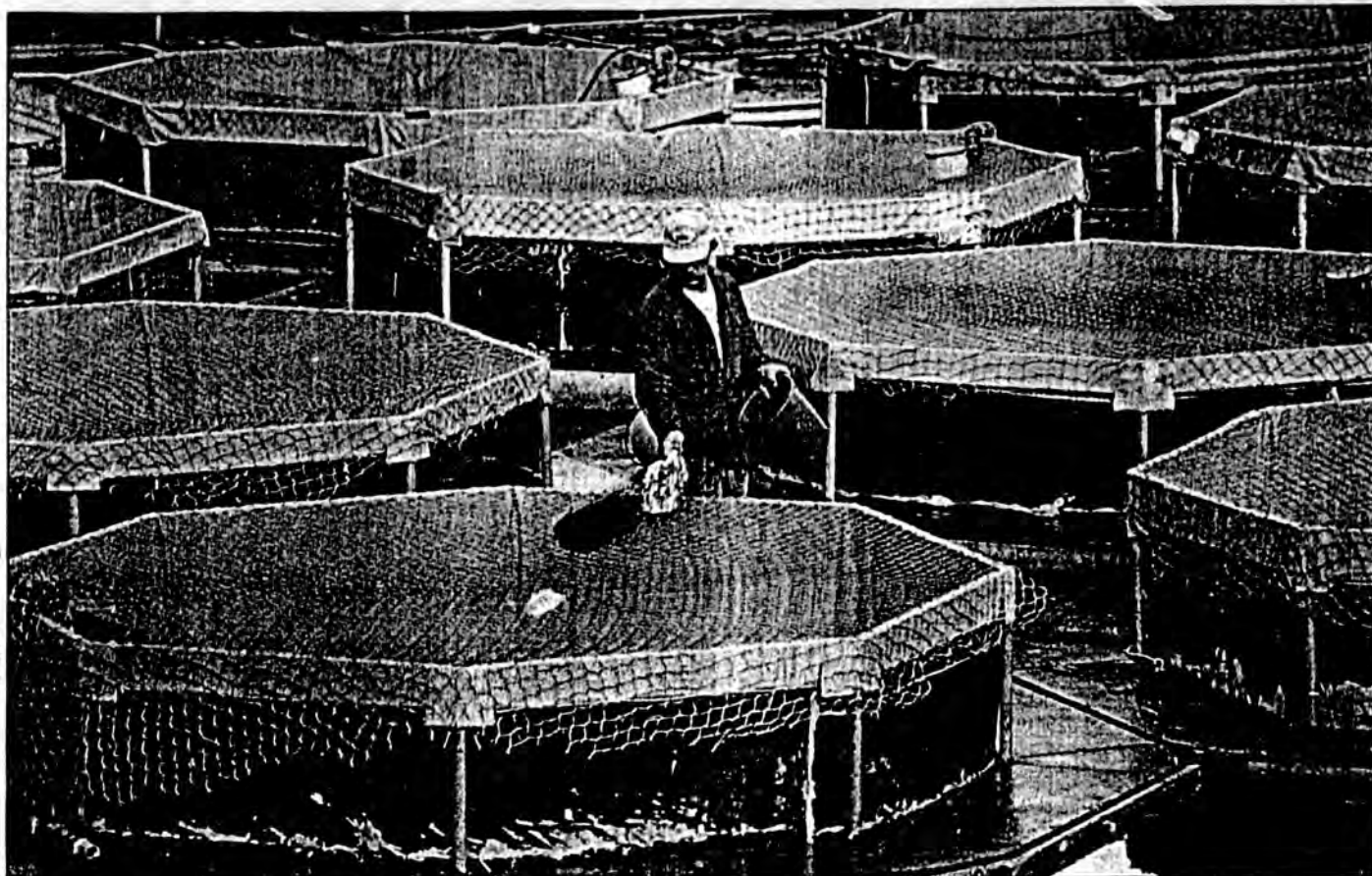
Fresh- and salt-water pens for salmon surround the Little Port Walter fish hatchery.



Jeff Hard dumps just-tagged fish into hatchery pens.



Bill Heard, project manager, holds a 3-year-old king salmon that has spent its entire life at the Baranof Island fish farm.



Fish and Game fish technician Roger Vaillon feeds penned salmon at Little Port Walter.

How a fish farm operates

The federal fish farm at Little Port Walters is an extension of a research hatchery that for decades has raised young pink, silver and king salmon for release into the wild, where they supplement both commercial and sport fisheries. The practice is known as aquaculture, and has widespread support from Alaska fishermen. Such hatcheries — some owned by nonprofit organizations supported by fishermen, others by the state Department of Fish and Game — release close to a billion fish into the ocean each year.

The farming process at Little Port Walters begins with collection of eggs from the more than 5,000 king salmon that now return each August to spawn at the hatchery. The salmon are captured as they swim up a fish ladder and placed in fresh-water holding ponds until eggs and sperm are ripe.

The fish produce more than 6 million eggs, most of which are given to other state and private hatcheries. Fertilization of the eggs is achieved by mixing them with sperm milked from male kings. About 300,000 eggs are incubated at Little Port Walters until they hatch in December or the following May, depending on the system of incubation used.

For scientists seeking to propagate the species, female kings are more desirable than males. A small amount of sperm can fertilize a vast number of eggs. They have discovered that a mix of ultraviolet radiation and warm-water

baths can change the genetic material of the sperm and eggs to almost eliminate male offspring.

Addressing fishermen's fears

Once the fish hatch, they are placed in 13-by-12-foot, corral-like plastic raceways that float in a fresh-water estuary. The oxygen the fish need to survive is provided by a constant flow of fresh water through the pens.

Normally, the young salmon are kept in raceways for about a year, until they are ready to make the transition to a salt-water environment. But scientists have learned to speed up that process by gradually mixing salt water into the raceways.

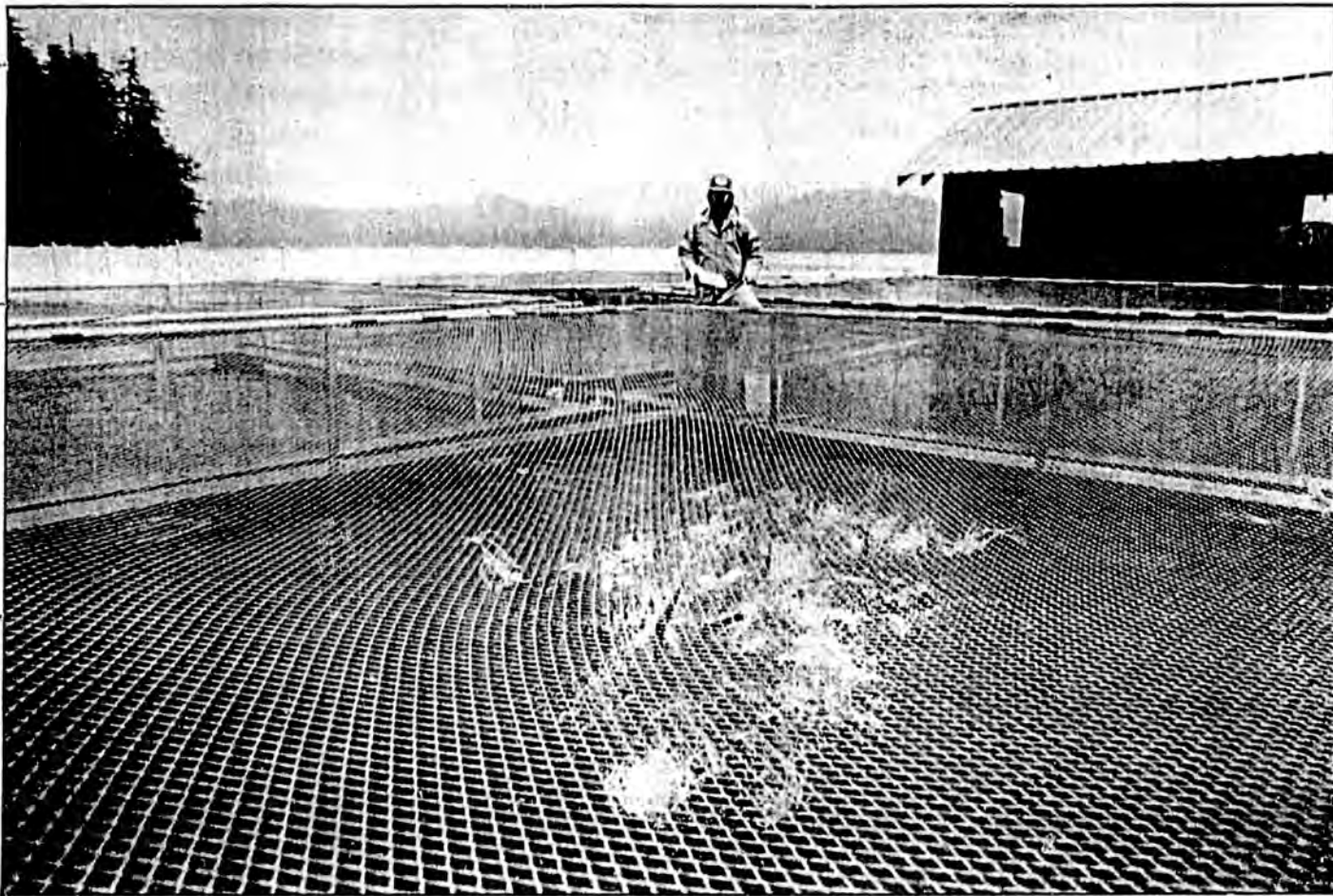
Fishermen are worried that the fish-farmed salmon — crowded in their raceways — will be susceptible to diseases that might then ravage wild salmon stocks. Salmon in the fresh-water phase at Little Port Walters have been struck by a bacterial infection that attacks fish kidneys, and in the salt-water phase by another bacterial infection known as vibrio.

But these diseases also are common in wild stocks, as well as in fish raised by fishermen's aquaculture cooperatives, according to Frank Thrower, a research biologist.

Both diseases can be easily treated with antibiotics, Thrower said.



Blood samples are taken from the fish to determine sodium levels.



Frank Thrower watches as 1-year-old salmon break into a feeding frenzy.

Location crucial

Most of the 300,000 king salmon raised annually at Little Port Walters follow the traditional Alaska hatchery cycle. They are released into the sea. Some will end up in the holds of commercial fishing boats; some may be caught by sports fishermen; a few will return two to four years later to spawn at the hatchery, where their eggs and sperm will be harvested to propagate the new generations.

The fish farm experiment involves a few thousand of the smolt. These fish will never know the freedom of the open sea. They're confined to salt-water pens, where they're fattened on feed until ready for harvest.

If Little Port Walters were a commercial salmon farm, several hundred thousand of these fish might be raised in the pens to sizes ranging from 1/4 pound to more than 6 pounds.

The fish-farming experiment began in 1984, when scientists transferred the first 2,000 young kings from the fresh-water raceways to salt-water rearing pens at Osprey Bay. The pens are made of plastic pipe and nylon mesh formed into 40-foot-long squares, and hold between 3,000 and 5,000 fish each.

The salmon dine on protein-rich pellets made from the herring and salmon wastes of seafood processing plants. The salmon is remarkably efficient at converting waste protein into edible meat; each 1.5 to 2 pounds of feed yields about 1 pound of salmon flesh, a much more efficient conversion rate than achieved by either chicken or cattle farmers.

What little waste is produced by the Osprey Bay salmon doesn't foul the surrounding water.



Concentrated fish food.

Three times a year, the pens are cleaned of barnacles and algae. Little fish waste or unused feed has been found to pile up on the bottom underneath the pens.

Thrower says the lack of pollution is due to a steep-sloping bay floor and strong currents that help flush wastes out to sea. "If you fish-farmed in an area that was relatively shallow, then you would accumulate feces and food on the bottom," he says.

Currents and ocean topography are just two of many factors that need to be considered when choosing a site for a salmon farm, according to biologists. To prevent mixing of farm-reared salmon with wild stocks, the farms also must be kept at least 30 miles away from bays that support wild runs.

"I personally think that if you apply this conservative approach, there's a great limitation on the numbers and kinds of locations where (Alaska) salmon farms can occur," says Bill Heard, a biologist at Little Port Walters.

In British Columbia, the salmon farming industry boomed in the mid-1980s with little

regulation. Bitter conflicts arose among salmon farmers, recreational boaters and other coastal-water users, prompting the provincial government to re-examine its permit policies.

In Alaska, legislative bills to legalize salmon farming call for the state to develop extensive regulations over the location of fish farms.

Industry's future uncertain

The salmon farm now has about 8,000 fish at different stages of development confined in salt-water pens.

After eight months on a high-protein diet, the salt-water kings have grown to weights of up to 2 pounds, a pan-size fish suitable for sale to some supermarkets. After 2 1/4 years on the diet, the fish weigh up to 9 pounds, large enough to compete with Norwegian-farmed salmon for the gourmet restaurant trade.

After three years in the pens, some fish have reached sexual maturity, Thrower says.

These growth rates compare favorably with those of the Atlantic salmon, the favored fish of Norwegian fish farmers.

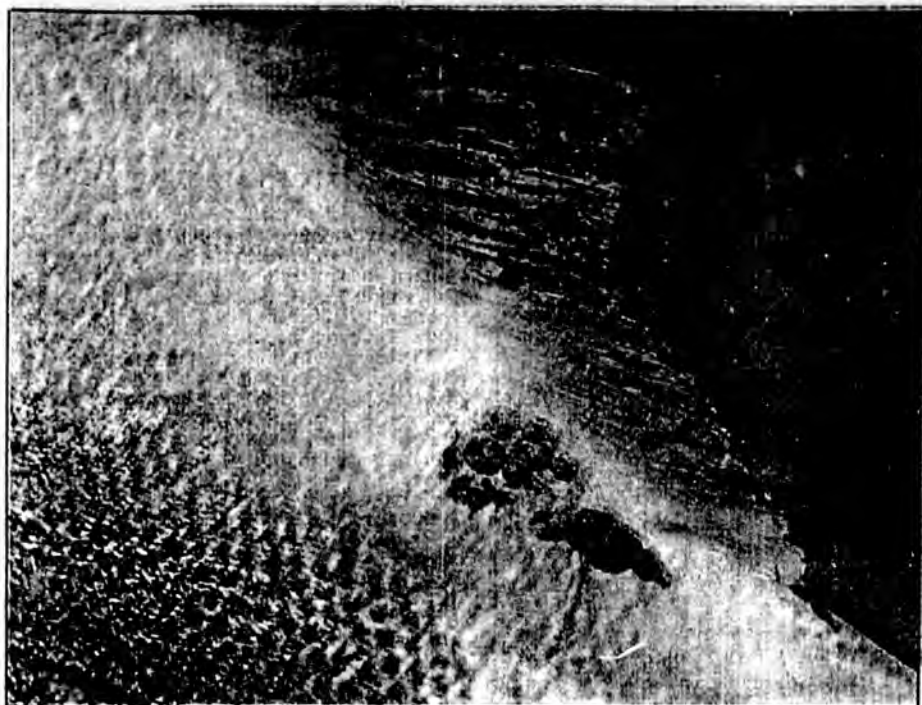
Biologists at Little Port Walters now think no major technical obstacles stand in the way of Alaska salmon farming.

And would-be salmon farm entrepreneurs think they could use this technology to create a major new industry for coastal communities. Fish feed, for example, could be created from the wastes now jettisoned by many processing plants.

"Considering our state's economic situation, we need to take advantage of mariculture," says Paul Fuhs, mayor of Unalaska.

But the Alaska future of salmon technology remains much in doubt.

"Ninety percent of the wild salmon in the



A captive salmon fin with fish lice attached.

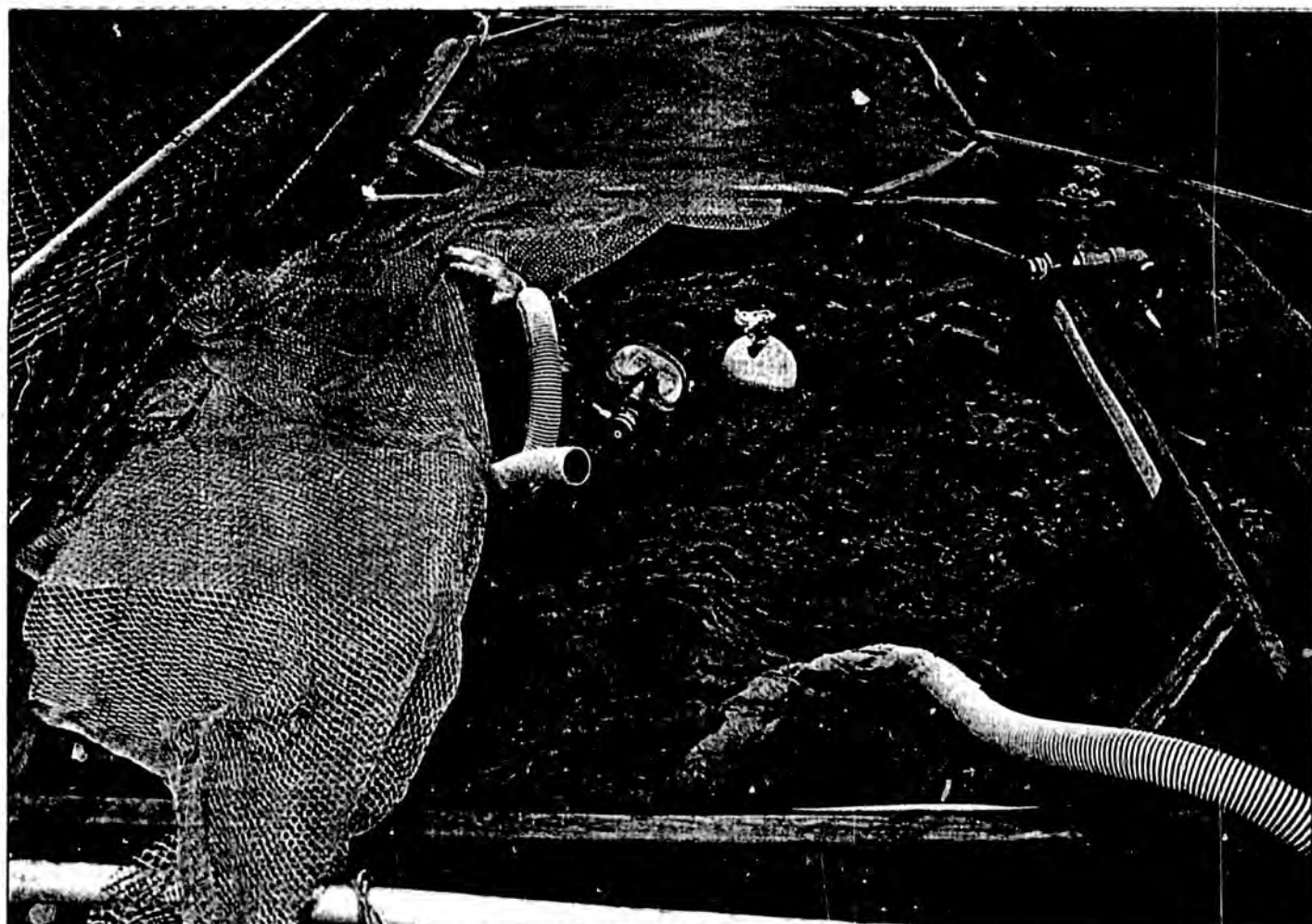
“Ninety percent of the wild salmon in the U.S. and 43 percent of the wild salmon in the world swim in Alaska waters. We believe Alaska has a prime responsibility to protect that wild resource . . .”

— Cheryl Sutton of the Kenai Peninsula Fishermen's Cooperative Association

U.S. and 43 percent of the wild salmon in the world swim in Alaska waters. We believe Alaska has a prime responsibility to protect that wild resource for both economic and environmental resources,” says Cheryl Sutton, executive director of the Kenai Peninsula Fishermen's Cooperative Association, a group lobbying to ban salmon farming in Alaska.

If the fishermen win their battle, sea-farming technology in Alaska will remain the part-time preoccupation of a handful of research scientists. **A**

□ Hal Bernton is a Daily News business writer. Michael Penn is a Daily News staff photographer.



Project supervisor Roy Martin surfaces in a salmon pen with the vacuuming equipment used to clean the nets.

THE FISH-FARM BOOM

Aquaculture raises huge profits — and troubling questions

By NATALIE FOBES

Salmon culture is a phrase buzzing through the seafood industry, terrifying fishermen, titillating restaurateurs and seducing investors.

Raising salmon specifically for harvest may change the way we think about those incredible creatures. The potential is there to produce low-cost, high-protein food. The smart money says that potential will be realized.

It was only a matter of time before the salmon's instinct to return to its natal rivers was exploited. People asked: Why not ranch them? Rear them in a hatchery to smolt size, send them out to graze in the ocean, and when the adult fish come back in three to four years, harvest them. It makes more sense than chasing salmon all over the ocean as commercial fishermen do now.

Or maybe we can farm them, they continued. Raise salmon in net pens in salt-water bays as well as fresh-water rivers and lakes until a restaurant or broker puts in an order. Harvest the fish and deliver them to the customer. Salmon on demand — fresh, the right size and only hours out of the water. Salmon farming is a big industry in Norway, Great Britain and even Tasmania, and has been for years. No reason it can't be done with Pacific salmon.

Simple concepts, yes. Controversial, absolutely. The idea of ranching and farming salmon has exploded in debate.

Environmentalists claim that fish feces and feed debris from salmon farms will pollute the water and accumulate on the ocean's bottom.

Property owners with spectacular views don't want net pens in the way.

Commercial fishermen say large-scale ranching might very well put them out of business.

Sociologists question whether the public domain should be used for private profit.

Biologists worry about disease contamination between farmed or ranched salmon and native stocks, and how the infusion of millions of ranched fish will affect the food supply in the ocean and rivers.

Some go so far as to suggest interbreeding could mean the end of wild native salmon, currently found in decreasing numbers in the Northwest. Others say salmon culture will be the salvation of the stocks because it will decrease the commercial salmon harvest.

Everyone has an opinion. But all agree salmon culture is here to stay.

"It's not a matter of whether it will go," said Connie Mahnken, aquaculture specialist with the National Marine Fisheries Service. "It's a matter of who's going to do it."

And companies in the United States, Canada, Chile, Japan and New Zealand are all trying their hand at it.

□
New Zealand is a nearly perfect location for salmon culture. The water is cool and clean. The introduced quinnats (chinook salmon) have been adapted to pen-rearing and ranching. Labor costs are low. Few people complain about the sight of net pens or ranches because few people live near them. The seasons are opposite those in the Northern Hemisphere, so the product doesn't compete with Alaska and Pacific Northwest salmon in the marketplace. And there is no commercial salmon fishery.

The industry has boomed since the first ranch was formed in 1977. Two years later, 100 fish returned to the ranch. In 1986, more than 23,000 fish were harvested at four recapture



Anchorage Daily News file photo

Commercial fishermen are among those who fear that salmon farming is not the breakthrough its proponents claim.

sites in New Zealand, accounting for approximately one-fifth the world total of ranched Pacific salmon.

Today, six different companies raise salmon in pens in Big Glory Bay. When commercial fishermen in the Northern Hemisphere hang up their lines and nets in November, the harvest begins at the salt-water pens in New Zealand. The farmers ship fresh fish to ports like Seattle and Tokyo until March. Most of the 800 metric tons harvested annually ends up on the plates of restaurants at least 17 hours' flying time from New Zealand — a world away to those who harvest the salmon.

At 5 a.m., employees have already assembled on the wharf in Oban. Outlines of the New Zealand Salmon Co. net pens are barely visible as the boat nears the farm. Four separate farms with 28 or 30 pens each are anchored to the bay's bottom by a series of 2-ton concrete blocks.

This morning, the water is undisturbed, save for the wakes of yellow-eyed penguins and the boat. The vessel pulls aside the first of two pens to be harvest.

Salmon are herded from the 8-meter net into a smaller net pen. A blue plastic tarp has been placed under the pen, preventing the circulation of fresh water. Carbon dioxide is pumped into the water to stun the fish.

Within seconds, the glasslike pane of water breaks. Silver scales scatter light. Splashing obliterates the sound of the portable radio. Gills working, mouths gasping, the salmon leap and dive.

For five minutes the splashing continues unabated. Then the activity in the water slows. Salmon float belly up, their tails occasionally powering a last futile attempt to escape. Tom Learmouth, the company's harvest manager, nods. "Let's go," he says.

The beauty of salmon farming is its harvest efficiency. Two-and-a-half tons of fish are taken from the pen in less than two hours. Three hours after the salmon have been killed, they are on a plane bound for the United States. Thirty-six hours later, the filets are a dinner entree.

Despite the jet-age efficiency problems may eventually sabotage the industry.

Many observers suggest that New Zealanders too readily accept risky ventures. "The 'kiwi into the wind' trait runs deep here," said Lawrence. "Unregulated development, a carte-blanche approach, could have a negative effect. We just don't know." The number of salmon the waters of the continental shelf can feed is unknown, he added.

□
It's 5 a.m. at the fish market in Tsukiji, Japan.

Horns blare. Engines roar. Styrofoam squeaks. Voices shout. Look alive, step quickly, or run the risk of becoming a spot on the spotless floor.

Stacked on tables and floors are bluefin tuna the size of Honda Civics, crates of live crab in sawdust, fish in boxes, fish in crates, fish in aquariums and salt water tanks and freshwater buckets.

An auction begins. Laughter and talk ebb as rows of men, numbers in hats, clipboards in hand, turn their attention to the auctioneer. He blasts out the prices and lot numbers, commanding the men to bid. Fingers pierce the air as brokers reply. No stopping, no slowing; the group moves from row to row of salmon or tuna or roe or squid until the section is gone. Then the buyers disappear.

Here a person begins to get a sense of the importance of seafood to the Japanese. The Japanese have the highest consumption of fish in the world: 75 pounds per person per year. They raise shellfish and seaweeds, octopus, eels, sea urchin and salmon, and are known as the foremost aquaculturists in the world.

But it isn't until you see the acres of sample fish spread out in one spot that you begin to understand why the Japanese own 80 percent of the salmon-processing plants in North America. Why they are involved in aquaculture in Chile, Canada and New Zealand. Or why some individuals risk going to jail and paying a fine for illegally importing Asian salmon laundered through the United States.

From the sashimi bars at Tsukiji to Aihara's Restaurant in Ishikara, salmon is an honored guest. Twenty years ago, that salmon might not have been a guest at all. But Japan's production of chum salmon has increased tenfold since 1965.

In 1955, the government began a series of five-year plans designed to increase domestic salmon production and reduce dependency on offshore fishing. When the United States and Soviet Union extended their coastal zones in the 1970s, limiting that fishing even more, the Japanese were ready.

"We anticipated the expansion of the zones," said Takeshi Yamamoto, a government fisheries official. "So we expanded our production." The country's domestic chum stocks now repre-

A look at salmon farming around the world

Where did that alder-smoked salmon filet with a hint of rosemary come from? Was it pulled from the sea by exhausted fishermen in the middle of the night, in the middle of a storm? Or was it taken from a net pen and rushed to the restaurant in which you are dining? There's a one-in-10 chance that the fish was from the latter. Three years from now, those odds will likely triple.

United States

Three problems face salmon culturists in the Lower 48: The resistance of waterfront property owners to farms and ranches that impede their views; water quality and bottom debris from farms; and the political clout of commercial fishermen.

California has one experimental ranch, Oregon has 12 ranches but no farms, Washington has no ranches but three companies with seven farms, and Alaska has 15 private, non-profit hatcheries that for all intents are ranches, and a federal research station in Southeast Alaska where National Marine Fisheries Service biologists are experimenting with a small-scale fish farm (see the story on Page 6).

Canada

Salmon farming has exploded in the last two years on the largely uninhabited Sunshine Coast of British Columbia. When asked how many net pens were operating in the province, Bud Graham of the Department of Fisheries and Oceans replied, "Which day of the week do you want? The number is growing exponentially." As of March 19, 1987, a hundred farms were operating with 466 applications in the permit process. A year before, there were only 30.

Japan

Japan is the largest producer of farmed Pacific salmon. The country supplies 2,500 metric tons of the world total of 10,000 metric tons, the vast majority from Shizu-gawa.

Pollution from the last decade of farming may throw a wrench in the works. Tests indicate sediment buildup of 15 to 30 centimeters on the bottom of the 14- to 22-meter-deep bay. The fishermen are trying to find an answer to the problem. They are considering solutions as simple as "crop" rotation to one as complex as coating the bottom with a charcoal-based material.

Norway

The giant of salmon culture, Norway

raises only Atlantic salmon. The country's production of salmon has been estimated at 43,000 metric tons per year. Three years from now it will be well over 90,000 metric tons. For perspective, the world's natural production of wild coho and chinook is between 45,000 and 60,000 metric tons per year. Norway's companies are investing in Canada, the United States, Chile and Tasmania.

Chile

A half-dozen companies from four different countries are producing coho, chum, chinook and Atlantic salmon. Jon Linbergh, a salmon culture consultant, is convinced Chile will be second only to Norway in tonnage of farmed and ranches fish in a decade.

Like salmon culture everywhere, the endeavors have not been without trials and tribulations. Only five chum out of thousands released returned in one experiment with ranching. To add insult to injury, the salmon returned 500 miles south of where they were supposed to.

□ From "The Promise of the Future" by Natalie Fobes, published in "The Reporter," a publication of the Alicia Patterson Foundation.

sent 38 percent of the world's production of Pacific salmon.

Forty-nine million chum salmon return each year to Japan's northern coast, an area about one-third the size of California. More than 168,000 metric tons of fish are harvested. All of the 2 billion smolts released annually are raised in hatcheries.

The statistics are staggering. The United States, in comparison, released approximately 805 million smolts in 1986.

"Salmon culture has developed like a flower taking a hundred years to blossom," said one government official.

The technology is certainly not new: the Chinese propagated fish as early as 2,000 B.C., and probably passed their knowledge to the Japanese. In 1716, samurai Buheiji Aoto divided a river into several channels to increase its spawning area, and in 1888 the first hatchery was built on the northern island of Hokkaido. Salmon are now produced in 16 northern prefectures, or states, and on the island of Hokkaido by 313 private, prefectural and federal hatcheries.

"We are changing our target from increasing the amount to improving quality," said Takeshi Yamamoto of the Japanese Fisheries Agency.

There are two ways to create higher-grade fish, he said. One is to emphasize hatchery programs featuring different species such as sockeye, coho or cherry salmon. The other is increasing the oil content of the flesh, making it more succulent. The government is attempting to reach that goal through egg transfers from one river to another and through genetic manipulation.

Many are concerned that the gene pool's diversity is shrinking due to these egg transfers and the years of interbreeding. Negative characteristics that tend to be weeded out by nature may surface because of these practices, experts warn. These traits include a sensitivity to disease or a tendency toward smaller fish.

To prevent this problem, Hokkaido's fisheries agency wants to set aside four island rivers that would act as gene banks. Stock in these streams would not be mixed with salmon from

other waterways, thus keeping its gene pool unadulterated.

Officials admit that the installation of the "gene bank" plan is many years away. First streams must be found where the stock is relatively pure. After a hundred years of aquaculture, that may be easier said than done. And once those streams have been chosen, the commercial fishermen must agree to the plan. The architects of the plan anticipate a three- to four-year fight as the co-ops and government negotiate the necessary restrictions. Salmon culture is at best a precarious compromise.

□

The future of Pacific salmon lies in the hands of many cultures — the Ainu and Yakima Indians, the Russians, the Americans, the Japanese and Canadians, the New Zealanders and the Chileans. But no matter what policies these people adopt, one thing is certain, say most observers: The future will include salmon culture. It must, in order to provide enough fish for commercial and sport fishing.

All countries supplement their wild salmon runs with hatchery-produced fish. Even the Chinese are enhancing their stocks. The question that must be answered is how these releases and the private salmon-ranch releases affect the well-being of wild stocks.

Few question the hypothesis that accidental interbreeding between native and farmed or ranches stock will weaken if not devastate the genetically unique wild salmon. What is not known is the impact that large numbers of hatchery-produced salmon may have on the amount of feed in the ocean, rivers and streams.

Scientists believe the ocean and watersheds have a finite amount of food. While the number of salmon now produced doesn't begin to come close to historic levels, some ocean and river feeding areas may be "overgrazed." In the food fight between wild salmon and artificially propagated fish, the latter will win, experts say. Hatchery-produced fish, raised in high density situations, spend their entire lives competing for food.

Biological concerns are not the only salmon-culture questions with which to wrestle. Who

owns the privately ranches fish when they are at sea? Once in the ocean the fish become a public commodity, according to legal precedent. While salmon ranchers accept the concept, they claim that commercial fishermen prey upon the returning ranches salmon. This is unfair, say the ranchers, because the fishermen know when and where the fish are returning.

The fishermen respond that the salmon ranchers are making private profit from a public resource and ask if this is just.

Critics ask commercial fishermen if they, too, are not making a private profit from a public resource. Half of the salmon produced in Washington state are hatchery fish. General fund tax money supports these hatcheries. Therefore, the public subsidizes the fishermen.

Certainly these questions must be addressed before salmon culture can come into its own. But the day may come when all the salmon we eat is raised in pens or harvested by ranchers. The thought is disturbing to many.

Pacific salmon mean much more to the people of the Pacific Northwest than a great-tasting source of protein with low cholesterol. Salmon represent the underdog, always struggling and sometimes winning against great odds. They are a reminder that nature has a plan for all creatures, that the environment is indeed a series of interlocking spheres. The salmon symbolize an innocence lost when the vast forests were cut and the raging rivers dammed, and when the views of the mountains were replaced by city skylines. And maybe a bit more of that innocence will be destroyed when salmon are raised like chickens.

"The lack of pure nature destroys the human mind," said anthropologist Masakazu Yoshizaki. And pure nature is the essence of the Pacific salmon. ■

□ Excerpted from "The Promise of the Future" by Natalie Fobes, reprinted from "The Reporter," a publication of the Alicia Patterson Foundation. Natalie Fobes, a photographer on leave from The Seattle Times, received an Alicia Patterson Fellowship and chronicled the struggle of the Pacific salmon to survive.



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Shellfish Mariculture

by

Michael Kaill

Mariculture Coordinator

FRED Division

Alaska Department of Fish and Game

Introduction

Alaska has the potential to enter a new resource industry — shellfish mariculture. Although oyster farming has been with us for some time, its growth has been hampered by lack of infrastructure. Culture of other species of shellfish, though unproved in Alaska, has been demonstrated in Japan, Canada, and the Pacific Northwest as well as other places. Recent action by the Alaska legislature has begun to clear away some of the obstacles keeping Alaska from realizing its potential.

Environmentally, Alaska is well suited to shellfish mariculture. However, there are some challenges that must be addressed.

Bourne and Brett (1984) suggest that:

"Several criteria must be considered when deciding if an animal is suitable for culture; three of the most important are an inexpensive and plentiful source of juvenile (seed), a rapid growth rate (or reasonably so), and a high price for the product."

Added to this are the technical as well as social factors involved in site selection for a sea farm in Alaska's tidewaters.

Permitting and Permit Activity

Legislation has been passed to authorize the collection of spat for bivalve shellfish farming. In order to meet the intent of this legislation, the Alaska Department of Fish and Game (ADF&G) has undertaken the following tasks:

1. Created a permit system for commercial collection of spat (juvenile shellfish) to be used as seed for bivalve shellfish farming. At this time there are three commercial scallop spat fishermen.
2. Revised the Fish Transport Permit (FTP) so that it will be appropriate for the shellfish program. The purpose of the FTP is to protect natural and enhanced stocks against disease problems and unwanted mixing of gene pools.
3. Proposed new regulations for the shellfish mariculture program. At the time of this

writing, these regulations are under public review.

4. Prepared a unified application system for a shellfish farm. One of the problems expressed by the public is the heavy load placed on applicants as they deal with the many agencies involved in permitting. ADF&G, working cooperatively with other agencies, has produced a single application form for ADF&G, Department of Environmental Conservation (DEC), Department of Natural Resources (DNR), and the Governor's Division of Governmental Coordination (DGC). DGC will receive the application form from the applicant and coordinate review. The unified application form is now in the final stages of review.
5. Began to develop information on key issues in anticipation of the 1987-88 legislative session. This effort is being coordinated by ADF&G and involves DEC, DNR, Department of Labor, and the Commercial Fisheries Entry Commission (CFEC). CFEC is involved not from the point of view of limited entry, but of commercial fishery licensing. This information packet will include discussion papers on important issues, an analysis of management systems in other states and countries, and an analysis of selected policy options.

Permit Activity: The Department of Environmental Conservation has issued or is in the process of issuing certification for about 50 shellfish farming operations. Of that number, about ten oyster and mussel operations are producing product for the market. Main centers of production at this time are Halibut Cove Lagoon (in Kachemak Bay) and the Wrangell/Petersburg area. There are several operators in Kodiak, Ketchikan, and parts of Prince William Sound that are seriously working toward producing products in marketable quantities.

Promising Aspects of Mariculture in Alaska

Market: In order for a cultured product to be successful, it should command a high and stable price and be in high demand. For the species holding best promise for mariculture in Alaska (oyster, scallop, and mussel) the situation is encouraging — particularly since the American public is turning to seafood as one way to increase quality of life and health.

Sites for Sea Farms: One of Alaska's great advantages over the "lower 48" for mariculture is its extensive and highly complex shore line. Pollution (including the recent problems with "visual" pollution) seems to be a major obstacle to the continued development of mariculture elsewhere in the Pacific Northwest. Alaska's low pollution levels, together with the many protected coves and bays found in much of the state, show a real advantage in this area. Low population densities suggest that this will not be a problem for some time.

It is important to note that sea farm siting requires careful coordination, particularly in the areas of environment and consideration of alternative uses (subsistence, sport fishing, scenic esthetic, commercial fishing, use as anchorage, and others).

Stability: A successful mariculture industry would use one of Alaska's strongest renewable resources to augment sometimes problematical oil revenues. The "boom-or-bust" nature of Alaska's industries is frequently mentioned. Sea farming has the potential to create a steady economic benefit to the state.

Benefits to Rural Alaska: Since mariculture operations require remote siting and a fair amount of year-round labor, it is expected that coastal rural Alaska will receive a large share of any economic benefits coming to the state through mariculture.

Growth Potential: Mariculture is a growing industry. Even in countries where it is a major force, sea farms are a relatively recent development. There is good potential for increases in profit margin, ease of operating the farms, safety to the plants and animals being farmed, and for reduction of negative visual and environmental effects. Areas of promise are: advances in equipment technology (feeding, cleaning of cages, flotation systems, handling of product) and technical advances in biological areas (genetic engineering, inexpensive seed production from hatcheries, new species/polyculture development).

Working in coordination with the commercial fishing industry, innovative combinations of mariculture and commercial fishing can be developed. For example, one of the most profitable aspects of mariculture involves seeding some selected sections of the ocean floor with small scallop. Subsections of

Shellfish Mariculture *continued*

that area are then harvested by commercial fishermen, a plan similar to crop rotation.

Problems and Challenges

PSP: Bivalve shellfish are filter feeders and, as such, are capable of concentrating the toxin from several species of free-swimming microscopic organisms. The result can be Paralytic Shellfish Poisoning (PSP). The problems with this are primarily associated with human health, expense, loss of shelf life, and logistical problems involved with testing to make sure that a particular shipment of product does not have PSP toxin above tolerance levels.

One of the advantages of scallop culture is that the traditional product form (shucked adductor muscle) does not have appreciable amounts of toxin and can be marketed with a minimum of testing for PSP.

One need of the industry is for more efficient PSP testing, particularly for southeast Alaska.

Siting: Remote site locations may be necessary to get good water quality and to get away from conflict-prone high-use areas. However, the remote sites have problems from the point of view of getting and supporting workers on site, getting the products to market, and general logistics (maintenance service, supplies, etc.). Site selection must consider trade-offs between these factors.

Seed Supply: A basic need for any farm is an inexpensive and reliable seed supply. Shortage of seed is one of the reasons that shellfish mariculture in Alaska has not grown more quickly. Options are to purchase from a hatchery or capture from wild sources.

A joint ADF&G/OFCF project now under way in Kodiak is testing feasibility of capturing weathervane scallop spat using spat collectors developed by the Japanese scallop farmers. OFCF (Overseas Fisheries Cooperation Foundation) is a quasi-government Japanese foundation funding projects whose objective is to promote international goodwill. Other similar but smaller-scale projects are under way in various parts of the state.

Economics: The profit margin for a shellfish farmer may be narrow. To operate a successful business, the farmer must have a good financial plan, including an understanding of the critical economic parts of the farming operation. Examples are minimizing equipment cost, controlling logistic problems, getting best use of labor, and effective marketing.

Disease and Genetics Issues: These issues are not cause for serious concern as long as proper safeguards and programs are in place (inspections, lab support, etc.). In general (providing that there is no introduction of exotic stocks), any disease threats from indigenous stocks can be dealt with using existing policy and procedure. Review and policy adjustments are ongoing, as the resource agencies accommodate these new programs.



Mike Kaill examining kelp near Kodiak Island.

A Quick Look at Alaska Mariculture by Species

Scallop: here are several species of scallop in Alaska. Scallop of interest to mariculturists are: the weathervane (*Patinopecten caurinus*), the purple-hinge rock scallop *Crassodoma (Hinnites) gigantea*, and two or more species collectively called "bay scallop" (genus *Chlamys*). Of these, the large, commercial weathervane is of great interest. A close relative is the basis of the rich scallop culture in Japan. The weathervane has a high demand in the U.S., commanding a consistently high price based on product from the trawl fishery. The purple hinge is not commercially taken, since it is sparsely (though widely) distributed. If a hatchery program for seed could be initiated, this species, with growth and product quality close to the weathervane, could show much promise.

However, the bay scallop complex, composed of smaller, slower growing scallops, might be marginal for culture.

Oyster: There is currently a "half-shell" oyster industry in Alaska. Many of the farms are in the Wrangell-Petersburg area, though new interest is appearing in the Ketchikan area, Prince William Sound, and Kodiak. The Alaska-produced product (Japanese oyster, *Crassostrea gigas*) is of high quality. One of the reasons for this is that the oyster is on the edge of its range, and seldom comes into reproductive condition in Alaskan waters. Energy that would go into gonadal tissue is devoted to flesh, creating a plump, yet relatively fast growing oyster. Seed is provided by producers in Washington and Canada, which is a problem because of expense and logistics. The Japanese oyster is presently the only authorized mariculture Alaska import.

Mussel: Although not a common seafood item in Alaska, the blue mussel (*Mytilus edulis*) is a highly prized delicacy in Europe. There is an increasing appreciation for this species in Alaska, particularly when diners realize that the cultured mussel is far superior to the one taken from the beach. Culturing blue mussel has the advantage of readily available seed (dense concentration of spat settlement in some areas) and an 11-month growing season, compared to 2 to 3 years in other species.

Other Species: Other species of shellfish are candidates for culture in Alaska, but are not nearly as strong as the species mentioned above. These include surf clam, razor clam, as well as species not yet authorized by the legislature such as sea urchin, shrimp, and crab.

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Salmon Ocean Ranching in Alaska

by

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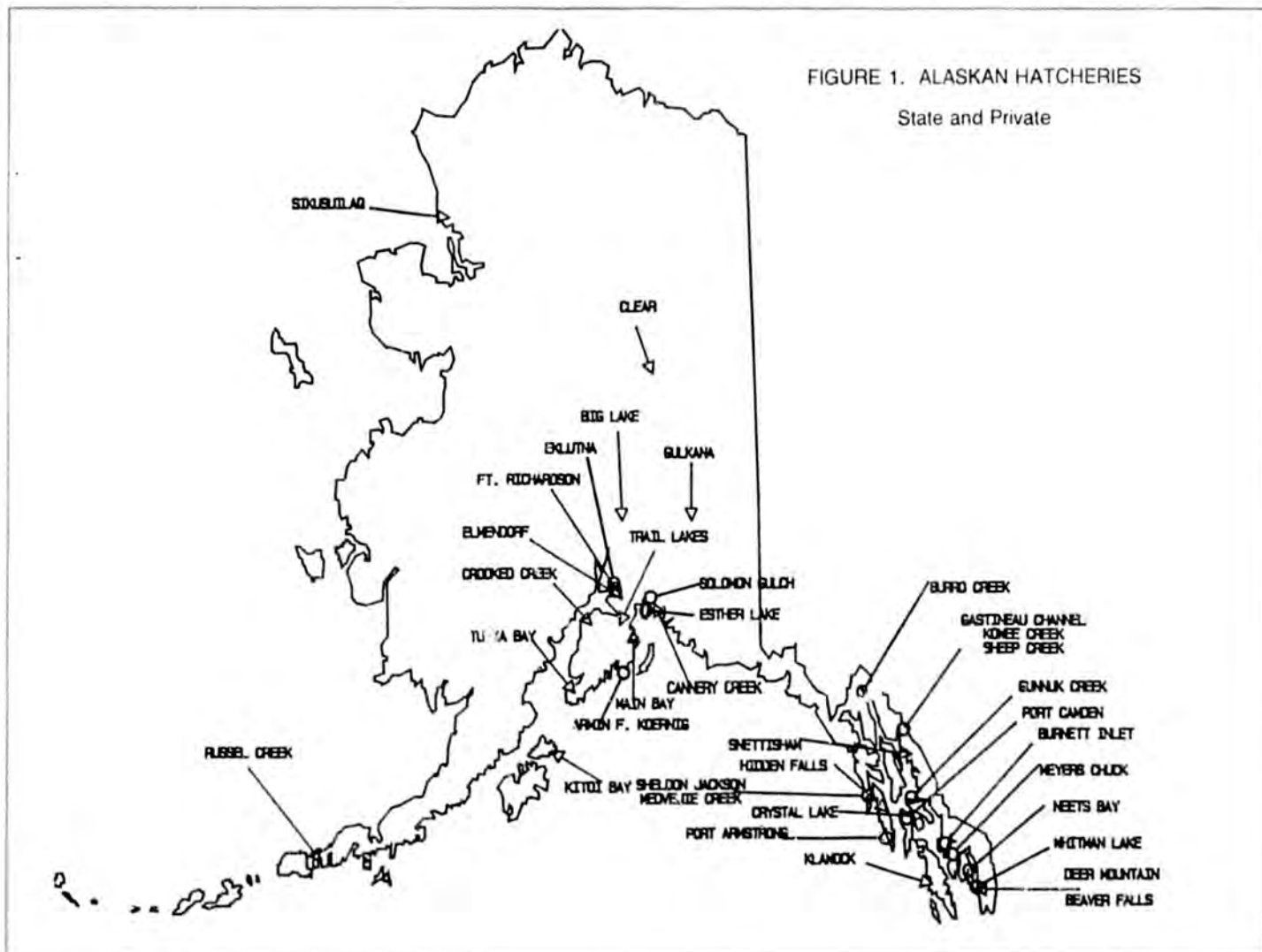
Alaska Department of Fish and Game

Introduction

The largest and most successful form of aquaculture in Alaska is salmon ocean ranching. It was created out of need by the state legislature in the early 1970s when natural salmon runs were depleted statewide. Enabling legislation in 1971 began with a public program and expanded in 1974 to statutes allowing for a private nonprofit sector. Ocean ranching of salmon is an established technology over 100 years old which takes advantage of the fact that salmon "home" or return unerringly to their location of release.

The source of initial production comes from freshwater hatcheries which control the environment such that roughly eight times the survival is achieved over their natural counterparts. This is true because a constant, reliable source of water is applied during the egg to juvenile salmon release phase, as contrasted to natural production which can be severely limited based upon lack of water flow, natural streambed dynamics, and freezing temperature regimes. Depending upon the species' life history strategy, the salmon are released into the marine environment as fry for chum or pink salmon, or as smolts for chinook or coho salmon, or into a freshwater lake as sockeye salmon fry. It is this unique, instinctual migratory behavior of leaving freshwater as juveniles, growing and initiating maturation in the marine environment with the return back to freshwater to spawn that

distinguishes Pacific salmon and sea run trout like steelhead and makes them so economically valuable. This life style is called anadromy and its survival value is obvious in that the richness of ocean pastures can be exploited by what was originally a freshwater fish. Moreover, the fact that salmon specifically return or "home" to their location of release causes aquaculturists to have some control over their migration as if they were on a chemical leash. That the leash is chemical has been determined by many laboratory and field experiments which all prove that anadromous salmon and trout have an uncanny sense of olfaction, or they smell their way home. In the course of going home, these fishes are caught in the commercial, sport, subsistence, and personal-use fisheries and contribute substantially to the social and economic lives of urban and rural Alaskans.



Ocean Ranching *continued*

Present Status

There are currently 19 public hatcheries run by the Alaska Department of Fish and Game (ADF&G), Fisheries Rehabilitation, Enhancement and Development (FRED) Division, and 25 private nonprofit permits with 18 operational hatcheries practicing the technology of salmon ocean ranching throughout Alaska. The scope of the program is bold and worldwide in perspective (Fig. 1). These hatcheries took 1.338 billion salmon eggs last year, plus over 10 million trout eggs (Fig. 2). The Alaskan salmon ocean ranching program is the largest in North America, approximately one-half the size of Japan's and roughly equal to Russian programs. Sockeye salmon production alone is the largest in the world with over 100 million eggs taken. These phenomenal records were achieved from inception in the early 1970s to the present, a relatively short 17 years. As yet, preliminary data suggests that the returns in 1987 from both the public and private nonprofit program account for roughly 18 percent of the total salmon harvest statewide. When the data for Alaskan hatchery returns in 1987 is graphed, it shows that most of the returns to date are from pink salmon, followed by chum and sockeye salmon (Fig. 3). The reason pink salmon ocean ranching has been so successful relates to their 2-year life cycle and the fact that they are economical to raise.

Aside from the biological successes, salmon ocean ranching has had a profound impact on the economic and social structure of Alaskan communities. One study conducted in 1984 predicts that the statewide program will generate net benefits over costs of \$90 million to the Alaskan economy for just the commercial fishery portion of the program. A more recent study to quantify the economic impacts of the ocean ranching program utilizes an impact model developed by the Institute of Social and Economic Research (ISER) at the University of Alaska Anchorage. This model determined that the economic contribution of ocean ranching to resident personal income was \$75 million and over 2,000 resident jobs from fish dollars directly earned in the fishing industry, or by indirect or induced spending in other sectors of the community.

Since these programs produce significant numbers of fish for the sport fishery as well, both economic studies have underestimated the total economic impact. Because values

FIGURE 2. ALASKAN HATCHERY EGG TAKES 1987

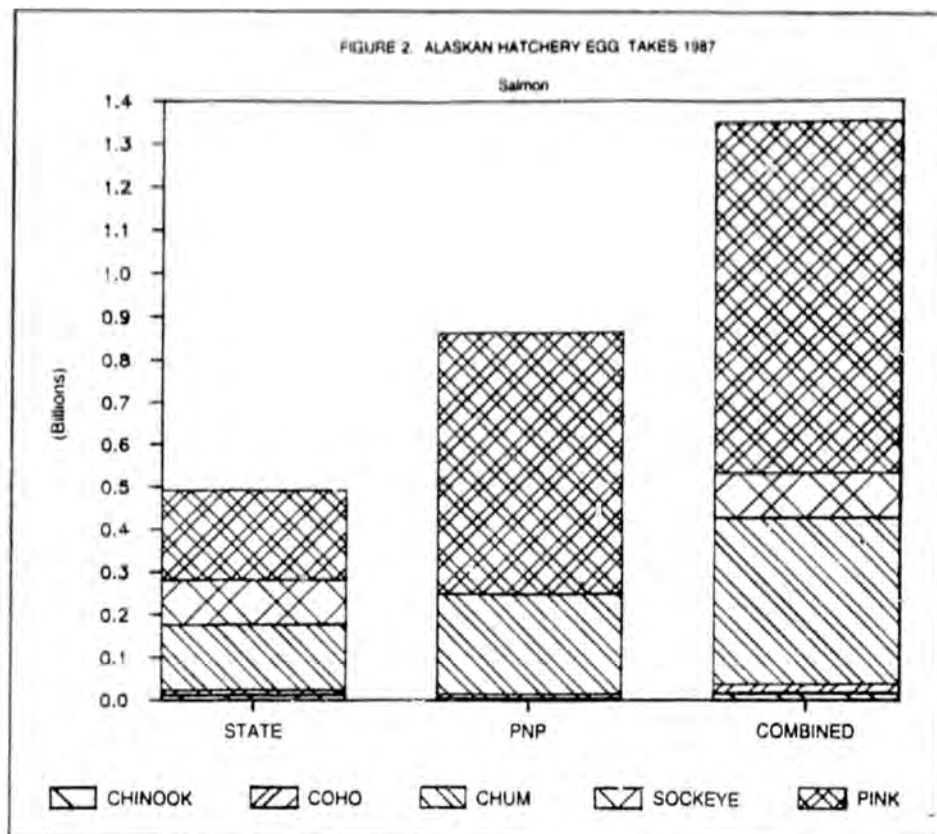
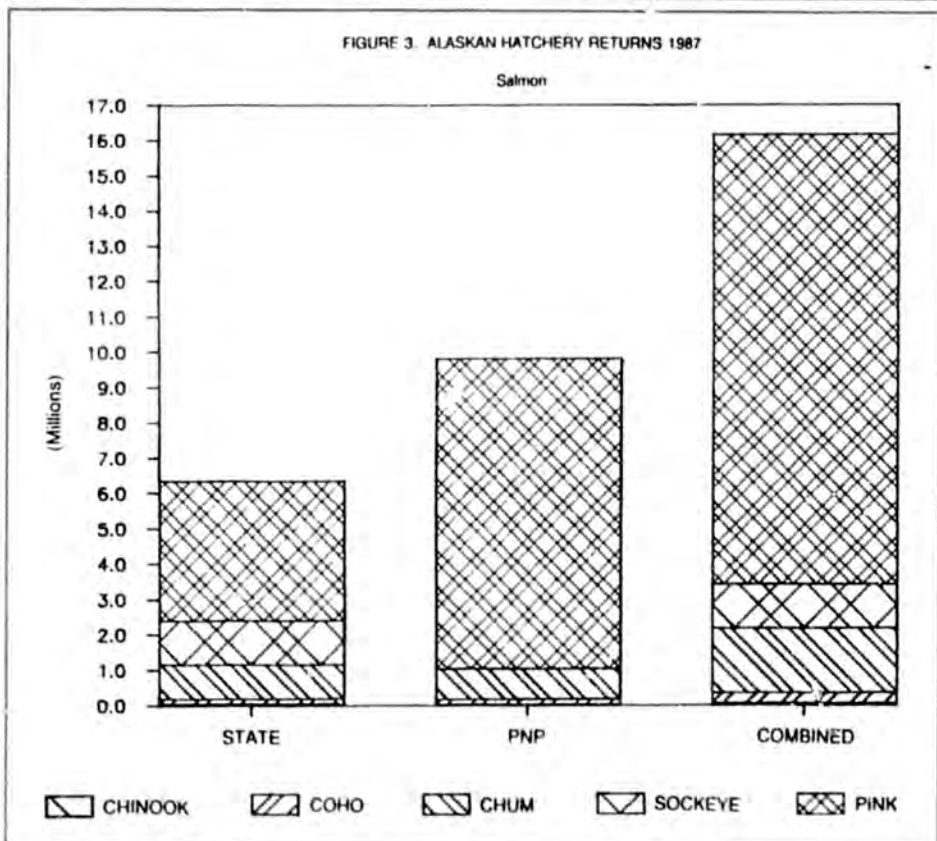


FIGURE 3. ALASKAN HATCHERY RETURNS 1987



Ocean Ranching *continued*

have not been generated for the recreational value, it has been difficult to compute the economic benefit in total to date; when this is done, an even greater economic impact than presently projected will result.

An insight into the scope of the salmon ocean ranching program in the immediate future can be seen in the projected adult return and revenue from the 1988 egg take. Given the generation times of the salmon species involved, this can be two years or 1990 for pink salmon and six years or 1994 for chinook salmon. The projected adult common property fishery harvest of salmon from both state and private nonprofit programs represent roughly 34 million fish and \$76 million in gross revenue (Figs. 4 and 5).

In addition to anadromous salmon and steelhead trout, the public enhancement program (the ADF&G/FRED program) produces substantial numbers of landlocked or resident species, such as rainbow trout, Arctic grayling, Arctic char, sheefish and, most recently, lake trout. The culturing and future production potential of these species is encouraging based upon sport fishermen demand from both resident and tourist sectors.

Salmon ocean ranching in Alaska is an unparalleled biological and economic success and has achieved a world-class status after only ten years of adult returns. On this basis, the full potential of the present program has not been reached yet based upon the capacity of the production systems. It is this production potential in terms of continuing salmon supply that will provide the foundation for Alaska's world market salmon share and help to strengthen the salmon industry against future salmon harvest fluctuations.

FIGURE 4. ALASKA STATE AND PNP HATCHERY PROGRAMS

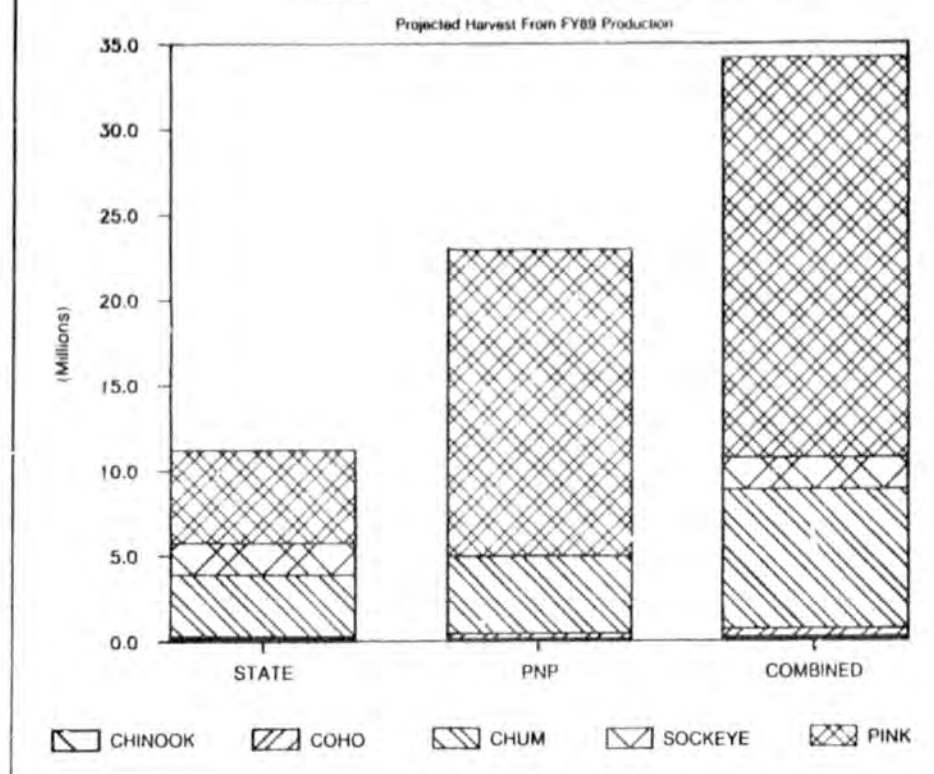
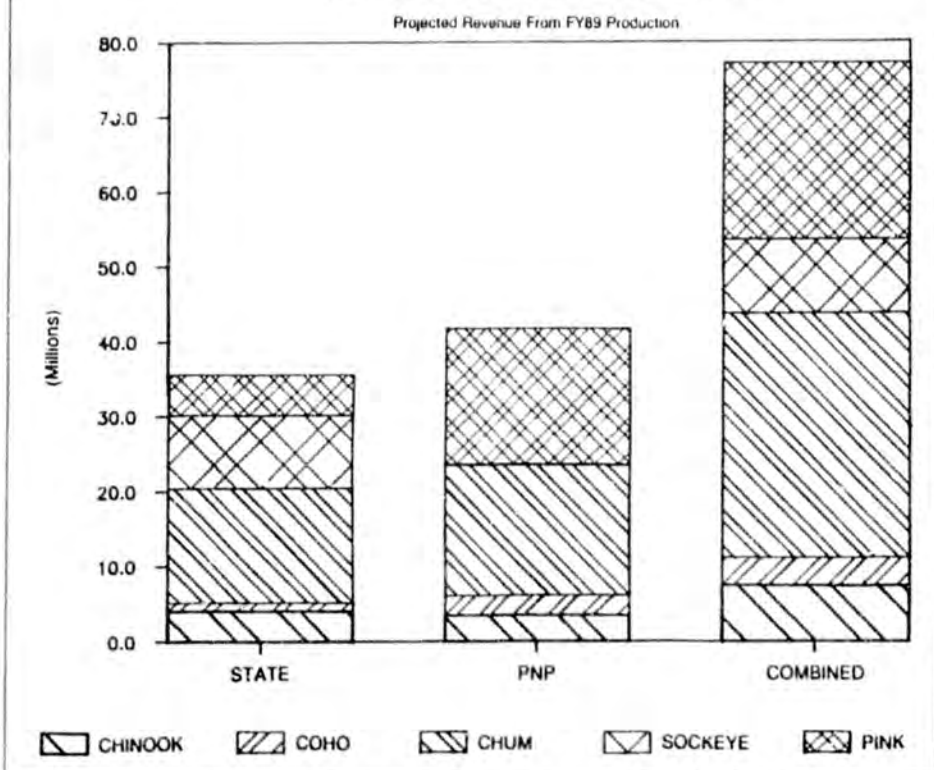


FIGURE 5. ALASKA STATE AND PNP HATCHERY PROGRAMS



Economics of Salmon Farming

by
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The recent debate in the Alaska State Legislature over aquatic farming legislation (HB 108 and SB 106) has been highly emotional and often lacking in basic factual information. The most controversial subject has been whether to allow finfish and, more specifically, salmon farming in Alaska. Conflicting testimony has been offered before legislative committees concerning the feasibility of salmon farming in the state and its potential economic effects on the existing commercial fishing industry. Offered below is some basic economic information on salmon farming and estimates of impacts I have gleaned from a variety of sources in the course of studying this subject for the legislature during the past year.

The worldwide development of salmon farming to date, beginning in Norway in the early 1970s, has largely been a phenomenon of small to medium-sized companies. This has been primarily the result of an 8,000 m³ (cubic meter) pen size limitation in Norway, which was designed to encourage family businesses. As a social policy, the volume limitation has been successful in maximizing employment and improving the economies of coastal communities. However, it has also been a major contributor to disease problems in the Norwegian salmon farming industry as it encourages farmers to use stock pens to maximize returns on their investment. Farmers in Norway routinely produce 200 mt of Atlantic salmon annually within these volume constraints. Farms in New Brunswick or Nova Scotia with a comparable production capacity would typically have 2-3 times this net pen volume and far fewer disease problems caused by stress from overcrowding.

There are substantial economies of scale in salmon farming, though these tend to be tempered by the risk of disease outbreaks in very large single-site operations. To avoid domestic volume constraints, the effects of exchange rate fluctuations, and to reduce shipping costs to primary markets in the U.S., many successful Norwegian aquaculture firms have invested heavily in the burgeoning British Columbia salmon farming industry. About 40 percent of the investment capital in the B.C. salmon farming industry has come from

Norwegian sources, although many other sources of capital (including the Vancouver Stock Exchange) have been used. Aquaculture is now the fastest growing industry in B.C. The result has been an evolving corporate farm type structure (as opposed to small family farms in Norway) to the Canadian industry as smaller operators have acquired investment capital and have purchased others or expanded their operations to multiple sites.

A recent survey of B.C. salmon farms (November 25, 1987) by the Ministry of Agriculture and Fisheries listed 113 operational farms and 38 sites which were licensed but not operational. Average farm volume has increased from 6,767 m³ in 1986 to 20,821 m³ in 1987, while total B.C. farm volume has increased from 466,805 m³ to 2,123,739 m³. Likewise, the average farm holding capacity increased from 53.5 mt in 1986 to 166.6 mt in 1987, and total holding capacity grew from

3,717 mt to 16,990 mt. According to the Ministry of Environment, there are 38 commercial fish hatcheries with a combined capacity of 65 million eggs, although due to limited egg supplies, actual production is less than half of capacity.

Estimates of stock on hand in B.C. farms by species are as follows (in mt):

Chinook	2,768
Coho	1,214
Atlantics	81
Rainbow trout	194
Total	4,257

The cost structure of a typical B.C. salmon farm (Table 1) is presented in terms of the break even cost per pound of operations. Generally, it takes at least 6 quarters between the time smolts are put in a pen until the first harvests begin and the farmer can realize some cash flow. By the time full production is

TABLE 1. COST STRUCTURE OF A 110 mt B.C. SALMON FARM*
(in U.S. Dollars)

Capital Costs		Total Initial Financial Requirement	
Buildings	\$ 22,500	Capital Costs	\$ 157,500
Cages & Nets	75,000	Operating Capital	262,500
Equipment	38,250		
Infrastructure	21,750		
Total	\$ 157,500	Total	\$ 420,000
Operating Expenses		Annual Costs	Cost per lb. Salmon
Smolts		\$ 26,925	\$ 0.12
Feed		150,626	0.67
Disease Control		2,640	0.01
Harvesting		20,024	0.09
Fuel & Supplies		18,000	0.08
Labor		22,500	0.10
Maintenance		4,875	0.02
Management Salaries		26,250	0.12
Communications		6,000	0.03
Insurance		6,000	0.03
Lease Fees		750	0.00
Professional Fees		6,000	0.03
Mortality Insurance		22,500	0.10
Miscellaneous		3,000	0.01
Depreciation		14,813	0.07
Term Loan Interest		9,286	0.04
Operating Loan Interest		1,738	0.01
Total Annual Expenses		\$ 341,926	\$ 1.52

*Source: Canada-British Columbia Subsidiary Agreement on Small Business Incentives.

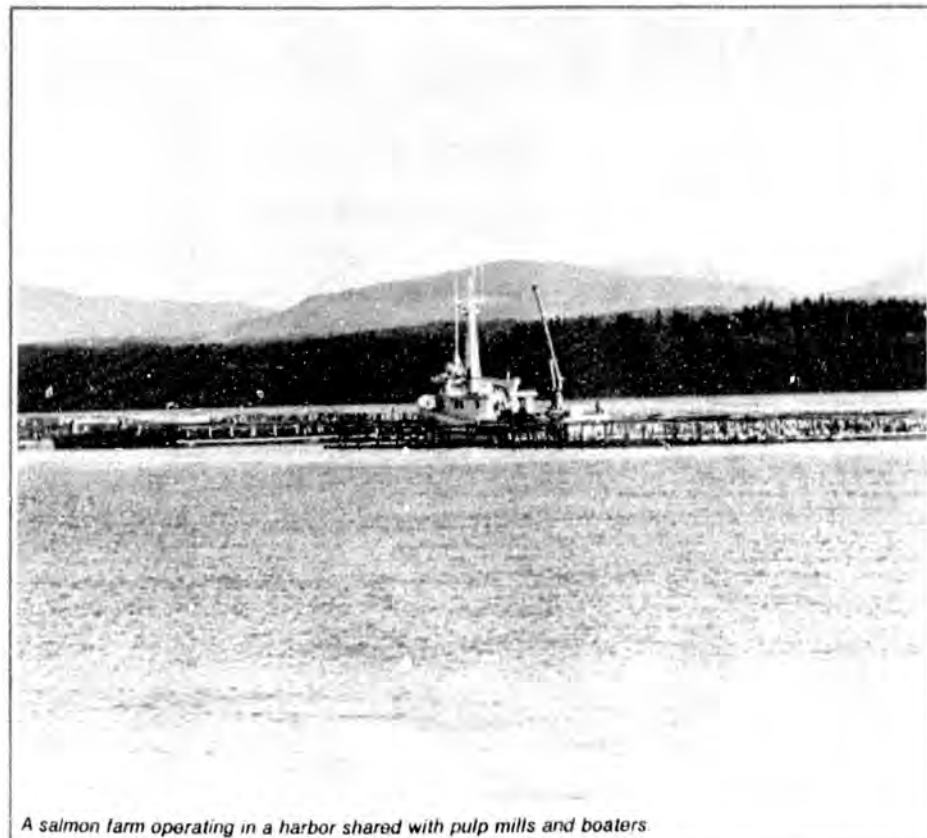
achieved (usually by the third year of operation) the average grower probably has a total investment of \$1 million (U.S.) in the operation. For 4-6 lb. fish, B.C. growers have been receiving farmside prices of \$2.30-\$2.65/lb. producing margins of 50-75 percent (larger fish command higher prices and produce greater margins). Production costs and mortality rates are expected to come down considerably in the near future through greater use of domesticated broodstock and improved husbandry techniques. These factors are likely to increase profitability even as increasing supplies of farmed fish in the marketplace tend to lower product prices.

The focus of the B.C. industry is turning from southern inside waters northward, to outside regions with more oceanic conditions. Colder water temperatures in northern B.C. produce slower growth rates, but these are more than compensated for in decreased mortalities (due to disease episodes and plankton blooms) compared to those experienced by southern B.C. farmers.

Currently the B.C. industry directly employs 544 persons - 318 full-time farm employees, 137 part-time workers, and 89 office employees. Salmon farming employees are not highly paid. The average annual wage assumed in another recent B.C. survey was \$18,000 - similar to wages paid in the seafood processing industry. The major difference is that salmon farming provides year-round employment to local residents, while the seafood processing industry tends to employ large numbers of seasonal nonresident workers. One has only to peruse a copy of the "Canadian Aquaculture Buyer's Guide" to realize that the industry is developing a substantial support sector with local businesses supplying smolts, net pens, feed, consulting and diagnostic services, processing, shipping, and marketing.

The Economic Impact of Salmon Farming in Alaska

During the past year, several attempts have been made to forecast the economic impact of a salmon farming industry (or varying scales of production) in Alaska with wildly differing results. Given the fact that growing conditions in Alaska are very similar to those in northern B.C. and the cost structure of the Canadian industry cited previously, there is little doubt



that salmon farming is economically feasible in the state. Even with marginally higher production and shipping costs, farmers in Alaska should be able to become competitive and realize reasonable profit margins.

A salmon farming industry in Alaska is likely to have purchasing and sales patterns that are similar to the existing fishing industry. For example, purchases of equipment are likely to be made outside the state, while basic supplies such as smolts and feed are more likely to be purchased locally. Alaska will have a smaller support sector than B.C. because the economy is much less mature. The most prudent approach to calculating economic impacts appears to be to assume an effect that is comparable (in proportional terms) to the existing commercial fishing industry. An additional consideration is that much of the capital investment for salmon farming is likely to come from outside the state as it has in B.C. (and as it has in the Alaska commercial fishing industry as well). This means that a certain amount of gross revenues will go to pay debt service and returns to outside investors, which will tend to offset the higher resident wage impact cited previously.

With these caveats in mind, my best guess is that a 10,000 mt Alaska salmon farming industry would produce 600 direct full-time jobs, a payroll of \$9.9 million and gross sales of about \$66 million. Note that a 10,000 mt industry is likely to be several years in the future, although a 4,000 mt industry could be realized within 4 years of the passage of enabling legislation. Purchases of feed from local processors (estimated at \$23 million) and eggs/smolts from public and private hatchery operators (about \$9.6 million) would also ripple through the state economy.

Presently, we do not have a feed plant in Alaska capable of supplying dry feed at economical prices. However, there are sunmi plants in the Aleutians that produce fish meal byproducts (currently sold to Taiwan eel farmers) that could easily convert to supply fish feed at prices that are competitive with feed costs in other salmon farming countries. Surplus salmon eggs from Alaska's ocean ranching program are readily available. In 1986, Alaska's public and private nonprofit hatcheries had 4.6 million chinook and 23.2 million coho eggs that could not be used for enhancement projects under current genetic

Economics *continued*



regulations. These surplus egg supplies vary from year to year, but are expected to remain at substantial levels into the foreseeable future.

Even though there is little evidence of direct price competition between wild and farmed salmon in the existing economic data, there is little doubt that farmed production is rapidly gaining a dominant share of growing premium markets worldwide, while wild production is declining in market influence. About 97 percent of the harvest of premium species in Alaska is marketed in frozen form and only three percent fresh, while almost all farmed salmon is marketed in fresh product form. There is a fundamental consumer preference for fresh fish that is likely to increase in the future as greater volumes of farmed salmon become available. Thus, the market impact of worldwide salmon farming production will occur regardless of whether or not a salmon farming industry exists in Alaska.

Various attempts have been made to model the future market impacts of farmed salmon production on the existing commercial fishing industry, with little success. Salmon markets are extremely volatile and do not lend themselves readily to mathematical modeling techniques. Recently both the supply of, and demand for, fresh farmed salmon have exploded. Seafood markets in general have been very strong worldwide. Farmed salmon is a relatively new phenomenon in the marketplace. In a sense, salmon farmers have created their own markets by offering a high quality product year-round. With such a short market history to trend from and only a vague idea of the potential market size, economists have a difficult time forecasting the market impacts of farmed salmon production with confidence. However, these recent attempts at estimating market impacts are useful in illustrating the relative impact of worldwide farmed salmon production on the commercial fishing industry in Alaska compared to a proposed local salmon farming industry.

We know that demand for salmon products in general is price elastic, i.e., a one percent increase in supply results in a less than one percent decrease in price. Estimates vary widely on the degree of price elasticity. A recent University of Alaska study applied the existing range of elasticity estimates for salmon products to the value of the Alaska commercial salmon harvest, assuming a 100,000 mt

increase in worldwide annual farmed salmon production by 1990. Several simulations were run varying the structure of a salmon farming industry (small vs. large farms) and the substitution effects of farmed for wild species. The worst case scenario forecast a \$36.4 million annual loss in gross revenues to Alaska commercial salmon fishermen, while the best case estimated a \$5.1 million loss.

Using this methodology, the potential market loss attributable to a 10,000 mt Alaska salmon farming industry would range between \$2.4 million (worst case) and \$0.4 million (best case). If we think of these market impacts in proportional terms and relate them to the 1987 Alaska salmon harvest value (estimated at \$458 million), worldwide farmed salmon production could potentially cause an 8 percent decrease in revenues by 1990. By comparison, production from an Alaska salmon farming industry could decrease commercial

fishermen's gross revenues by an additional one-half of one percent.

In conclusion, salmon farming is feasible in Alaska and development would offer substantial economic benefits to the state with minimal incremental impact on the existing commercial fishing industry. Aside from the immediate economic benefits, salmon farming would offer significant spinoff effects as the technology of broodstock development could be applied to the present ocean ranching system. Recently developed diploid techniques, which produce all female fry, seem particularly promising. Husbandry practices developed by farmers could also be applied to other species. Indications are that B.C. growers are 2-4 years away from the commercial farming of black cod, which offers another very large market potential. I hope this information contributes some perspective and clarity to the ongoing debate.



Transferring smolt (from hatchery location) to a salmon farm

Salmon Farming: Gambling with Alaska's Wild Stocks?

by
Alaska Trollers Association

The fishing industry feels the value of shellfish and vegetable culture to the state and local communities outweighs the associated costs. It is these forms of mariculture which will fit into the Alaskan style of life, and economy, with few negative impacts on our existing socioeconomic structure. On the other hand, we strongly oppose the implementation of salmon farming in Alaska. Our opposition rests not on the concern over a single issue, but rather the cumulative effect this proposed industry will have on the state's economy, the fishermen of this state, and our entire industry.

To begin, let's take the issue of what agency in the state government will be charged with the responsibility of regulating this proposed industry and the implications on the protection of our wild stocks. We should first consider that Alaska produces 90 percent of all salmon landings in the United States or 43 percent of the world's landings from wild, natural runs of salmon. While the spread of disease from penned to wild salmon may be of a low order of probability, the potential for major damage to the wild stocks does exist. Therefore, any discussion of this new industry must focus on the regulatory climate which will protect our massive investment, an investment, by the way, which has produced one of the world's most successful ocean ranching programs.

Currently the stringent regulatory safeguards on wild stocks is adequate. Still we are worried that regulations like strictly forbidding the importation of non-indigenous or exotic species of fish, a primary safeguard in our present system, may fall by the wayside because the development of the proposed industry is perceived as more important than the possible effects to the gene pool and disease on our wild stocks. For instance, in Norway this safeguard was circumvented in 1986 with the importation of Scottish smolts. In sidestepping the normal caution of nonimportation, the Norwegians introduced a new disease form into their waters which quickly spread and caused massive mortality to their inventory of fish. Just how much havoc this outbreak caused is hard to determine since there seems to be reluctance on the part of the Norwegians to let the rest of the world know what happened. Closer to home we have

seen British Columbia transfer Atlantic salmon to the Pacific coast. The threat this transfer represents to wild stocks, particularly steelhead, remains to be seen.

We are also worried about the possible effects to wild stocks from escaped pen-reared fish. It has become apparent that these fish do escape no matter how stringent the protections are. For 25 years Norway has been in the farming business and just this spring they discovered that 10 percent of the fish in their streams weren't from wild stocks after all, but instead were escaped farmed fish.

It is interesting to note that the promoters of pen-reared salmon are even now seeking to circumvent prudent regulatory controls. The proposed bills allowing mariculture in the state place the authority for management of the proposed industry under the Department of Commerce and Economic Development instead of the Department of Fish and Game which has the mandated safeguards needed to protect our wild stocks. Our concern with the placement of management is certainly not a reflection of the promoters purported position of wanting strict regulation and safeguards, but a reflection that the management of this prospective industry would be given to an agency with little experience in the biological and technical basis needed to protect our wild stocks and current industry.

Actions and incidences such as the introduction of exotics raise the question of how a private, for-profit industry will impact our wild runs of salmon and whether the profit motive will cause the industry to try to evade prudent regulatory safeguards in the interest of short-term profits.

The cumulative negative effect of salmon farming is again typified when one asks the question of where the resources will come from to manage this prospective industry. Herein lies one of our major concerns with the mariculture industry. Proponents suggest that their industry will take little from the existing system but as most of us know there are no free lunches out there; you just can't get something for nothing as the fish farm promoters suggest. There will have to be government programs created or expanded to regulate fish farming practices and these regulatory programs will cost money and state resources. It is a safe bet that the money and

resources won't come from an increasing state budget and we know the new operations won't be paying taxes until they start showing a profit, which will be many years down the road.

As you may know, state agency funding is determined by using one of two criteria, either through what is called formula funding or discretionary funding. Formulas are used to determine funding levels for such agencies and programs as the Department of Education and municipal revenue-sharing. The monies left over after formula funding are termed discretionary funds. Discretionary funds are what currently run agencies like the Department of Fish and Game and the Department of Natural Resources; these funds are determined by our policy makers every year at budget time. To many, a fish is a fish; therefore, it is a safe bet that the funds to run this proposed industry will come out of the current fish management programs. These are the same programs that are producing such a high rate of return to our state's economy, the same programs that are already being cut to the bone because of revenue shortfalls.

The question then is what happens when an agency such as the Department of Fish and Game sees budget reductions; it affects their ability to make accurate resource management decisions. Because of the lack of information on which to base sound management decisions, there is the tendency to manage the resource conservatively. This may appear good for the state, and is how any prudent manager would respond, but when one considers that a portion of the resource has been wasted when it could have been harvested, it becomes a loss to the fishermen and our economy. For example, a recent analysis done for the Bristol Bay fishery indicated that for each additional \$86,000 put into the management program, management error decreased by one percent. In this fishery one percent represents a direct loss to fishermen of \$2.75 million. In this instance if the funds had been available to reduce management error by the required one percent the economy would have seen at least a 3,000 percent return on investment. We might also point out that this doesn't include losses to other segments of our economy in which these dollars would have circulated if the resource had been optimally managed.

Salmon farming has become one of the most controversial subjects within the fishing industry this year. The following articles explain two opposing viewpoints on the issue.

If, by chance, mariculture management funds don't come out of fishery management funds, they'll come out of things like hatchery funding. This would be the ultimate irony — because if salmon farms get hatchery money, then fishermen will have to make up any deficits with moose assessment taxes to themselves in order to keep these hatcheries open. In this case, fishermen would be financing the fish farm industry, an industry they don't want in the first place and in fact would be in direct competition with them.



A fisherman picks wild salmon out of his gillnet on the Copper River flats.

Along with the guise of strict regulation and limited use of the states decreasing management resources, proponents of pen rearing like to say that their industry will provide a boost to our state and local economies. It should be pointed out that our current fishing industry already employs approximately 50,000 people directly, this does not include employment in associated support industries in all segments of our economy. We don't feel that salmon farming can even come close to the positive impacts the current industry has on our state, and in fact the economic impact this proposed industry will have is the transfer of jobs and wealth from an established segment of the economy to a new, smaller group who may not even be Alaskan residents. Although proponents are selling the concept that the farms will be owned and run by local residents and be typical of small business like your local fisherman, or grocer, the real world depicts a different reality. Small, locally-owned operations won't have a

chance. Because of the startup and operating costs involved, mom and pop type Alaskan operations may be able to get their food in the door, but it is doubtful that they could stay afloat if hit with a disease outbreak or a downturn in the industry which all experts project in the next 3-5 years. In fact we would submit that if fish farming were to come to Alaska we would see the industry dominated by a few wealthy individuals and multinational corporations predominantly from Norway. As with any other industry, as it progresses through its life cycle more technology is required in order for businesses in that industry to remain profitable. Technology usually means a more capital intensive industry with fewer employees. This type of industry is certainly not what most of our local community members can afford or are being promised.

At a seminar in Seattle, John Spence from Hardy Seafoods, a thriving mariculture company in British Columbia, told the audience that "mom and pop operations were just a dream." He said these small operations are being bought up by larger organizations and that by 1990 the industry in B.C. would be controlled by 20 or so large companies.

In the October issue of E.C. Business, an article titled "The Norwegian Connection" states that since Canadian banks aren't willing to advance funds for mariculture development, Norwegian financial offers are eagerly accepted, and the Norwegians are now estimated to control 60 percent of the industry in British Columbia. These financing packages also contain clauses which require the farmer to buy building facilities and supplies from Norwegian suppliers. The article goes on to state that should reality fail to live up to projected goals, the Norwegians could call in their mortgages and end up owning the industry in B.C. outright.

As mentioned above the isolated issues are bad enough but cumulatively they increase the damaging effects to our existing industry. In no other way is this point exemplified more than the issue of competition between product forms.

Proponents profess first, that their product will not compete with our wild-caught product for a share of the world market. Second, that even if Alaskan pen-reared salmon did compete with our wild product this competition would be such a small increment that it wouldn't make that much difference, and finally, that world seafood consumption is

increasing. Our response to their first claim is we must realize that there is only one market for fish products in the world; fish of all kinds compete on this market. Since the volume of pen-reared salmon projected by 1990 will triple, salmon farm producers will look to new markets and product forms to keep pace with production. In order to remain profitable, they will have to try to take traditional markets away from our wild-caught product. For instance, farmers in Alaska will attempt to target markets like Japan which currently consumes 84 percent of our frozen salmon each year.

Secondly, as the supply of all fish products increases, the price paid by the consumer will decline. As with all products, price is directly related to available supply. Since Alaskan pen-reared salmon will compete in the world market, as any product, the increases in production will have a direct effect on the current price of the product and certainly an effect on ex-vessel prices.

Finally, with regard to the fact that worldwide seafood consumption is on the increase, it must be borne in mind that we are primarily concerned with the consumption of salmon and not of seafood in general. The market for salmon is a much more limited demographic market and even though it will share in the general increase in consumption the increase won't be to the extent that mariculture proponents would lead us to believe.

Pen-reared salmon production will cost the fishing industry through lost management, fisheries enhancement, and possible harmful effects on our wild stocks. It is ironic that not only would we pay for production through losses to our existing industry, but that product which we inadvertently help produce will further cut into the existing economy by competing with our wild product in the world markets.

Mariculture proponents are fond of saying that we have a right to fail. We, the fishermen say yes, but not at our expense. We have in Alaska the last great wild salmon runs in the world, these runs are the second largest revenue generators in this state and are proving to be Alaska's true Permanent Fund. Pen-reared salmon compete with this resource and dilute the value of our already massive investment. No one can say for certain that no harm will come to our wild stock from pen-reared fish. It just doesn't make good economic sense to gamble with our industry's future knowing what the stakes are.

Salmon Farming: Bright Star for Alaska's Future?

by
Rodger Painter
Executive Director
Alaska Mariculture Association

Few issues in recent memory have sired a stronger debate in the seafood industry than proposals to remove the legal roadblocks to development of salmon farming in Alaska.

The Alaska Mariculture Association believes fishermen should not feel threatened by Alaska salmon farms.

A host of arguments have been raised against salmon farming, but the strongest objections involve concerns about the impacts on markets and threat of disease spreading from farmed stocks to wild populations.

Market Impacts

Nothing in the debate over mariculture has been more elusive than a common vision of the marketplace.

Opponents of salmon farming in Alaska contend the new production will add to an impending glut of world salmon markets and help drive down dockside prices. Advocates dispute this monolithic vision of the marketplace, saying that markets for cultured and wild products are discrete and there is little overlap. This means Alaska farmed salmon will compete directly against foreign imports, not traditional markets for wild salmon.

One group of researchers from the University of Alaska (UA) surveyed U.S. seafood buyers and concluded worldwide production of farmed salmon appears to have had a relatively minor impact on domestic demand for Alaska salmon. UA economists also completed a study showing Alaska salmon farms should have a negligible effect on salmon markets, but worldwide production could result in a significant lowering of price.

These conclusions have been bolstered by the record value of this year's salmon catch. According to preliminary figures, Alaska salmon fishermen were paid in 1986 a record \$461 million for 90 million fish, the smallest harvest of the decade. This is in sharp contrast to the 1985 record of 147 million salmon worth \$389 million.

These price increases come at a time when the overall imports of farmed salmon into the U.S. continue to increase, despite a drop in Norwegian production.

U.S. Consumption and Market Trends

Virtually all marketing experts agree the hottest seafood market is the United States. National Marine Fisheries Service (NMFS) statistics show the per capita consumption of seafood rose from 12.9 pounds (finished weight) in 1981 to 14.7 pounds last year. While a 1.8 pound gain doesn't sound like much, the increase means Americans ate 582 million pounds more seafood in 1986 than they did only five years earlier. That represents a 20 percent growth in market volume.

In the past, U.S. consumption of salmon increased slowly from .1 pound per capita in 1970 to .4 pound per capita in 1980. Increased supplies from Alaska and Norway then boosted that figure up sharply to .8 pound in 1985, but a drop in landings in 1986 pushed that figure back down to .5 pound, according to Pacific Fishing magazine.

Some analysts say consumption of salmon probably would not have fallen and overall seafood consumption would have been much higher if more seafood was available.

Domestic fisheries landings appear to have leveled off, and foreign producers seem to be the primary beneficiaries of improved seafood markets. Fishermen are earning more for smaller catches, but the primary effect of the laws of supply and demand has been to push up seafood import's alarming rates: imports of edible fish and shellfish increased by \$1.8 billion or 58.6 percent over the five-year period. These forces have resulted in a U.S. seafood trade deficit of \$3.5 billion in 1986, a 79.6 percent increase in five years.

The people who sell most of Alaska's salmon production appear to agree that Alaska's involvement in salmon farming does not pose problems for sales of wild salmon. Processing company officials testifying before the Alaska legislature or quoted in the industry and general news media generally voice concern about the growth of salmon farming worldwide, but discount the impact of Alaska's participation.

Ward Cove's President Alec Brindle says: "The Norwegians with their fish have nearly taken the U.S. market over. It's affecting our markets, but at the same time our market is growing. It's a question of whether or not the market can grow to accept the increased capacity. Frankly, I don't see how Alaska can stand still while the market passes it by."

Important to consider when debating the market impact of Alaska salmon farms is the fact that some major Alaska seafood companies already are purchasing farmed salmon to satisfy consumer demand. Super-market ads and restaurant menus in Anchorage show Norwegian salmon has even achieved substantial penetration of in-state markets. These are the fish that would be displaced by salmon farms in Alaska.

A Fairbanks resident interested in farming cohos recently observed that the only salmon available most of the year in the Interior city is imported from Norway. "How would commercial fishermen be hurt if I try to displace it from seafood counters?"



Disease Threat Differs Little from Hatchery Operations

An irony of the current debate over salmon farming is that the salmon industry is beginning to tout the virtues of Alaska's "wild" product. While this may have an appealing ring with consumers, the new tag doesn't jibe with the increasing percentage of the catch accounted for by fish released from private and state hatcheries.

The aquaculture component of Alaska's salmon production is becoming significant. In fact, state biologists estimate about 70 percent of Prince William Sound's record 25.6 million pink catch this year came from area hatcheries. Just what percentage of the

statewide harvest will come from enhanced stocks is unclear, but it should be significant and is likely to get larger in coming years.

More than 1 billion eggs were taken by Alaska's public and private hatcheries during 1986 and that number is increasing.

These massive numbers of eggs are taken to hatcheries and handled in ways identical to salmon farming facilities, except the juvenile fish are released to intermingle with wild stocks, often after short-term stays in salt water net pens. Farmers simply hold the fish in net pens to adult size.

These similarities are critical because private and state hatcheries have a very good track record in dealing with disease, and there have been no indications of infections spreading to wild stocks. One of the strongest objections many fishermen have to salmon farming is the potential risk of spreading disease from pen-reared fish to the wild and enhanced salmon runs.

While no person would argue salmon farming poses no risk to wild stocks, most scientists agree the disease threat of pen rearing differs little from ocean ranching.

Brian Allee, former president of Alaska's most successful private hatchery system and Director of Alaska Department of Fish and Game (ADF&G) Division of Fisheries Rehabilitation, Enhancement and Development (FRED), told a House Resources Committee:

"The Alaska Department of Fish and Game feels that a fish farm and a PNP (private non-profit) hatchery are functionally similar in terms of the biological concerns. And since all PNP hatcheries require permits, by way of consistency, so should all fish farms. Based on this assumption, the statewide disease and genetics policy should be applied to the fish farm permit, in order to reduce the risk of damage to the wild stocks of salmon, which are a common property resource. Both policies have been well developed and implementation of these policies will serve as more than sufficient control."

The most comprehensive U.S. scientific study of the effects of mariculture conducted to date (The Environmental Effects of Floating Mariculture in Puget Sound, by Dr. Donald Weston, for the University of Washington) downplayed the potential disease threat of salmon farming:

"While fish held in culture are likely to show more frequent appearance of disease than wild fish, disease does not appear to be transmitted to the wild populations. The bacterial diseases of salmonids in mariculture are not transmissible to humans... Increased bacterial abundance in sediments beneath a mariculture facility is quite probable, but it has not been demonstrated that this increased abundance is of any significance in terms of human health."

Control of disease is one of the challenges inherent in aquaculture and other forms of animal husbandry. The concerns voiced now by opponents of salmon farming are very similar to statements by some fishermen when Alaska's salmon ranching program was being debated in the legislature during the 1970s.

The success of Alaska in dealing with disease problems and the resulting strong support of fishermen testify to the ability of salmon culturists to effectively deal with disease.

Alaska has one of the world's best salmon aquaculture disease management programs, but even the best procedures do not completely erase the threat of disease. Many fishermen will recall serious outbreaks of disease in Alaska hatcheries which led state managers to destroy diseased brood stock and, in some cases, start all over again. But, these problems have been overcome and these same hatcheries are unqualified success stories with no apparent effect on wild stocks.

Salmon farmers also are likely to have reoccurring disease problems, but are showing the industry can respond quickly to those challenges. The large losses of Norwegian farmed stocks to the Hitra disease this year provides a prime example. The National Marine Fisheries Service reports that a new vaccine for Hitra already is being used by Norwegian farmers and the smolt surviving the outbreaks have built a resistance to the disease and are in high demand.

Some critics have questioned whether disease management practices such as the use of antibiotics would affect other marine organisms or lead to the development of disease-resistant strains of bacteria. Most scientists discount these theories, saying the levels of antibiotic usage will be so low that it won't be measurable in the marine environment and, even if it was, the selective

build-up of disease-resistant organisms is highly improbable.

The effect of salmon farming upon water quality is another issue raised frequently. The experience of two of the largest and longest operating salmon farming facilities in the U.S., as described by Bill Waknitz of the National Marine Fisheries Service, is:

"Domsea Farms has a very large facility in Clam Bay, Washington, near the town of Manchester.. This facility is not only 5.4 times larger than the Norwegian size limit, but is thought to be the largest single salmon farm in the world, and it has been in continuous operation for almost 15 years. This facility is located 300 yards from the end of a pier owned by the United States Environmental Protection Agency (EPA). Attached to the end of this pier is the National Marine Fisheries Service net pen research complex. This is the largest net pen research system in the U.S. seawater intake for the EPA Region 10 Water Quality Laboratory is located at the end of this pier, 20 feet from the NMFS facility and 300 yards from Domsea Farms. The water drawn through this intake is used by EPA as the clean reference water against which samples of suspected polluted marine water are compared, through a variety of laboratory tests... If the water quality in Clam Bay were adversely affected by the presence of the giant Domsea facility and the NMFS complex, EPA would take remedial action."

Tests on the Domsea farm by the EPA reveal that sediments under the net pen complex are only two inches deep and extend no further than 100 feet from the pens. The EPA compared the effect of the farm on the sea floor with that of a dock.

This information does not suggest that the concerns of mariculture critics should be dismissed. To the contrary, these scientific findings point out that the biological and environmental problems posed by mariculture are manageable if proper siting and culturing practices are followed.

Alaska's ocean ranching program has encountered only minimal problems because of a conservative approach. These policies should be imposed upon mariculture operations in Alaska to ensure we continue to enjoy the benefits of the state's most important natural resources - its abundant fisheries resources.

Environmental Effects of Mariculture

by

Richard D. Reed

Regional Supervisor

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The evaluation of floating mariculture facilities in Alaska is needed to determine if there are any environmental effects resulting from these operations. There have, however, been studies of mariculture facilities in Washington's Puget Sound. From that, insights into potential environmental effects from floating mariculture can be gained.

Based upon Puget Sound studies, Weston (1986) suggests floating mariculture operations may result in one or more of the following potential environmental effects: (1) accumulation of organic-rich sediments beneath the facility, (2) changes in water circulation, and (3) changes in water quality. In addition, predation problems can arise if not properly addressed in the operation of the facility.

Probably the most common environmental effect associated with floating mariculture is accumulation of organic-rich sediments in the form of wastes, uneaten food, and shell debris on the benthic substrate below the facility. Møller (1976) found that the magnitude of pollution (feed loss and excrement) from a Norwegian fish farm using fresh or wet feed can reach 60 percent of the total amount of food used. Such deposition can result in physical and chemical changes in the natural bottom sediment (Milne, 1979). Included in these changes are increased oxygen consumption within the sediment and increased concentrations of total volatile solids, total organic carbon, sulfides, nitrogenous compounds and phosphates (Weston, 1986). Although Weston (1986) reported that organic-rich sediments occurred around most culture facilities reviewed, the depth of the accumulations depended upon the water depth and current velocities. In general, he found that accumulation of sediments can be expected beneath any culture facility located in less than 15 meters of water. Accumulation of such sediments and the resultant oxygen depletion in the interstitial water can have effects upon the infaunal invertebrate community. Loss of species that are intolerant of organic enrichment (such as echinoderms, crustaceans, and molluscs) often occurs (Weston, 1986). In addition, impacts to bottom vegetation such as eelgrass beds can be expected if facilities are sited over such areas.

Conversely, such mobile species as fish and crabs can be attracted to culture facilities. Romero et al. (1982) reported that the highest densities of crabs in Ria de Arousa, on the northwest coast of Spain, were associated with mussel culture rafts. Pease (1977) found crab and fish species more abundant under culture facilities in Puget Sound than in control sites, and Beveridge (1984) mentions high densities of wild rainbow trout observed around Scottish fish rearing facilities. Increased numbers of crabs and fish under and around culture facilities are probably a result of abundant food supply and possibly cover opportunity.



A farm worker hand feeds penned salmon.

Any anchored floating facility can be expected to somewhat alter water circulation in its immediate vicinity, and floating mariculture operations are no exception. Milne (1979) reported that studies done on Japanese floating fish farms showed reduced currents within the pens as compared to the surrounding water. The effects of these circulation changes are generally minimal but can result in increased sedimentation below the facility when water velocities are reduced and any suspended material is dropped (Beveridge, 1984).

Changes in water chemistry can also result from mariculture operations. These changes are usually an increase in ammonia concentrations and decrease in dissolved oxygen (Beveridge, 1984; Weston, 1986).

Normally these changes do not cause a problem unless the facilities are sited in areas of extremely restricted flushing or in areas of intense mariculture operations which is beyond what would be expected in Alaskan locations.

Proper siting of facilities can usually address the effects discussed above. Floating mariculture facilities should be located in well flushed locations with water depths adequate to prevent grounding at all tidal stages. Sensitive marine habitats such as eelgrass beds or the mouths of anadromous fish streams should also be avoided.

Predation is a common problem with mariculture operations throughout the world. The list of predators includes all types of fish or shellfish-eating mammals, fish and birds (Lindberg, 1976; Milne, 1979; Beveridge, 1984). Usually precautions such as installation of screening or netting will significantly reduce losses. However, if large numbers of predators are present, predator control can become a problem. Given the undeveloped state of most potential mariculture sites in Alaska, predation might be expected from such important mammalian species as mink, marten, otters, seals or sea lions. To reduce potential predation problems, especially from seals and sea lions, care should be taken to avoid known concentration areas such as haulout locations.

Currently, there are no formal guidelines or siting criteria intended to minimize environmental effects for mariculture facilities in Alaska. Instead, each application is evaluated on a site-specific basis through the state's interagency review process for projects in the coastal zone. During reviews, the Departments of Fish and Game, Environmental Conservation and Natural Resources, among others, evaluate all aspects of the proposal, including potential environmental effects.

To improve this process, an interagency team is developing criteria for identifying sites where mariculture facilities would be most suitably located. Included in the criteria will be consideration of competing uses, the physical and ecological requirements of mariculture sites, and human-use patterns. It is hoped that guidelines can be established which will provide potential mariculture operations with sites that have the necessary physical and biological attributes, but which

Criteria for Establishing Salmon Farms

Environmental Effects

continued

cause minimal social and environmental conflicts.

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by

David Benton

Special Assistant to the Commissioner
Department of Fish and Game

The prospect of pen-rearing salmon in Alaska has become one of the hottest topics in the state. From fish camps, to city hall, to the legislature, the topic of whether or not to allow salmon pen-rearing is causing a heated debate.

The market success of the Norwegian salmon farming industry and the growth worldwide in fish farming generally have spurred interest in pen-rearing salmon in Alaska. During the 1987 session of the Alaska State Legislature, bills were introduced to legalize salmon pen-rearing. Senate Bill 106 and House Bill 108 would "encourage the establishment and growth of an aquatic farming industry" in Alaska. The bills would establish a permit system which would be administered by the Department of Commerce and Economic Development for aquatic farms and private-for-profit hatcheries.

In response to this action in the legislature, Governor Cowper directed the Fisheries Cabinet to review the mariculture issue and prepare a recommendation to him. The cabinet prepared for the governor a set of criteria for judging any authorizing legislation. The governor approved these criteria, and they were presented to the legislature.

The governor's position stated that mariculture may provide substantial economic benefits to our coastal communities and help diversify and stabilize our economy if it is developed in an orderly fashion which provides the maximum benefit to Alaskans. The governor emphasized that we must ensure protection for our fisheries resources, other resource users and the environment.

The governor then set out eight points which he felt legislation must satisfy to meet these goals. These are:

1. **The mariculture industry must benefit Alaskans.**

The mariculture industry must be developed in a manner which does not result in unfair competition with existing fisheries or cause undue economic

displacement in our coastal communities. Legislation should, to the extent possible under the law, provide for local hire at mariculture facilities and give preferential access to mariculture permits and mariculture related tidelands leases to Alaskans.

2. **The mariculture industry must pay for itself and the state should get a fair return for the use of state resources.**

Legislation should contain provisions for recovering administrative and other state costs associated with managing the industry. The legislation should also ensure that the state gets a fair return for the use of tidelands and other resources.

3. **The development of the mariculture industry in Alaska should be done in an orderly fashion which encourages a stable, dependable industry.**

Legislation should provide general criteria which will lead to the development of a regulatory program which discourages speculation on permits and tidelands leases, encourages sound financial planning, and provides for a diverse industry ranging from "Mom and Pop" ventures to larger corporate operations.

4. **The mariculture industry must meet all state and federal requirements for human health, product quality and sanitation.**

Legislation should ensure that mariculture facilities meet all state and federal requirements for human health, safety, and sanitation. Legislation should also require that mariculture products meet or exceed all state and federal product quality and human health standards, and provide the means to ensure that state regulators can protect human health and product quality.

5. **Mariculture activities must be managed to ensure protection of the biological integrity of natural plant and animal stocks.**

Legislation must address the issues of pathological and genetic protections for natural sea vegetable and fish stocks.

6. Mariculture activities must be managed in a manner which ensures adequate environmental safeguards and habitat protection.

Legislation must ensure that mariculture facilities are sited, designed and operated to protect air and water quality, to provide for proper disposal of wastes, and to minimize adverse effects to important fish and wildlife habitat.

7. Mariculture facilities must be sited to minimize land-use conflicts, maintain navigation and ensure access to upland areas.

Legislation should provide guidance for siting facilities to minimize conflicts with other tidelands users, reducing visual and aesthetic impacts, maintaining navigation and ensuring access across state tidelands.

8. Broodstock acquisition for mariculture purposes should be carefully regulated, especially for species subject to limited entry fisheries.

- Legislation should contain provisions limiting the acquisition of broodstock for species subject to limited entry fisheries.
- Legislation should grant the Department of Fish and Game the authority to regulate the acquisition, transport, and propagation of mariculture broodstock, and provide the Board of Fisheries the ability to resolve allocation decisions regarding broodstock acquisition if necessary.

Last March, the House Resources Committee held extensive hearings on House Bill 108. As expected, the bill generated considerable controversy statewide with proponents arguing that mariculture represented a significant new economic opportunity for Alaskans; and opponents expressing concerns over the potential effects on wild fish stocks, restrictions on traditional uses of our coastal areas, and a loss of income from existing commercial fisheries.

Late in the session it became apparent that authorizing legislation was not going to pass. All parties became concerned that the questionable legal status of pen-rearing salmon could lead to speculation on tidelands sites and a "gold rush" mentality similar to the

situation which developed in British Columbia. The resulting confusion and inevitable litigation would not be to anyone's advantage, so a carefully crafted moratorium bill was introduced and passed in the waning hours of the session. This bill (Senate Bill 297) placed a moratorium which expires July 1, 1988, on issuing permits for most finfish farming. It also authorized shellfish farming and limited finfish farming in fresh water.

At the close of last session, the legislature established an informal workgroup to continue working on the mariculture issue. This group included Senators Eliason, Duncan, and Zharoff and Representatives Hermann, Ellis, and Pearce. The administration has continued to work on this issue under the auspices of the Fisheries Cabinet.

In May, following the end of the legislative session, the Fisheries Cabinet identified two major tasks to be performed over the interim. First, the cabinet agreed that a consistent and uniform permitting program for shellfish mariculture needed to be developed and implemented. Second, the issues identified

during last session needed to be addressed in a systematic fashion.

Given these two tasks, the agencies set about to develop a shellfish permitting program. This has involved developing a new shellfish farm permit from the Department of Fish and Game and streamlining existing permitting procedures under the Alaska Coastal Management Program. This will result in a package where the prospective farmer will be able to secure most state permits through one application instead of going to numerous agencies.

At this time, the administration is working on a number of fronts on the broader issue of finfish mariculture. The resource agencies have gone through an extensive process to identify the key outstanding issues which remain to be resolved. Research is being conducted to see how these issues are addressed in other parts of the world, most notably British Columbia, Washington, California, and Maine. These areas were chosen because they offer a range of management systems and have social, economic and biological characteristics similar to Alaska.



Washington state salmon pens anchor in a nonresidential area.

Selecting a Site for a Salmon Farm

by

Curt Kerns
Aquaculture Specialist
University of Alaska
Marine Advisory Program

Salmon farming, an endeavor that began in the Pacific Northwest, has become one of the fastest growing industries in neighboring British Columbia, as well as in a number of other countries located in higher latitudes on both sides of the equator. To be successful, however, experience suggests much more is required than just tossing a dart at a map. A site meeting a number of different criteria is required. Requirements of husbandry for the species and species life stage must be met. The physical characteristics of a good site fall within a somewhat narrow range. For the firm to be successful factors involving social, political, regulatory and transportation criteria must be met as well. This article will discuss the physical and biological requirements of siting salmon farms.

Physical Requirements

The physical/environmental characteristics of waters surrounding ice-free coastal Alaska are determined largely by the source, the massive Japanese or Kuroshio Current that moves easterly across the Pacific Ocean, dividing at approximately the border of the State of Washington and the Province of British Columbia. Those waters being the natural habitat of Pacific salmon, they quite satisfactorily meet the requirements of temperature, salinity, and oxygen for salmonids during their juvenile to nearly mature life stages. Waters which emanate from the open ocean appear to be associated with some of the most successful farms. Some important exceptions, however, have been noted in Puget Sound - particularly during the chaetoserous bloom of October/November, 1987. Local conditions that alter the basic physical and chemical parameter of open ocean waters typically do so in an inimical manner, particularly in Alaska. Fortunately most of the waters of Alaska that are adjacent to the Gulf of Alaska may well be suitable for salmon farming. The gulf is, after all, the main rearing area of Pacific salmon of both North American and Asian origin.

Physical/Environmental Influences: The optimum temperature for salmonids (salmon and trout) is 38-60°F; salinity 22-30 ppt; oxygen levels should be above 7 mg/l. Certain

local land forms and characteristics can create localized conditions that fall beyond these ranges, so are to be avoided by the would-be salmon farmer. Areas with extensive freshwater inputs, particularly that of glacial origin; bays, sounds or other relatively enclosed areas with shallow sills barring access routes to deep water; extensive tidal flats; very high current velocities; insufficient water depth; and areas subject to industrial or organic pollution are the main problem spots.

Freshwater influences: Salmonids are referred to as being anadromous. That is, they typically mature, reproduce, incubate their eggs and spend their first days, months or even years in fresh water, and then migrate to salt water for their main growth. Once capable of osmoregulating (physiologically adjusting their blood sodium and chloride ion content) in saltwater (during this life stage salmonids are called "smolts"), they migrate downstream into saltwater. King, coho, and chum salmon and steelhead trout oftentimes spend days or months in areas of intermediate salinity such as estuaries or moving back and forth between oceanic waters and river mouths. Consequently, the upper reaches of narrow arms, with extensive freshwater inputs may be highly satisfactory to the rearing of fry (the free swimming life stage after absorption of the yoke sac and before smoltification), and to smolts and shortly thereafter. Low salinities are thought to assist with the transitional phase incurred during and just after smoltification by assisting with keeping blood salinities normal, between 10 and 12 ppt. Experience indicates, however, that areas of low salinities, <5-10 ppt particularly if salinities change with depth, tides, or weather, can cause problems during the later grow-out phase. Once salmon have adapted to sea water they appear to prefer salt concentrations to remain consistently high. Areas that have wide salinity changes (greater than 5 ppt within a period of less than a day) should be avoided, as should sites with extensive freshwater lenses (>2-4 ft), especially during the summer months.

Glacial waters are often quite cold (<36°F), and highly turbid, which can irritate a fish's delicate gill membranes. Generally, glacial water should be avoided for those reasons. There may be, however, an occasional exception. If a site offers many other advantages and is some distance from the source, or the source is of low volume even during periods of high runoff, and the glacial

water is very shallow (<1-2 ft) and inexpensive power is available, deep water might be upwelled satisfactorily. Some sort of solid material skirt or shroud that encircles the pens and runs from above the water line to below the glacial runoff (which offer other advantages such as keeping floating debris or oil away from the fish) would be helpful. Careful temperature and salinity measurements over the course of a year or more during a variety of weather conditions, however, should be made before a site with glacial influence should be chosen.



Seafoods of Norway salmon farm operating in Port Angeles, Washington, harbor.

Enclosed areas: A satisfactory site should have water that is exchanged often. Bays, sounds, or arms that have a sill or shallow area (depth of less than that found at the pen site) between the site and open water should be avoided. Nutrients from metabolic waste products and uneaten feed can stimulate algae growth in an enclosed area. After the algae dies and sinks, bacteria and fungi consume cell walls and contents. The respiration of the decomposing organisms can deplete oxygen. High winds can then bring the oxygen deficient water to the surface. At best, fish grow poorly and are much more susceptible to disease in low (<5 mg/l) oxygen water. At worst (<2 mg/l) they all die.

The most desirable location for a cabin, float plane or boat moorage may not be the best place for a salmon farm.

Tide Flats: Large tidal flats can cause wide temperature changes. Waters can become too warm (>65°F) in summer and too cold (<38°F) in winter for good growth. Extensive tide flats typically are found near the mouth of

Selecting a Site *continued*

large rivers which carry heavy sediments. The strong fresh water influence can be harmful, as was mentioned previously.

High current velocities: With the high tidal range found in coastal Alaska there are probably no open areas with insufficient current velocities. Norway, for example has a tidal range of about 10 ft. Too high of current speeds are much more likely. At water flows above 5 mph (7 ft per second) it becomes difficult to keep nets from billowing up and forming pockets. Fish do not appear to grow as well or remain healthy in net pens that routinely deform sufficiently to trap them in pockets. While very heavy (1,000 lb) anchors can be used to secure the corners of net pens, much heavier webbing and support ropes must be used to avoid tearing of the net fabric and consequent loss of fish. Anchoring the pen complex becomes much more difficult and consequently expensive in high currents.

Water depth: Adequate water depth assists in spreading wastes and uneaten feed over a large enough area to prevent buildup. Minimum water depth should be 60 ft at the lowest tide on the shallow side of the pen complex - unless special accommodations (such as rearing species that typically use just the upper portion of the water column such as steelhead/rainbow trout) are made. In essence, the deeper the better. An ideal site would have 90 ft or greater depth right next to shore. Stiff legs (rigid attachments between shore and the pens) could then be used to anchor the complex.

Weather Protection: While cages are built that will sustain near-open ocean conditions caring for fish during extended periods of heavy waves is difficult and can be hazardous to operators and workers. Shelter from storm winds and waves is highly desirable. Moderate waves (2-4 ft) can be smoothed by the use of a log boom. Log booms must be properly constructed, however. More damage can be done by a loose log than by the waves that have turned it into a battering ram. Due to the complex manner that storms often move in, picking a site with less than one-half mile of open water in all directions is advisable. Adequate shelter from the prevailing storm winds and waves may require open water distances of less than that.

Biological Requirements

There are several important biological requirements in siting a prospective salmon

farm: The presence or freedom from harmful algae blooms, certain marine plants, predators, and large numbers of other salmonids can spell the difference between success and failure of a farm.

Algae: There are at least two species of phytoplankton that are harmful to salmonids. *Chaetoceros convolutus* is a diatom that has long setae (spikes) with hooks on the ends that can form long chains. They can block and damage gills. The initial response of fish is to feed poorly or not at all. After gill damage occurs troubled fish will be at the surface with their heads pointed up current, next to the netpen edge. Gills become coated with mucus, can have a mottled appearance, and bleed easily. If examined under a microscope the gills appear inflamed as the diatom causes a reaction not unlike that of an insect bite on a human. Dead fish, particularly small ones, often are found with their mouths stretched wide open.

Blooms occur most often in the fall under conditions of little wind and sunny weather, although spring blooms do occur. Water clarity is not a useful guide as even very low concentrations of *Chaetoceros* can cause problems (>5 cells per milliliter). Rainbow trout and Atlantic salmon appear to suffer the worst with neutered coho salmon following. Smaller individuals of the same species may have higher mortalities than do larger ones. This algae is known to occur and to have adversely affected fish in Southeast Alaska and in Prince William Sound.

Heterosigma akashiwo caused extensive mortalities of farmed salmon in certain areas of southern British Columbia during late June of 1986. Thought to occur in heaviest concentrations near the interface of nutrient-laden rivers and salt water, it may produce a mucous-like substance that is toxic to fish. Rainbow trout are the most susceptible species; larger individuals of a given species appear to be troubled more than smaller ones. Its occurrence in Alaska is unknown to the author.

Kelp Beds: Locating a farm near large kelp beds should be avoided. Kelp beds can experience large seasonal die-offs and create huge volumes of drifting materials that can foul nets or in extreme cases cause damage to pens. Herring spawn on kelp also. Eggs can foul nets to the point of blocking water flows.

Predators: Seals and sea lions can wreak havoc with salmon, their natural prey. Farms should have heavy guard nets surrounding pens and placed far enough away so that tidal currents do not cause the nets to touch. Locating a farm near haulouts is to be avoided.

Other salmonids: Large populations of salmon nearby can bring diseases and predators. Consequently, farms should be located some distance away from streams with large spawning populations of salmon.

Other Criteria

This article has been a brief discussion of some of the factors to be considered in siting a salmon farm. There are additional criteria, some rather abstract, to be used before a final choice is made. Social and political considerations of neighbors should not be overlooked. It is quite difficult to argue with the contention that salmon farms change the vista of waterfront property. Proximity to people, goods, services, and transportation figure in importance to costs and chances of success. Lastly, and perhaps the most important, is the site and its location must be suited to the personalities, capabilities, and desires of the operator(s) and his or her staff.

A Cautionary Note: It must be emphasized that selecting an optimum location for salmon farming is, as yet, very much more an art than a science. The vagaries of weather can cause severe problems to salmon farmers. While our pool of knowledge of the cultural requirements of salmon and trout is quite extensive, there is a lack of knowledge about specific weather conditions and the resultant physical and biological oceanographic effects. Cells of low oxygen waters are the principal physical concerns, and the ecology, and distribution of blooms of at least two species of single-celled algae that can cause harm to salmonids are of very high biological importance. It must be emphasized that due to our lack of knowledge about the above mentioned physical and biological oceanographic concerns, even by closely following the guidelines contained in this article and others of a similar nature, success in farming salmon may be elusive. One thing is well known - failure is very expensive.

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Dolly Garza

Dear Reader:

The Marine Advisory Program is pleased to send you the fourth edition of the Alaska Marine Resource Quarterly. We hope you find it full of useful research and technology information as it applies to the fishing industry and other marine resource use groups.

We would like to continue sending this publication at no charge, but this year the Marine Advisory Program has taken some federal and state budget cuts. As a result, we are requesting a subscription of \$8 per year. The fee will cover the cost of printing and mailing.

In these economically troubled times, a new subscription fee is probably the last thing you would like to hear about, but the information you will receive in this publication should far outweigh the cost.

So please send for your subscription right away and make the Alaska Marine Resource Quarterly a part of your resource library.

If you would like to continue receiving our quarterly, please fill out the subscription card accompanying this issue and return it with your payment to: Marine Advisory Program, 2221 E. Northern Lights Blvd., Suite 220, Anchorage, Alaska 99508.

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December 30, 1986

Senator Richard Eliason
P.O. Box V
Juneau, Alaska 99811

Dear Senator Eliason:

The Alaska Mariculture Association (AMA) is looking forward to working with you during the upcoming session to help strengthen Alaska's economy by developing a diverse mariculture industry.

Mariculture, or sea farming, represents one of the most promising opportunities for providing new jobs for Alaskans, but the lack of a clear state policy has resulted in confusing patchwork of often conflicting regulations and statutes. While it is virtually impossible to obtain permits to farm most native stocks of finfish and shellfish, the farming of non-indigenous oysters is allowed.

AMA is working on legislation leading to an easily followed path through state regulatory requirements and essential government services to protect public health and our valuable common property fisheries resources. We will be contacting you in the near future with additional information.

Attached is a report on mariculture developed over the past several months by the Alaska Mariculture Technical Work Group. The work group, which was sponsored by AMA, was composed of representatives of various state and federal agencies. This report presents an unbiased analysis of some issues involved in mariculture development and how they may relate to government programs.

In an effort to keep you informed about the growing interest in mariculture, AMA also is providing you with a complimentary subscription to our monthly newsletter.

We look forward to working with you. Please do not hesitate to contact me for additional information.

Sincerely,

Rodger Painter
Rodger Painter
Executive Director

M A R I C U L T U R E I N A L A S K A

An Examination of Government Programs
by the Alaska Mariculture Technical Work Group
December 1986

December 16, 1986

Mr. Rodger Painter
Alaska Mariculture Association
P.O. Box 020704
Juneau, AK 99802-0704

Dear Mr. Painter:

As chairmen of our respective technical subcommittees, we are pleased to present the enclosed documents representing the product of our committee's deliberation on a variety of topics relating to development of a mariculture industry in Alaska.

Our purpose is to provide, to the extent possible, an unbiased and accurate analysis of issues relating to a potential mariculture industry in Alaska. We recognize that final decisions must be made by the people of Alaska working through the public process. Because of the complexity and uncertainty of these often new issues, decision makers should find the enclosed documents very useful.

On behalf of the entire technical committee, we would like to thank you for your role in this important effort. We expect that the educational process will continue as Alaska moves forward into this new area of resource development. Hopefully, the information provided here will be of continuing use.

In the interest of public education, we would appreciate the widest possible dissemination of this information.



Michael Kaill, Ph.D.
Alaska Department of Fish & Game
Co-Chair, Siting and
Operations Subcommittee



William G. Paulick
Alaska Department of Commerce
and Economic Development
Co-Chair, Development and
Research Subcommittee

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Enclosure

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Reference Materials

Alaska Mariculture Technical Work Group

Broodstock Development--Bill Heard, NMFS

Feed Development & Research Facilities--Ole Mathisen, UAJ

Investment Incentives/Financing--Kellus Sewell, Nordic Alaska

(These discussion papers are available through the Alaska Mariculture Association, P.O. Box 020704, Juneau, AK 99802-0704.)

The Environmental Effects of Floating Mariculture in Puget Sound

Donald P. Weston, School of Oceanography, University of Washington
August 1986

Marine Net Pen Salmon Rearing

Larri Spengler, Alaska Department of Law, Memo, 1/31/85

DNR Tideland Permit for Shellfish Culture

Bob Palmer, Alaska Department of Natural Resources, Memo, 9/19/86

US Forest Service Permitting of Uplands Use for Alaska Oyster Farmers

Michael Barton, U.S. Forest Service Regional Forester, Letter,
7/25/86

A Philosophy for Aquaculture Development in Alaska

Governor Sheffield's Aquaculture Advisory Committee, Memo, 1/20/86

I N T R O D U C T I O N

Mariculture--or sea farming--is the for-profit captive culture of shellfish, finfish and sea vegetables in the marine environment. This is distinct from Alaska's existing salmon ranching program which involves the release of juvenile fish into the ocean to intermingle with wild stocks. The latter also is non-profit and returning fish are a common property resource.

Food products from sea culturing operations are becoming increasingly important throughout the world as seafood consumption climbs and wild fisheries landings remain relatively static. The world aquaculture production (fresh water and marine culture) was estimated at 22 billion pounds in 1983, and is expected to reach 48 billion pounds by the turn of the century.

The productive, unpolluted waters of Alaska's many sheltered bays and fjords are considered ideal for mariculture operations.

The first mariculture operations in Alaska involved the experimental culturing of oysters near Ketchikan in the early 1900s. Several oyster and mussel farms are now in operation and other farms are underway or are under consideration in Southeast, Southcentral and Southwest Alaska.

The State of Alaska recently began a joint project with Japan to test the feasibility of growing scallops in Kodiak and giant kelp (Macrocystis) in Sitka. The National Marine Fisheries Service also is cooperating with the state in an experimental research station in Southeast dealing with problems related to salmon farming.

A general need for policy and issue clarification was recognized by state and federal agencies, potential fish farmers and industry. The Alaska Mariculture Technical Work Group was formed at the invitation of the Alaska Mariculture Association. This cooperative effort represented here could assist in meeting the need for an information base to be used by policy makers.