MARINE BIRDS AND AQUACULTURE IN BRITISH COLUMBIA:
Assessment and Management of Interactions
PHASE III REPORT: PREVENTING PREDATION BY SCOTERS ON A WEST COAST MUSSEL FARM

Harriet Rueggeberg
Jacqueline Booth

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Hammond Bay Environmental Services

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PREFACE

This report documents the results of Phase III of a project aimed at assessing the effects of British Columbia's growing aquaculture industry on its marine bird populations. The project is comprised of three phases. Phase I reviewed the relevant literature, describing the nature of interactions that can occur between marine birds and the various types of aquaculture, and providing an analytical framework for the subsequent phases (Booth and Rueggeberg, 1988). In Phase II, a computer database and geographical information system is developed to examine the overlap between areas of current and potential aquaculture development and areas of marine bird habitat. Phase III consists of two studies that examine on-site interactions between birds and aquaculture, one dealing with salmon farming (Rueggeberg and Booth, 1989a) and the other with mussel farming (this report).

ACKNOWLEDGEMENTS

Our sincere thanks goes to R. Baden of Ocean Gold Seafarms Inc. for collaborating with us throughout this study; his help in its planning and execution was invaluable. We also wish to thank J. Westob for her assistance in the field. The following people also contributed to this project, for which we are grateful: P. Hicklin, E. Hiscock, and A. Lock (Canadian Wildlife Service); I. Jefferds (Penn Cove Mussels); G. Miller and P. Olson (Pacific Biological Station); H. Milne (Munalchy Research Station); S. and N. Pakula; J. Parsons; D. Reid (Redden Nets Ltd.); J.-P. Savard (CWS); R. Stephens. The manuscript was reviewed by S. Wetmore, K. Vermeer and J.-P. Savard; we thank them for their comments.

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ABSTRACT

Predation by overwintering scoters (*Melanitta* sp.) is a major problem to mussel farming along the coast of British Columbia. The objective of this study was to investigate ways of improving predator protection measures that would be effective in preventing predation but would not entangle birds and would be relatively inexpensive and convenient to install and maintain.

Using a raft culture site located on the west coast of Vancouver Island, an experimental underwater predator net was designed to examine differences in mesh size, colour and weight on the occurrence of predation and entanglement of diving birds. A net fence was tested for its ability to prevent bird access from the surface and from the air. Observations during the course of one winter season indicated that scoters could still dive under the underwater predator nets as well as fly in and out of the mussel raft, but the extent of their predatory activities was reduced.

Raft culture with underwater predator nets is currently considered to be the most appropriate means for avoiding major losses of mussel stocks to scoter predation in British Columbia. Underwater predator nets should be 9-10.5 m (30-35') in depth in order to substantially reduce, if not eliminate, access to mussel stocks by scoters. To avoid entangling the birds, the mesh size of underwater nets should be no greater than 10 cm; gauge and colour of the mesh used is less important except with respect to realtive cost and durability. It is suggested that surface access can be curtailed by using a fence or a raised raft structure combined with buoys or other surface structures spaced at 1-1.5 m within the raft. Scaring techniques can enhance the effectiveness of physical barriers. Other recommendations regarding site selection and management are made. An alternative to raft culture with underwater predator nets is also proposed.

RÉSUMÉ

La prédation par les macreuses (Espèce Melanitta) qui hivernent dans la province pose un sérieux problème pour les mytiliculteurs, sur la côte de la Columbie Britannique. L'étude visait a améliorer les mesures de protection contre les prédateurs, c'est-à-dire à trouver des dispositifs dans lesquels les oiseaux ne risquent pas de s'empêtrer, qui soient efficaces comme moyens de prévention, peu coûteux et relativement faciles à installer et à entretenir.

Dans une moulière de la côte ouest de l'île de Vancouver, où se pratique l'élevage sur radeaux flottants, on a conçu un filet anti-prédateurs sous-marin expérimental pour déceler comment la grosseur des mailles, la couleur et le poids des filets peuvent influer sur l'activité des prédateurs et augmenter ou diminuer les risques que les oiseaux plongeurs se prennent dans les filets. Une clôture de filet a aussi été mise a l'essai pour établir dans quelle mesure elle peut prévenir l'intrusion d'oiseaux nageant à la surface de l'eau ou plongeant du haut des airs. Selon les observations faites pendant un hiver, si les dispositifs en place n'ont pas empêché les macreuses de plonger sous les filets sous-marins ou d'entrer et de sortir du radeau d'élevage en volant, ils en ont limité les activités prédatrices.

L'utilisation combinée de radeaux flottants et de filets sous-marins est considérée aujourd'hui en Colombie-Britannique comme le meilleur moyen de prévenir la destruction par les macreuses de stocks importants de moules. Les filets anti-prédateurs doivent être installés à une profondeur de 9 m - 10,5 m (30 - 35') pour limiter, sinon empêcher, l'accès des macreuses aux stocks de moules. Afin de prévenir le risque que les oiseaux s'empêtrent dans les filets, il convient d'employer des filets dont les mailles sont d'au plus 10 cm; le poids et la couleur des filets sont des considérations secondaires, sauf en ce qui concerne le coût et la durabilité. Les auteurs mentionnent qu'une des façons de contrer les prédateurs à la surface de l'eau consiste à utiliser une clôture ou un radeau ayant une structure surélevée et dans laquelle flottant des bouées ou d'autres moyens d'obstruction disposés à 1 m - 1,5 m d'intervalle. Des techniques d'effarouchement peuvent renforcer l'efficacité des barrières physiques. Les auteurs font aussi d'autres recommandations concernant le choix et la gestion des installations d'élevage. Une solution de rechange de la technique combinant l'usage de radeaux flottants et de filets sous-marins anti-prédateurs est également proposée.

1. INTRODUCTION

The technical and economic feasibility of mussel culture in British Columbia is currently being demonstrated, but several constraints to development of a mussel culture industry have been identified. One of the most serious is loss of mussels to predation by diving ducks. Mussel farms on the west coast of Canada and the United States hang predator nets around their grow-out structures to prevent predation, a measure that has met with some success but can be expensive to install and maintain. In addition, diving birds have become entangled in predator nets, which may have detrimental effects on local bird populations. The development of a cost-effective, low-impact method to protect mussel farms from duck predation has been identified as a high priority for the mussel industry (Lutz, 1980; Emmett, 1988).

1.1. Purpose

The objective of this field study was to investigate measures for improving protection from bird predation on a mussel farm in British Columbia The measures should also reduce the potential for bird entanglement and be cost effective.

1.2. Mussel Culture

The culture of blue mussels (*Mytilus edulis*) was originally developed in France, but is now practised in Canada, Denmark, Germany, Great Britain, the Netherlands, Norway, Sweden, Spain, and the United States. Spain is presently the world's leading producer of cultured mussels, with an estimated annual production of 210,000 tons. Atlantic Canada produced about 3000 tons in 1987. In British Columbia, the mussel industry is still in a development phase, with 3 or 4 growers producing about 30 tons in 1987. Production is about twice that amount in Washington State where growers are concentrated in Puget Sound (Emmett, 1988).

Three general methods are used to grow mussels:

i) bottom culture: seed mussels are placed on the bottom in intertidal areas, and harvesting is done by dredging. This is practised in the Netherlands and Germany (Hurlburt and Hurlburt, 1980) and to some extent on the east coast of the U.S.

ii) near bottom culture: seed mussels are hung from poles or "bouchot" driven into intertidal mud flats. This is commonly practised in France.

iii) suspended culture: seed mussels are grown on ropes, mesh "socks" or other mesh structures and suspended from longlines or rafts. Farms in Canada, the U.S., Norway, Sweden, Spain and Scotland use this method.

Suspended culture has become the most widely practiced method in Canada. The main advantages are the mussels can feed continuously with no tidal interruption and have greater access to food organisms (plankton), factors that lead to faster growth (Milne and Galbraith, 1986).

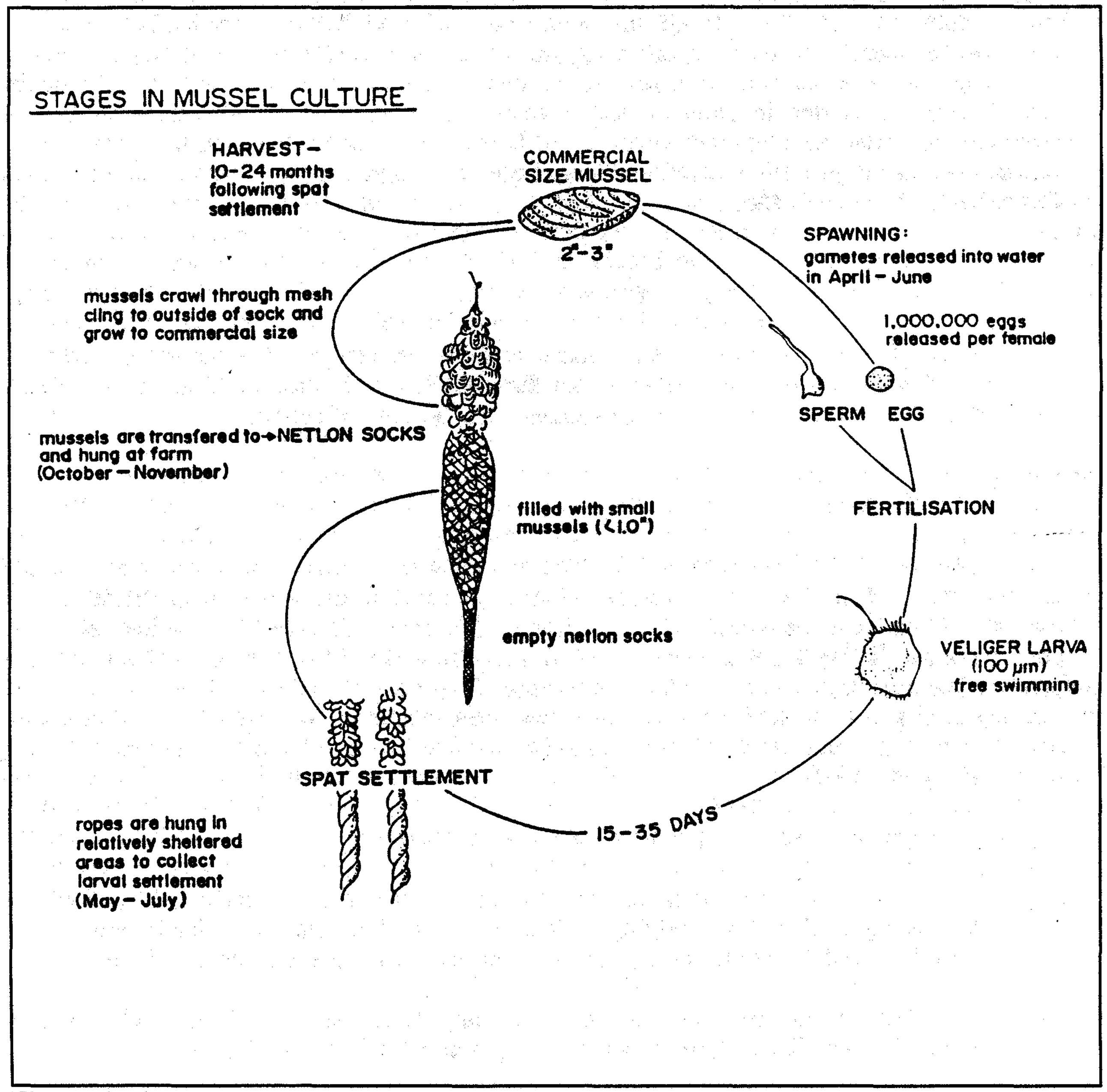

Figure 1: Stages in mussel culture (Emmett, 1988: 2).

Suspended culture uses either longlines or rafts. In longline culture, grow-out structures are suspended from lines hanging from buoys or other floatation devices. Longlines are usually 80-100 m long, although large operations may have rows of longlines stretching several hundred meters. Raft culture differs only in that grow-out structures are suspended within floating frames; 10x10 m is a typical raft size. Raft culture has higher capital costs but provides for more intensive culture as well as being easier to protect from predation.

In British Columbia, peak spawning generally occurs in May-June, once water temperatures exceed 12°C. "Seed" mussels are collected by suspending ropes or webbing in sheltered bays populated by wild mussels during spawning season (Figure 1). The free-swimming larvae settle on the ropes as "seed". The seed mussels may be simply transferred to a grow-out site and raised on the collectors to full size. Alternatively, once they reach 0.5-1.25 cm (4-6 months), they may be stripped from the collectors and placed in plastic mesh "socks". The latter method is more labour intensive but has the advantage of allowing greater control of grow-out densities to optimize size and yields. Grow-out structures are typically suspended at 5-10 m to optimize growth and reduce fouling. Mussels are harvested at 5-7.5 cm in length when meat-to-total-weight ratios reach approximately 40%. This may take 9-24 months after seeding, depending on grow-out conditions; in British Columbia, commercial-sized mussels can usually be harvested in under 15 months (Emmett, 1988).

1.3. Avian Predators on Mussel Farms

Scoters are the main predators of concern on farms in British Columbia, of which there are 3 species: Surf (*Melanitta perspicillata*), White-winged (*M. fusca deglandi*) and Black Scoters (*M. nigra americana*).

1.3.1. Distribution and abundance

All 3 scoter species winter along the Pacific coast from southeast Alaska to Baja California, occurring in a ratio of approximately 69% Surf, 28% White-winged and 3% Black Scoters (Bellrose, 1976). Scoters are most abundant in British Columbia during spring and fall migrations. Vermeer (1981) estimated a total population of 700,000 scoters present along the entire British Columbia coast in March 1978 (Figure 2).

Surf Scoters have the highest densities of all the sea ducks in British Columbia (Vermeer, 1981; Vermeer *et al.*, 1983), being common to very abundant during migrations and abundant to locally very abundant in winter. About 130,000 birds winter in North America (Bellrose, 1976), of which about 10% may occur in British Columbia (Campbell *et al.*, 1989). Surf Scoters breed from northeastern British Columbia to the Mackenzie Delta (Campbell *et al.*, 1989), but are also common to abundant in specific coastal areas in summer as large moulting flocks (Campbell *et al.*, 1989; Savard, 1988). Surf Scoters occur in highest numbers in sheltered straits, bays and inlets (Robertson, 1974; Vermeer, 1983; Campbell *et al.*, 1989).

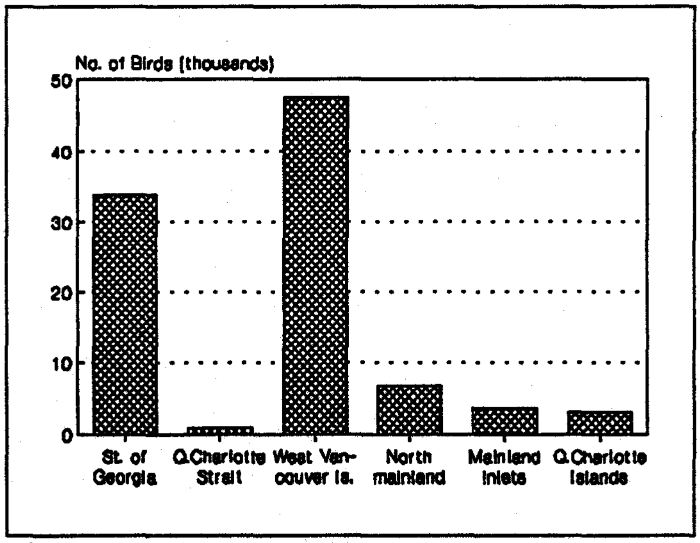

Figure 2: Numbers of Scoters observed in March 1978 from aerial surveys (from Vermeer, 1981; Vermeer *et al.*, 1983).

White-winged Scoters are less abundant than Surf Scoters in most coastal areas of British Columbia About 40,000 birds are reported to winter south of the Aleutians (Bellrose, 1976). Winter bird counts along the British Columbia coast have resulted in about 5000 birds (Campbell *et al.*, 1989), concentrated in the Strait of Georgia, on the north coast near Prince Rupert, and on the north coasts of the Queen Charlotte Islands (Robertson, 1974; Vermeer *et al.*, 1983). White-winged Scoters are very common to very abundant during spring and fall migrations and abundant to very abundant in winter. They breed throughout eastern British Columbia and the prairies, north to the Arctic Ocean (Bellrose, 1976). In summer, nonbreeding, postbreeding and moulting males are found in heavily used wintering areas, although the distribution is more restricted (Savard, 1988). White-winged Scoters are also found in bays, inlets, estuaries and around rocky headlands (Bellrose, 1976; Campbell *et al.*, 1989) but appear to favour more open water than the other scoter species (Hirsch, 1980).

Black Scoters are less abundant and more local in their distribution than the other two species. They occur in the Straits of Georgia, some inlets on the west coast of Vancouver Island, in the Queen Charlotte Islands and in some northern mainland locations (Robertson, 1974; Savard and Kaiser, 1982). They breed primarily in the Arctic (Bellrose, 1976; Campbell *et al.*, 1989). Like Surf Scoters, Black Scoters are most abundant in sheltered straits, bays and inlets (Robertson, 1974; Vermeer, 1983; Campbell *et al.*, 1989).

1.3.2. Feeding habits

Blue mussels are the chief food of both Surf and Black Scoters along the British Columbia coast. Most of the mussels consumed are first year stock under 30 mm in length. The proportion of mussels in Surf Scoter diets varies with location and season, ranging between 2 and 96% (Vermeer, 1981; Vermeer and Ydenberg, 1989). Surf Scoters switch to herring spawn as their staple diet during spawning season; concentrations of several thousand birds have been recorded in the vicinity of spawning areas in March (Campbell *et al.*, 1989). Other food species include other bivalves, gastropods, crustaceans (barnacles, crabs and isopods), vascular plants, and algae.

Both species are bottom feeders, although Surf Scoters also feed extensively on mussels attached to steep rock walls in fjords or rock outcrops (Vermeer, 1989). The average water depth of areas used by Surf Scoters in Puget Sound is 9.7 m (s.d.= 7.9m;

Hirsch, 1980). In British Columbia they are reported to use beaches, spits and points where depths are generally less than 6 m (Campbell *et al.*, 1989) but are able to dive to depths of 10 m or greater (Hirsch, 1980; R. Baden, pers. comm.).

White-winged Scoters feed primarily on mollusks and crustaceans. In Georgia Strait, they feed mostly on clams and snails, although crustaceans (especially barnacles) were used heavily at times (Vermeer, 1983; Vermeer and Bourne, 1984). In Puget Sound, food components were recorded as 84% clams and 11% snails (Hirsch, 1980); in Humbolt Bay California, they were 80% clams and 20% crabs and snails (Bellrose, 1976). Like Surf Scoters, they feed extensively on herring spawn in the spring (Vermeer and Ydenberg, 1989). White-winged Scoters dive an average of 10.9 m with maximum depths of approximately 12 m (Hirsch, 1980), but they prefer to feed at low tide when food is not so deep (Bent, 1925).

Of the 3 species, Surf Scoters may pose the greatest predation problem to mussel farms because they are the most abundant and feed primarily on mussels in the wild. White-winged Scoters may be able to dive to greater depths to access cultured mussels, but may not capitalize on mussels to the same extent as Surf Scoters. The threat diminishes in the spring when scoters switch to herring spawn and remains low over the summer when the birds move to their breeding grounds, except for the fairly specific, traditional areas where nonbreeding and moulting ducks concentrate.

1.3.3. Other species

Barrow's Goldeneye (*Bucephala islandica*) is another commonly occurring diving duck in British Columbia that feeds extensively on mussels (Vermeer, 1981; Koehl *et al.*, 1984). Although they are often seen around mussel farms, Barrow's Goldeneye apparently rarely feed on the crops and therefore do not pose a predation problem (I. Jefferds and R. Baden: pers.comm.; personal observations). Only once are they mentioned in the literature as being involved in predation on mussel farms (Waterstat *et al.*, 1980). The maximum diving depth of Barrow's Goldeneye is reported as 2-4 m (Koehl *et al.*, 1984); hence, they may be unable to reach the mussel cultures, which are often suspended below these depths, or to dive under surrounding predator nets.

1.4. Extent of Predation

Scoters can apparently eat mussels up to 55 mm in length but prefer those in the 20-30 mm size range (Lutz, 1980; Waterstat *et al.*, 1980). Mussel culture structures can be completely stripped or patches of mussels may be removed randomly or on a size-selective basis. The patches can be recolonized but this creates uneven class distributions, which greatly reduces the efficiency with which crops can be harvested (Milne and Galbraith, 1986).

The extent of scoter predation on cultured mussels has not been documented, but measures of predation by Common Eider (*Somateria mollissima*) have been recorded. Large concentrations of eiders migrate along the Atlantic coast of Canada and the U.S. and breed in several coastal areas of Nova Scotia and Newfoundland. They also range throughout Scotland, Sweden and Norway. Like Surf Scoters, blue mussel comprise the greater percentage of their diet.

The loss of 270 kg of mussels in a 1-month period at an experimental mussel farm in Scotland was attributed to 24 eiders (Dunthorn, 1971). The most extensive study of bird predation was conducted by Milne and Galbraith (1986) on mussel farms on the west coast of Scotland. Experiments were conducted from 1983-1986 to determine the damage that can be caused by eiders, of which about 10,000 inhabit the Scottish west coast. In one experiment, 293 5m-long ropes, each containing 30 kg of partly grown mussels, were exposed to 140 eiders. The ropes were completely stripped in 24 hours. This represented 9072 kg or 2.7 kg of mussels removed per bird per day. Another experiment using 25 ropes containing 1016 kg of 1st-year mussels resulted in losses of 2.59 kg/bird/day over a 4-week period. In a third experiment, 1 protected and 1 unprotected raft of 30 ropes each were placed at one site. After 1 year, the unprotected raft had only 35% of the harvest of the protected raft. "A loss of at least 65% of the crop, therefore, could be expected within the first crop cycle when unprotected rafts are located in areas of 'high' eider density" (Milne and Galbraith, 1986: 99).

The authors maintained that not all of the mussels were eaten as the birds were observed pulling clumps of mussels off ropes but only consuming one mussel at a time. Eiders feeding on a farm in Maine were thought to knock off the larger mussels in their quest for seed and small mussels (Myers, 1980). However, experiments to determine what percentage of the mussels removed were actually consumed proved inconclusive (Milne and Galbraith, 1986).

Anecdotal information indicates that losses of a similar nature and scale have occurred on mussel farms in Canada and the U.S. On the west coast of Canada, Ocean Gold Seafarms Inc. used an unprotected longline system in its first year of operation in 1980 but the site was "cleaned out" by wintering scoters (R. Baden, pers. comm.). The farm was converted to rafts surrounded by underwater nets but still sustains predation losses. In Puget Sound in Washington State, a pilot mussel culture operation carried out by the Washington State Department of Natural Resources found that diving duck predation accounted for losses of about 80% of seed stocks (Waterstat *et al.*, 1980). Growers in Puget Sound feel that losses to diving ducks constitute a "large" proportion of potential harvests, even when protective measures are taken (*ibid.*; I. Jefferds, pers. comm.).

In Nova Scotia, federal and provincial wildlife authorities have received letters from mussel growers complaining of losses to diving ducks, primarily eiders and scoters. One company claimed losses of 4000 lb. of seed mussels during April and May (McFarlane, 1988). Another grower estimated losses of $40,000 (Hicklin, 1988). A third company had 360,000 seed collectors stripped in early spring (Hicklin, pers. comm.).

1.5. Entanglement

Dunthorn (1971) notes that 14 eiders were killed out of a local population of about 50 birds by being tangled in predator nets around a mussel farm in Scotland. A farm in Puget Sound, Washington estimates an average of 1 bird per week is pulled from the nets during times of peak bird numbers (I. Jefferds: pers. comm.).

Scoters and other diving birds (e.g. grebes) are occasionally found entangled in underwater predator nets at the Ocean Gold farm (R. Baden: pers.comm.). However, a higher incidence of entanglement occurred at this site in nets stretched over the surface of water inside the raft. These surface nets were installed in 1984, when scoters were observed hopping onto and over the raft frame in order to access the cultured mussels inside the raft. The surface nets were considered to be the most expedient method for protecting the mussels from the birds while at the same time being easily removed to allow entry and harvesting within the raft. However, birds that were diving under the predator nets that surrounded the raft would emerge and become entangled in the surface net. The birds would get their heads or upper bodies caught in the net, panic and struggle thereby worsening their entanglement. Total numbers of birds entangled in the surface nets during the time they were used were not documented, but on 1 occasion when a large number of birds were able to dive into the raft due to storm damage to the underwater nets, about 40 birds were found tangled in the surface net.

2. METHODS

2.1. The Study Site

The farm site of Ocean Gold Seafarms Inc. was used for this study. It is located in Robber's Passage between Tzartus and Fleming Islands in Barkley Sound on the west coast of Vancouver Island (Figure 3). The Passage is characterized by a mixed pebble-gravel-cobble-boulder shoreline. The site is situated within a sheltered cove in the Passage.

At the site, mussels are grown on net panels suspended within a 45x45 m raft frame (Figure 4, Plate 1). The raft is divided into three 15x45 m pens; each pen can hold up to 780 m of panels. The panels are hung 2-5 m below the surface, the deeper depths being used during the summer to avoid fouling. The raft is surrounded by an underwater predator net made of 7-cm black nylon seine netting. The net was initially hung to a depth of 5.5 m and later extended to 9.5 m in an attempt to exclude more birds. It was put in place in October before wintering birds arrive and removed in late April or May when the birds leave the area for their breeding grounds. Surface nets of the same mesh have been used for the last 4 years. These were suspended from the raft frame and covered the surface of water in the pens. As described, Ocean Gold still experienced predation as well as bird entanglement in the surface net.

2.2. Design of Improvements to Predator Net System

The following factors were taken into consideration in designing improvements to the predator net system:

- ***net depth:*** the underwater net needed to be deep enough to exclude birds but still be manageable in terms of cost and maintenance. The net should not touch bottom as this could allow starfish, another predator of mussels, to access the stocks.

- ***net mesh size:*** smaller mesh sizes would be best in presenting a greater visible barrier and reducing the chances of entanglement, but they are also more prone to fouling and reducing water flows around farm crops.

- ***mesh colour:*** coloured nets may be more visible underwater than black nets.

- ***net strength and durability:*** this is a function of material, mesh size, and gauge or thickness of strands.

- ***surface protection:*** entry of birds by "waddling" over the raft frame and entry from the air needed to be prevented without presenting an entanglement hazard. Ease of access to the pens for harvesting and maintenance activities was also a factor in the design of surface protection.

- ***cost***: Nets are priced on the basis of weight, which in turn is a function of net size, mesh material, size and gauge.

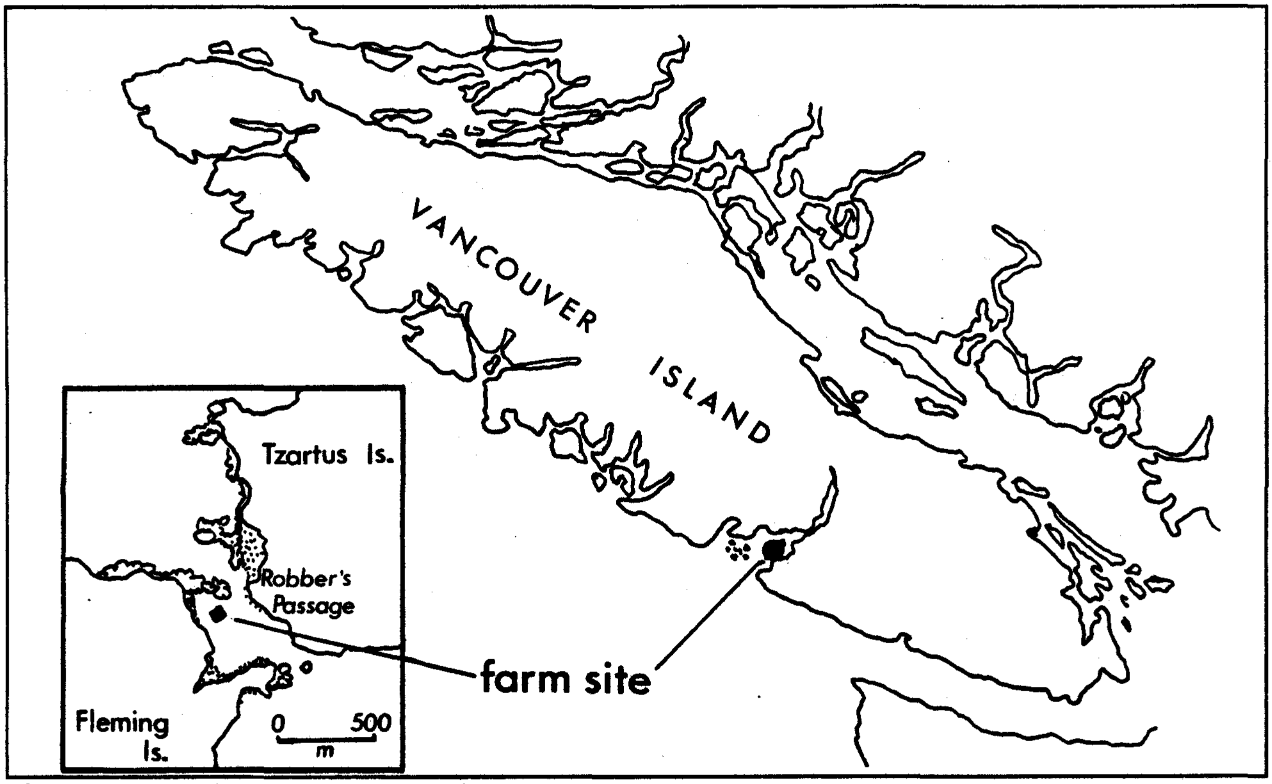

Figure 3: Location of the study site.

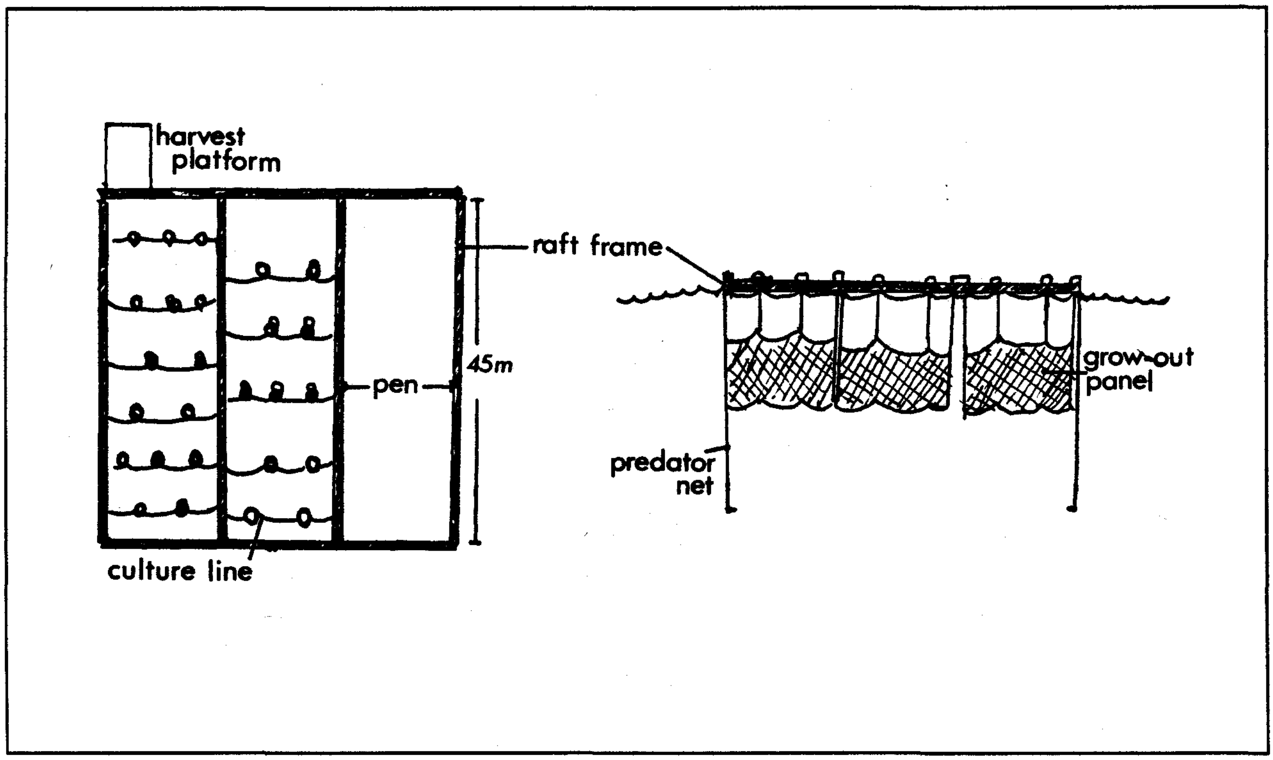

Figure 4: Raft system at the study site: top and side view.

2.3. Design of Underwater Protection

Four types of net material, 3 "experimental" and the original or "control" netting, were used to investigate whether net colour, mesh size and weight affected the occurrence of predation and entanglement (Table 1). Panels were cut from each type of netting and sewn together to form one continuous net surrounding the raft (Figure 5). It was originally intended that each side of the raft would be covered by 3 panels. When suspended in place, however, the net system had to be stretched in order to fit the raft snugly and to keep the nets taut, which resulted in an excess of netting material. Consequently, 2 panels were removed to yield 10 panels surrounding the raft (Figure 5). The sides of the net system were extended (made deeper) through the course of the experiment as observations indicated that birds were diving under the nets. The panels were extended by sewing a 5m-wide strip of extra netting to the bottom edge of each panel. The entire system was weighted with lead line sewn to the bottom edge.

PANEL TYPE NO.	MESH [1] SIZE cm (in)	COLOUR	GAUGE[2]	MATERIAL	PANEL DEPTH (m)	COST PER PANEL
1[3]	7 (2.75)	brown	210-160	nylon	6.4	(on site)
2	10 (4)	orange	2.5 mm	polypropylene	10.7	$296.00
3	4.8(1.9)	black	210-18	nylon	7	$120.00
4	3.8(1.5)	white	210-36	nylon	8	$200.00
Fence	15 (6)	orange	5 mm	polypropylene	1.5	$1560 for entire raft

[1] "Stretched" dimension; i.e., the measure from end-to-end of one mesh when pulled flat.
[2] An index of the relative thickness of net strands. 210-18 is the lightest of the nylon nets.
[3] "Control" netting used in original predator net.

Table 1: Characteristics of predator net panels.

2.4. Design of Surface Protection

A net fence was built around the perimeter of the raft (Figure 5, Plate 2). The fence consisted of a 1.5 m-wide strip of heavy-weight, orange, polypropylene net (Table 1) hung from 1 m-high steel supports bolted to the raft. The bottom edge of the fence was sewn to the top edge of the underwater panels so that the heavier fence netting would be exposed to flotsam rather than the lighter-weight predator net material.

2.5. Observations

The underwater net system and fence were in place by October 16, 1988. The pens were checked daily or every second day for entanglement and the presence of birds inside the pens. Observations of several hours duration were carried out every 2-3 weeks from October 1988 to February 1989 from the harvest platform attached to the raft. Species, numbers and location of birds, the occurrence of entries to and exits from the pens, and general behaviour of birds in the vicinity of the site were recorded during the observation periods.

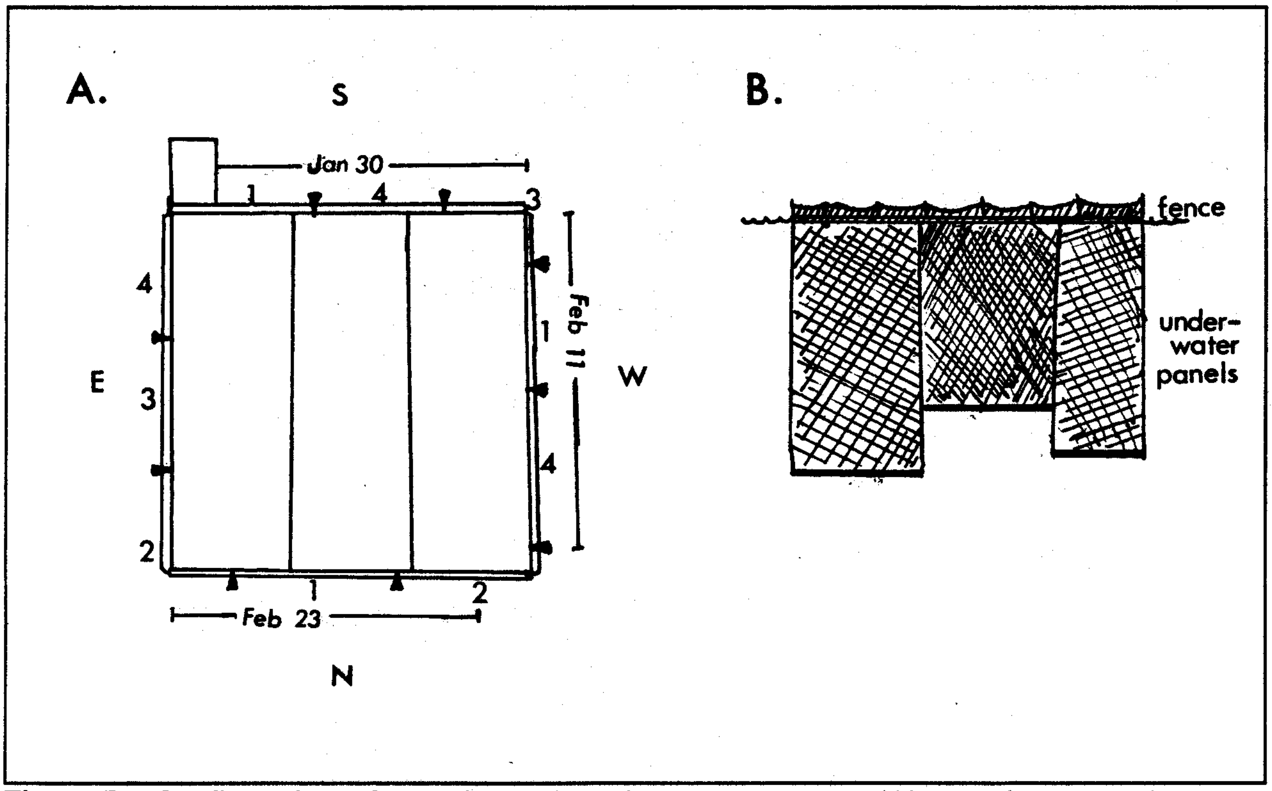

Figure 5: Configuration of experimental predator net system. (A) top view - numbers between markers indicate type of predator net panel (see Table 1); dates with lines indicate extensions of sides. (B) side view - fence and underwater panels.

Plate 1: Raft at study site.

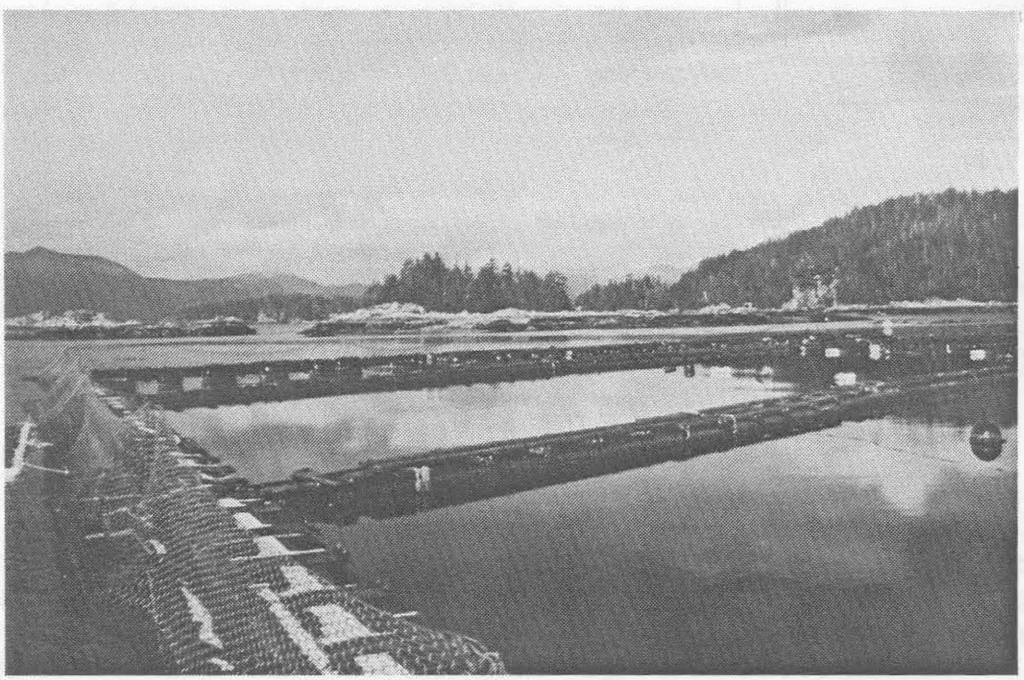

Plate 2: Raft with net fence installed.

3. RESULTS

3.1. Presence of Birds Around the Site

Flocks of 50-100 scoters were usually observed feeding or resting among the rock outcrops at the east entrance to Robber's Passage, 0.5-1 km from the raft. From 10 to 50 birds were typically present in the Passage, within 200 m of the raft. The majority were scoters but other species present included cormorants, Red-necked Grebe, Barrow's Goldeneye, Great Blue Heron, mergansers, gulls and crows. Only a few scoters were observed near the raft at any one time. The majority fed on wild stocks of mussels attached to rock faces and wharves along the shoreline, and on the anchor lines and buoys around the raft. The gradual loss of mussels on the harvest platform and log breakwater was evidence of feeding activity around the raft when no one was on the site.

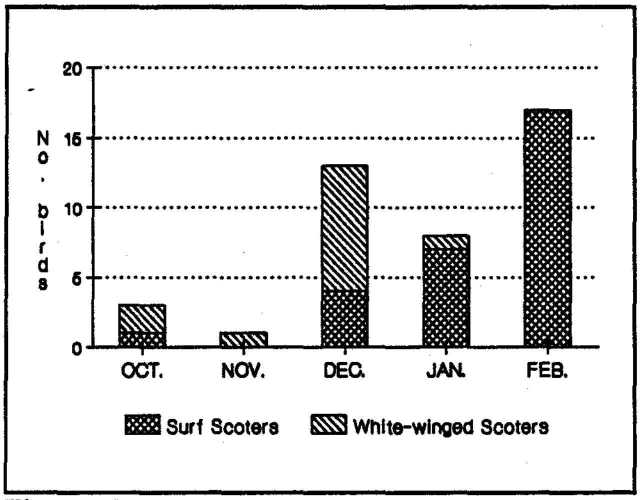

Figure 6: Birds observed entering the pens.

The composition of the scoter population around the site appeared to change over the period of observation; the majority of birds from October to mid-December were White-winged Scoters, whereas Surf Scoters were dominant from mid-December to March. This general pattern was reflected in the species that entered the pens during this period (Figure 6). Whether this pattern is typical of past seasons or of other wintering areas is not known.

3.2. Entries into Pens

Approximately 22 hours of observations were carried out on the site. During this time, entries into the pens by 42 scoters and 2 Red-necked Grebes were recorded. The majority of entries were by diving under the predator nets (Figure 8). Entries occurred at all times of day; tide heights were not consistently recorded.

Three sides of the predator net were extended an extra 4.8 m (15') during the course of the study in an effort to discourage diving entries (Figure 5; Table 2). However, there was not enough extra net material to extend the west corner of the north side. The locations of diving entries relative to the sides of the raft were observed in 22 cases (Table 2; Figure 7).

As one side of the predator net system was extended, the birds tended to dive under other sides that were not yet extended (Figure 7), with some exceptions. Relatively few birds dove under the east side of the raft, even though the predator net was less than 9 m along most of this side and it was never extended (Table 2). The proximity of the

SIDE OF RAFT	BEFORE EXTENSION: DEPTH	#ENTRIES	AFTER EXTENSION: DEPTH	#ENTRIES
South	7.6m (24')	3	12.4m (39)'	3
West	7.6m (24')	2	12.4m (39')	0
North	9.7m (30')	7	14.5m (45')	0
			except for NW corner - 10.5m (33')	6
East	9m (28')	3	not extended	-

Table 2: Extension of predator net.

harvesting platform (Figure 4), from which observations were carried out and where most human activity on the site occurred, may have deterred the birds. The east side of the raft also faces the main entrance to the Passage through which most traffic travels to and from the farm site. In contrast, the majority of diving entries after extensions occurred in the northwest corner (Figure 7), which not only was not extended but was also furthest from the harvest platform.

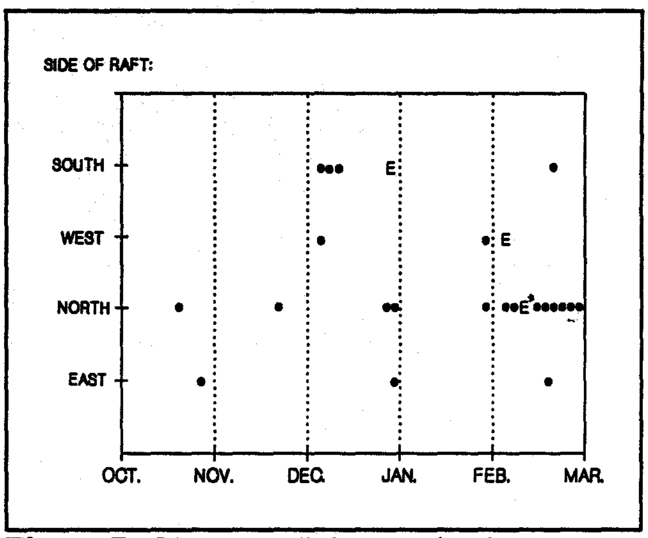

Figure 7: Observed diving entries into pens: black dot = entry; "E" = extension of net; "E*" = extended except for northwest corner.

3.3. Bird Activities in the Pens

Once inside the pens, some birds were observed diving among the mussel culture panels. Dives lasted for 5-10 seconds, and the birds often came to the surface with mussels. More frequently, birds were observed pulling at mussels attached to the inside edge of the raft and to floats within the pens, or just slowly swimming around inside the pens.

3.4. Exits from the Pens

The majority of birds exited the pens by flying (Figure 9). Although scoters need a fairly long runway to become airborne, by using the width of the raft to take off, most birds inside the pens had little problem clearing the 1-m net fence. Floatation buoys inside the pens limited these movements to some extent, but there were still areas of open water of sufficient size to allow take-off's as well as landings. The fence posed less of an aerial barrier wherever it drooped, which occurred as the result of the support struts bending under the weight and wind resistance of the fence. Rising and falling tides also had the effect of alternately pulling and slackening the anchor lines of the raft, which in turn stretched and loosened the fence.

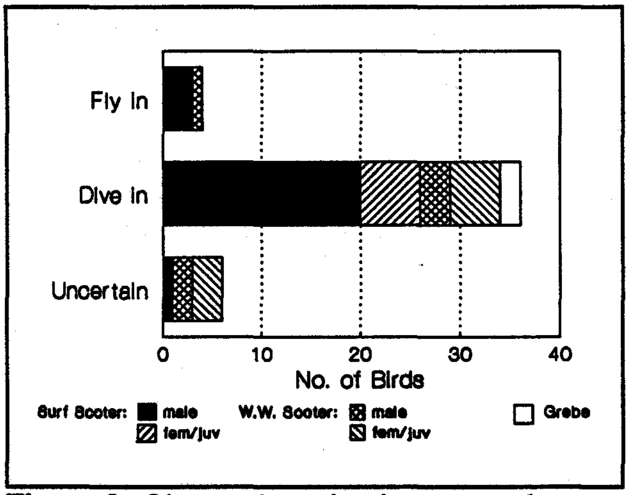

Figure 8: Observed entries into mussel pens.

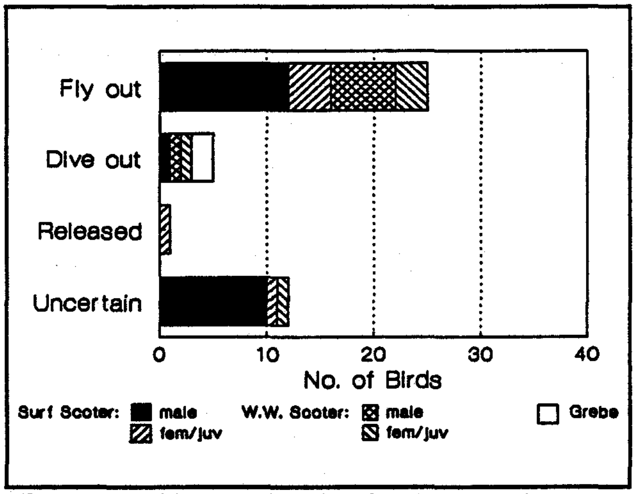

Figure 9: Observed exits from mussel pens.

3.5. Entanglement

There were 3 instances of birds becoming entangled in the fence. All involved female or juvenile scoters flying into the fence while trying to exit from inside the pens; they apparently did not gain sufficient height to clear the fence. The fence mesh, which was 15 cm in stretched dimension or approximately 9x9 cm in square configuration, was of adequate size to allow a scoter to get its head and perhaps part of a wing through; this was the usual state when the birds were rescued and released. There were no cases of bird entanglement in the underwater nets.

4. DISCUSSION

4.1. Effectiveness of the Experimental Predator Protection System

The number of scoters in Robber's Passage and around the farm site during the course of this study appeared to be lower than in past years (R. Baden, J. Westob: pers. comm.). Whether this perceived reduction was due to more effective deterrence as a result of this study or to natural variation in the size and distribution of the scoter population in the Barkley Sound area is uncertain.

It was not possible to quantify the losses to bird predation in terms of number or weight of mussels removed as a percentage of the total potential harvest, as only a proportion of the mussels grown in the pens were harvested in the spring. Losses to predation in the past were simply judged visually, based on the absence of mussels in patches near the bottom of the grow-out panels. On this basis, losses of mussels within the pens were noticeably less than in past years (R. Baden, pers. comm.). Therefore, the measures taken in this study may have decreased the level of predation by scoters on the cultured mussels. Notably, they have substantially reduced the entanglement of birds on the site.

4.1.1. Effective features of underwater nets

Depth: Depth appears to be the main factor in the effectiveness of underwater predator nets. In our observations, birds were still diving under nets that were 9-10 m (30-35') in depth (Table 2). Scoters have been observed to dive to 10-11 m on unprotected mussel ropes (R. Baden, pers. comm.). It appears, however, that the incidence of predation decreases as birds are forced to dive deeper (Figure 7), suggesting that predation can be substantially reduced if not eliminated by hanging predator nets to 10 m or more.

One limitation to increasing the depth of predator nets at the Ocean Gold site was the need to avoid touching the bottom of the bay. Extending predator nets to the bottom may have been very effective in blocking bird entry. However, it would have also allowed benthic organisms that feed on mussels (crabs and starfish) to climb up the nets and potentially access the farm stock that hung near the predator nets. Furthermore, these benthic organisms foul the nets, making them difficult to clean.

Other limitations to increasing the depth of predator nets are increased capital costs and labour in making, setting, and maintaining the nets. Obviously, capital cost increases with size of net, as does maintenance and handling time and effort. Furthermore, the depths of the experimental panels used in this study reflect the width at which each type of net material was commercially available. Wider material could be special ordered but at considerable extra cost. Alternatively, greater depths could be attained by sewing standard widths together, but this is highly labour intensive.

An alternative to using deeper predator nets is to use hanging nets in conjunction with a bottom net, such that the mussel pens would be completely encased by a predator net. This method is employed in finfish farming, where net cages are either surrounded by "bag" nets or are equipped with double bottoms and surrounded by "curtain" nets (Rueggeberg and Booth, 1989). Certain conditions of mussel farming, however, aggravate the use of bottom nets. Individual mussel rafts are often larger than finfish pens, such that equipping them with a totally encasing predator net would not only be costly but the nets themselves would be very difficult to maintain and pull up for cleaning. Furthermore, it is frequently desirable to be able to lower mussel grow-out ropes or panels several meters in summer to reduce the effects of fouling. This measure would be constrained by a bottom net, but constructing a net system that would deep enough to allow for this measure would be prohibitively expensive.

Mesh size: Mesh size is a consideration in avoiding entanglement of birds. The experience with the fence netting indicates that a 15 cm mesh (stretched dimension) may be a hazard to birds if the same size mesh was used underwater. This is supported by experience on farms in Puget Sound, where a 17.8 cm (7") mesh is used in predator nets, with the result that birds are entangled fairly regularly during times of high bird numbers. Overall, the results of this study indicate that mesh sizes should be less than 10 cm to avoid entanglement. A minimum mesh size can be chosen based on the extent of fouling and the need to minimize any decrease in flow rates on site.

Mesh colour: Mesh colour made no obvious difference in deterring or entangling birds. It is noteworthy that with the exception to some extent of the orange polypropylene mesh, the net panels were so covered with foulants within a month that differences in their colours underwater were largely indiscernible.

Mesh gauge: Nets of different mesh gauges were used to see if there was any effect on the occurrence of entanglement and on net durability. As there were no underwater entanglements, we assume that the gauges that were used were effective as visual barriers. As for durability, none of the nets were torn or showed excessive signs of wear at the end of the first season of use (October, 1988 - May, 1989). If properly maintained (which includes removing them from the water and thoroughly cleaning them every summer), nets made of the seine netting or the orange polypropylene are expected to last 8-10 years (B. Baden). Whether the lighter-weight netting would have a similar longevity is uncertain.

Availability, relative cost and known or perceived durability are probably the major criteria in choosing among net material of the colours and gauges tested in this study. It should be pointed out that although it may meet these criteria, clear or very fine-gauged mesh (e.g., monofilament) was not tested because of the obvious entanglement hazard it poses.

Comparative costs: Because net material is sold on the basis of weight, the capital cost of a given predator net increases not only as a function of the size of the net, but also according to the mesh material, size and gauge. In this study, the polypropylene netting was chosen for its large mesh, strength and bright colour; the black netting was selected for its small mesh size and because it was inexpensive relative to the other types of netting (it is normally used as barriers on golf courses). To surround a 10x10 m raft with the orange polypropylene netting would cost over twice as much as using the 210-18 black

PANEL TYPE NO.	NET MATERIAL	MESH SIZE/GAUGE	WIDTH (depth of net)	LB. NEEDED FOR 10x10m RAFT	COST[1]
1	Seine netting (control)[2]	7cm/ 210-160	6.5 m	270	$1080
3	Black nylon	2.8cm/ 210-18	6.7 m	75	$300
4	White nylon	3.8cm/ 210-36	8.3 m	125	$500
2	Orange polypropylene	10cm/ 2.5mm	10.7 m	185	$740
-	Black nylon predator net[3]	9.5cm/ 210-48	13 m	96	$384

[1] Based on average cost of $4.00/lb before taxes.
[2] Originally obtained as used netting; it is clearly too expensive to purchase as new product.
[3] Typically used for predator nets on finfish farms.

Table 3: Example of cost estimates of a predator net for a 10x10 m raft using different types of net material.

nylon netting (Table 3). Hence, on a purely capital cost-basis, the 210-18 nylon netting would appear to be the best buy. However, as pointed out above, its durability relative to the heavier weight netting is unknown. Also, it is available only in a narrower width than the other types of netting, such that strips would have to be sewn together to achieve comparable depths, which adds significantly to the overall cost of a predator net.

The costs indicated in Table 3 are for netting material only; added to this would be the cost of weights, floatation structures and building materials as well as the labour to make, hang and maintain a predator net. Hence, the total capital cost of a predator net for a 10x10 m raft may be roughly $1000.00, exclusive of labour. A raft of this size may produce from 3000 to 6000 lb of mussels over an 18-24 month period, depending on the type of grow-out structures and growing conditions. At an average price of $1.00/lb, this translates to $3000-6000 of product within a 2 year period. Hence, the cost of a predator protection system may represent from 16-33% of the anticipated yield of the first crop (2 years of operation). Assuming that it will last 8 years or 4 crop rotations, the cost of a predator net system represents approximately 4-9% of the yield that might be expected over that time period. This does not include additional costs associated with its maintenance and repair.

4.1.2. Effective features of surface protection

The net fence did not present the same entanglement hazard as the surface net used in previous seasons. It prevented scoters from "waddling" over the raft to enter the pens. In addition, the height and bright orange colour of the fence may have served as a visual barrier from the water, and may have deterred some birds from landing in the pens from the air. Also, because it extended 0.5-1 m below the surface of the water, the fence was also useful in acting as a barrier to flotsam which could have damaged the predator nets.

However, problems were encountered with supporting the fence so as to maintain its height above the water. The fence tended to sag wherever the supporting struts were unable to withstand the weight of the heavy-gauge net and the force of the wind against it, such that the fence was at times less than 0.5 m above the surface of the water. This reduced its effectiveness, evidenced by the fact that most birds that did get into the pens had little problem flying out over sagging portions. On one occasion, a bird was observed swimming to within 2 m of the raft and doing a short fly-over a sagging part of the fence into the pens.

There may be other means for presenting aerial barriers that would not encounter this problem. A common practice in agriculture is to surround crops with string or wire to which plastic strips or streamers are attached. The irregular movement of the streamers in the wind are considered effective in scaring birds off (Milne and Galbraith, 1986). On a mussel raft, wires or rope spaced 10-15 cm apart and extending around the perimeter of the raft to a height of 1 m could act to prevent birds from hopping over the raft frame. Their visibility could be enhanced by tying flagging tape at 5-10 cm intervals along the wires or ropes that would flap in the spaces between the wires. Compared to a net fence, this method would involve less weight and windage and would also be less expensive to install.

Alternatively, the frame of the rafts used at Ocean Gold could be constructed so as to be higher above the water's surface. For instance, birds are unable to hop over the sides of rafts on farms in the Puget Sound area mainly because the raft frames rise 2' above the waterline (I. Jefferds, pers. comm.).

A consideration in deterring birds from entering pens from the air is the amount of open water available in the pens. Farms in Puget Sound have narrow walkways spaced 0.75 m apart running the width of their rafts from which mussel ropes are suspended. These effectively block any entry from the air. Floatation buoys distributed throughout culture pens could fulfill the same function. However, the buoys used as floatation for the culture panels at the Ocean Gold site were often clustered only in those parts of the pens being used for grow out, leaving large spaces of open water in other parts of the pens. Entry from the air could be more effectively prevented by ensuring a more even distribution of buoys at all time. A spacing of 1-1.5 m throughout the pens would likely be sufficient to deter birds from landing. This may require additional buoys to those used as floatation for mussel ropes or panels.

4.1.3. Human presence

The apparent reluctance of birds to approach or dive from the east side of the raft indicates that human presence had a significant effect on bird activity around the site. This suggests that regular activity on the site may enhance the deterrence effect of a predator protection system. The almost constant presence of operators and staff, many of whom live on site, at farms in Puget Sound is probably a major factor in deterring birds (I. Jefferds, pers. comm.). However, this negates one of the attractive features of shellfish culture; i.e., that the farm stocks do not need to be fed or maintained on a constant basis. Effective, self-sufficient predator protection is a key ingredient to preserving this feature.

4.2. Significant Behavioural Characteristics of Diving Ducks around Mussel Farms

Several characteristics of the behaviour of diving ducks around mussel farms emerge from this study as well as from the literature and anecdotal information. These characteristics influence the effectiveness of predator protection methods.

- Diving ducks that feed primarily on mussels display a preference for cultivated stocks over wild populations (Milne and Galbraith, 1986). Cultivated mussels have thinner shells, higher length/width ratios and higher dry/wet weight ratios than wild mussels. Furthermore, mussels are of uniform size on a farm, such that an entire crop falls within the size range (20-30mm) preferred by scoters for a significant length of time. As such, mussel farms provide "a concentration of suitably sized mussels within a small spatial area... they represent a network of small but rich food patches" (*ibid.*: 2).

  In our study, it is conjectured that the scoters feed first on unobstructed sources of mussels around the site, but as these are grazed down, they become increasingly interested in the mussel stocks within the pens (R. Baden; pers. comm.). Putting up a barrier in the form of predator nets countered the effects of this shift from wild to cultivated stocks to some extent. The general implication is that cultivated mussels must still be protected even if wild mussels occur in abundance around a farm.

- Many farm sites are subject to a turnover of birds that reflect migrational patterns as well as local movements (Milne and Galbraith, 1986). In British Columbia, scoters are most abundant from November to April, using the coast as migration routes and wintering grounds (Vermeer, 1981; Vermeer *et al.*, 1983). There is an additional peak in number of birds in certain areas in the summer when post-breeding birds return to the coast to moult (Savard, 1988). The resulting turnover of birds through a farm site implies that any protection measures should be pulsed to match the arrival of the groups.

- Several species of diving ducks display faithfulness to traditional sites for nesting, moulting, and overwintering (Milne and Galbraith, 1986; Savard, 1988). In addition, the presence of birds at a site may attract more birds, and normally migratory birds may become resident around farms. Numbers of birds have increased with successive years of cultivation at a number of farm sites (Myers, 1980; Milne and Galbraith, 1986; I. Jefferds: pers. comm.). Farmers in Puget Sound claim that an initially low seasonal population of scoters has grown in 10 years to a year-round population of 1000 birds (I. Jefferds: pers. comm.).

These phenomena have two important implications for mussel farms. The first is that new operations should avoid areas traditionally used by large populations of mussel-eating bird species. The second is that mussel farms themselves may become sites of traditional use. For example, juveniles that are excluded from natural areas of traditional use may use a farm site instead, to which they return as adults, thereby establishing a new "traditional" area. To try to avoid this behaviour, farms should have preventive measures (e.g., predator nets, fences, regular attendence on site and scaring measures) in place before cultivation starts.

- Milne and Galbraith (1986) observed that eider ducks altered their feeding routines in response to scaring tactics. Scared birds fed in shorter bouts with fewer dives/bout and shorter dive and inter-dive periods. The authors pointed out that this did not suggest that fewer mussels were being removed, as the birds were likely simply removing mussels more quickly. They did suggest, however, that this change in behaviour could be exploited by combining scaring techniques with physical barriers, such that a higher percentage of the 'scared' time spent near the culture structures would be occupied with breaching the protection. This may be sufficient to discourage a greater number of birds from trying to feed on mussel stocks.

4.3. Comparison of Predator Protection Methods

Predator protection methods fall into 4 categories: removal, scaring, exclusion, and modification of farming methods to allow for predation (Table 4).

There has been little documentation of the use and effectiveness of removal of diving ducks from around mussel farms, although it likely does occur on an *ad hoc* or emergency basis. Milne and Galbraith (1986) suggest that if necessary, culling those birds that are habitually frequenting a farm may have some effect in terms of discouraging the establishment of the farm as a traditional site. They point out, however, that culling would likely be unsuccessful as a strategy for controlling predation by migrating populations due to the high rate of turnover of these birds.

In general, scaring measures have an immediate but short-lived effect in both the short and long term. Birds learn to ignore most scaring tactics unless they are regularly reinforced with a negative outcome. Scaring used in association with exclusion, however, enhances the effect of the latter measures.

Excluding birds from cultured mussels, both from the surface and underwater, appears to be the most feasible approach to long term protection. It is generally felt that underwater nets can be effective but also costly to install and to maintain; with extensive

TECHNIQUE	SUCCESS	LIMITATIONS
DETERRENTS:		
Chasing	- scares birds off and generates 'scared' behaviour.	- requires repeated applications. - expensive in labour and fuel costs; can be reduced by organizing regular activities around the site to maximize a chasing effect.
Shooting cartridges from gun or .22	- loud bang and flare initially scares birds off.	- birds acclimatize; hence, short-lived effectiveness without reinforcement. - labour intensive and expensive.
Automatic gas guns (cannons)	- initially scares birds off.	- birds acclimatize: hence, short-lived effectiveness without reinforcement. - noise pollution.
Recorded distress calls	- initially alarms birds.	- birds acclimatize; hence, short-lived effectiveness without reinforcement.
Remote-controlled mechanical models (eg. boats, seals)	- scares birds off for short distances. - can control up to 1 km away in good weather and hence, can replace manual chasing to some extent.	- birds return quickly without repeated applications. - of limited use in rough weather and poor visibility. - requires expertise to operate effectively.
Aerial models	- most are helium-filled kites resembling birds of prey; scare birds off to some extent.	- birds became habituated. - design weaknesses make most models unsuitable for use in coastal conditions.
EXCLUSION:		
Horizontal surface nets on longlines	- 10m-wide strip of 70 mm polypropylene floating net placed along longlines. - reduces damage by "scared" birds in that birds are too wary to approach lines. Only 11.9% damage vs. 100% on unprotected lines.	- "non-scared" birds are not deterred; hence, prior or simultaneous scaring is essential for effectiveness. - expensive for dispersed, long-line culture.
Horizontal surface nets around rafts	- 5m-wide net laid around perimeter of raft, anchored to buoys at each corner. - some reduction in numbers of birds feeding on raft.	- birds learn to dive under net. - use of scaring techniques could increase effectiveness.
Plastic skirting around rafts	- plastic strips hung from raft deck to 25 cm below water; strips flap in wind. - effective for 3-7 weeks with "scared" birds.	- birds, especially when not scared, can become slowly habituated. Periodic scaring enhances effectiveness.
Vertical netting around rafts	- 70 mm mesh net hung to 5 m depth. - reduction in number of birds at site. - 9% loss of mussels vs. 74% on unprotected raft. - no significant decline in growth rates in mussels caused by presence of net.	- birds will dive on protected raft once unprotected alternative food is gone, but dive durations increase significantly.

Table 3: Predator protection methods tried on mussel farms; summarized from Milne and Galbraith (1986).

FARMING METHODS:		
Alternative food supply	- spatfall of "feed" mussels provided on open rafts or longlines prior to stock rafts being established. - birds feed preferentially on "feed" rafts before moving to "stock" rafts.	- "feed" rafts must be in place prior to stock rafts so that birds become established in feeding habits; stock rafts must be protected from outset to maximize effect. - for farms already experien-cing damage, "feed" rafts must be placed close to stock in order to attract birds away from habitual site. - long-term effect may be to draw increasing numbers of birds to area.

Table 4 (*continued*)

longline mussel culture, such costs may be prohibitive (Milne and Galbraith, 1986). In addition, without proper attention to net configuration (e.g., avoiding the use of nets covering the surface of pens), the use of predator nets can lead to bird entanglement.

Adapting farm practices to allow for a certain amount of mussel predation by, for example, providing "sacrificial" crops appears to be effective if properly timed with the establishment of harvestable crops. However, there is debate as to whether this practice simply attracts more birds to the site and leads to larger predation problems in the long term (Milne and Galbraith, 1986).

Another possibility in adapting farm practices is to suspend mussel crops at depths greater than the birds are able or willing to dive (R. Baden, pers. comm.). In British Columbia, this would mean seeding culture ropes in the summer at regular depths when scoters are not around, and then dropping the grow-out structures to 13 m or more in the fall as the birds return. The increased depth would cause slower growth rates in the mussels, such that harvest would have to be delayed by up to 6 months to attain marketable size. However, the initial delay in harvest returns may be more than offset by the reduction in costs of installing and maintaining predator protection structures. It could also mean that mussels could be cultured on longlines rather than having to use the more costly rafts in order to protect the stocks from predators. This option, however, requires research into the maximum depths to which scoters will dive and into reductions in growth rates in mussels with increasing depth.

5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are derived from the results of this study and from comparing these results to information gathered from the literature and from discussions with mussel farm operators in British Columbia and Washington State.

- Prospective mussel farmers should avoid establishing sites in areas that are traditionally frequented by concentrations of scoters. In British Columbia, this applies particularly to scoter wintering and summer moulting areas.

- It is generally agreed that protective measures are needed in order to avoid high losses of cultured mussel stocks to scoters in British Columbia. This requires the use of raft culture, as rafts are much easier to protect than longlines.

- The experiences reported in the literature and by west coast farm operators indicate that protective measures should be in place from the start of farm operation. This prevents birds from establishing the site as a traditional area of use.

- Underwater nets are currently considered the most effective method for protecting mussel stocks grown in raft culture from diving duck predation. To deal with scoters preying on mussel farms in British Columbia, our study indicates that the depth of such nets should be at least 9 m (30'). In order to avoid entangling birds, mesh size should be no greater than 10 cm (stretched dimension). The colour and gauge are less important except in terms of relative cost and durability.

- It has been generally found that underwater nets are not feasible for protecting farms that use extensive longline culture. In these situations, operators have to rely on deterrence techniques, such as chasing and shooting, on an intensive basis during times of high bird presence.

- An alternative to the use of underwater nets proposed by a British Columbia mussel grower is to grow mussels at depths greater than the predatory birds are willing or able to dive (greater than 12 m or 40'). The reduced growth rates and longer times to harvest may be offset by the absence of expenses associated with installing and maintaining predator protection structures. This option, however, requires research into maximum diving depths of scoters and decreases in growth rates in mussels with increasing depth.

- Bird access to the rafts from the surface of the water and from the air must also be prevented. Past experience at the Ocean Gold farm shows that horizontal nets covering the surface of the water inside a raft should not be used, as these lead to entanglement of birds that come to the surface beneath them or that attempt to fly into the raft. Our study shows that a net fence on top of the raft frame and running around the perimeter of the raft can prevent birds from hopping over the frame. However, it was difficult to adequately support the net fence against winds and movements of the raft. An alternative method employing several lines of rope or wire spaced 10-15 cm apart, with tape or streamers attached to them to enhance the visual effect, is suggested. Alternatively, the raft frame itself could be constructed so as to rise at least 0.5 m above the water. Placing buoys, floats or other above-water structures throughout the pens at 1-1.5 m intervals should deter birds from landing or taking off within the pens. A combination of these measures should be effective in preventing bird access from above water.

- Studies conducted in Scotland indicate that exclusion measures have greater effect on "scared" birds than on birds that have no experience of being chased away. Those studies suggest that scaring techniques should be applied frequently when birds first appear on the site, to discourage the development of feeding behaviour and augment the effect of exclusion measures. Experience in out study and on farms in Washington state indicates that human presence serves to deter birds and enhance the overall effect of physical barriers. Normal activities around the site can be organized to maximize deterrence effects.

- The cost of predator protection versus the benefits reaped in terms of increased harvest is as yet difficult to assess in British Columbia due to the youth of the mussel culture industry and newness of the predator problem. Rough estimates indicate that a predator net system may cost in the order of $1000.00 per 10x10 m raft, exclusive of labour. This may represent 16-33% of the gross revenue from the first crop (18-24 months) from a raft of this size, but may be only 4-9% of the gross revenue of harvests over 8 years (the presumed life expectancy of a predator net).

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