Aquaculture risk management and marine mammal interactions in the Pacific Northwest

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Abstract

This paper reviews current aquatic farm production in the USA and estimates an annual financial exposure of US$350 million in the marine and coastal environments made up of sales, standing crop value and capital investment. In addition, nationwide aquatic farming creates almost 200,000 jobs and, with secondary and downstream activities combined, contributes about US$5600 million to the GNP. The paper then reviews the increasing risk that elements of the coastal aquaculture industry in the Pacific Northwest face from interactions with populations of marine mammals. These are particularly California sea lions and seals, which have greatly increased in the last 20 years from California to British Columbia. Specifically: (i) shellfish from traditional beds have been contaminated by fecal coliforms from seals and made unfit for human consumption, and have been experiencing increasing losses to river otters and sea otters; (ii) culture-based salmon fisheries, including endangered salmon stocks, have been exposed to heavy predation by sea lions and seals, resulting in both direct losses and reduced market value of wounded survivors; (iii) net-pen farms have been exposed to the same heavy losses from predatory sea lions and seals attacking fish in the pens, together with added financial burdens for anti-predator nets, increased maintenance and labor; and (iv) workers in aquaculture and fisheries, and other waterborne industries, have been observing less fear of humans by sea lions and seals, and more direct damage to servicing facilities. The four issues are discussed both technically and economically, and a number of solutions proposed for managing and controlling these increasing risks. © 2000 Published by Elsevier Science B.V.

Keywords: Aquatic farming; Marine mammals; Pacific coast

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1. Aquaculture production in the USA

Aquaculture is no longer an artisan craft of rural people. It is a vital economic sector operated by professional managers, scientists and engineers. On a global basis aquaculture products are worth almost US$50,000 million annually, and the industry provides almost half the fresh fish and shellfish consumed by the public (FAO, 1999).

Aquaculture technologies have diverse uses in the USA, but predominantly they raise fresh seafood for human consumption by either (i) farmed production of fish and shellfish, or (ii) enhancement of indigenous fisheries.

1.1. Farmed production of fish and shellfish

Annual production from aquatic farming in the USA has remained consistently between 350,000 and 400,000 metric tons (mt) for a decade. This is because declining shellfish production has been offset by increased fish production. Aquaculture products for human consumption have a current value of around US$736 million (FAO, 1998), and the industry overall is estimated to contribute about US$5600 million annually to the national GDP (Dicks et al., 1996).

The freshwater environment supports about 65% of all farmed products, mostly catfish, baitfish, rainbow trout and crayfish produced in ponds or raceways. The marine environment supports the rest, with 30% for shellfish and 4% for diadromous fish.

In the marine environment over 70% of production is sessile molluscs (such as oysters, clams and mussels) farmed in traditional tidal beds in large estuarine flats or suspended from floating rafts. Another 15%–20% is crustaceans (shrimps and prawns) farmed in coastal ponds provided with pumped seawater. The remaining >10% is salmon, raised in coastal net-pen enclosures anchored in deep water for good tidal interchange.

Expressed in financial terms, aquaculture enterprises operating in the coastal/marine environment have an annual exposure of about US$350 million, made up of current values of aquatic livestock on site, and capital assets (Fig. 1). The aquaculture business in the USA provides about 16,500 primary direct jobs (in production) and a further 40,500 secondary direct jobs (in support activities related to equipment, feed, fertilizer, financing, etc.). There are another 125,000 jobs downstream, in transport, processing, storage, sales, etc. Although these figures are based on 1992 data (Dicks et al., 1996), the present industry probably still creates 180,000–200,000 jobs.

1.2. Enhancement of indigenous fisheries

Many commercial fisheries are enhanced by propagation and release of juveniles from production hatcheries. The most valuable culture-based fisheries in the world are for caviar-producing sturgeon, particularly in the Caspian Sea, and for Pacific salmon in all Northern Pacific Rim countries (USA, Canada, Japan and the Russian Federation). In the USA public and private-non-profit hatcheries in Alaska release annually some 1200...
million juvenile salmon (mostly pink, chum and sockeye species) with an estimated 20–40 million adult-return to coastal fisheries. Public hatcheries in Washington and Oregon release about 500 million juveniles, with about 2–3 million returns (Heard, 1996).

Economic benefits of salmon enhancement vary considerably from country to country but, other than Japan where there is little sport fishing, viability in North America depends on a mix of values from commercial and recreational fishing. Using figures of 16%–30% of the total salmon harvest (U.S. Department of Commerce, 1998), the value of the commercial culture-based fishery in the USA is US$60–115 million. In the recreational fishery the value of salmon to the economy is about US$22 per fish (1992 data).

2. Risks to the industry from marine mammal interactions

Marine mammals are a risk to the aquaculture business in many ways. Typically, business risks are consumer-related, market-related, or production-related (Nash, 1995). The current risks of marine mammals for aquaculture are market-related (as they affect the quality of the product in some way) and production-related (as they affect some daily operations). They are found in the industry’s sub-sectors of:
- Shellfish farming,
- Enhanced or culture-based fisheries,
- Net-pen farming.
- Human resource management.

On the Pacific coast of the USA and Canada, the principal marine mammals that interact with aquaculture and the local fisheries are the California sea lion (Zalophus californianus), together with the harbor seal (Phoca vitulina) and Steller sea lion (Eumetopias jubatus). The river otter (Lontra canadiensis) interacts more with fish than the sea otter (Enhydra lutris), which prefers shellfish. On the Atlantic coast it is the harbor seal and gray seal (Halichoerus grypus). In Norway, otters and certain birds cause the greatest interactions, but harbor, gray and harp seals are also a problem, together with mink.

2.1. Shellfish farming

A small operational risk to shellfish farmers is the direct loss of product. Both natural and farmed shellfish beds suffer some predation by marine mammals. Sea otters are primary predators of clam beds. However, the risk of large crop losses to sea otters and river otters is currently very small. The more serious risk is market-related, and concerns the danger of selling a product unfit for human consumption and possibly endangering life. Some shellfish farms are becoming increasingly more threatened by microbial contamination from the growing populations of harbor seals.

Sessile shellfish, such as oysters, mussels and clams, are efficient filter feeders and concentrate large numbers of aquatic microorganisms in their bodies. Those organisms toxic to man, such as fecal coliform bacteria, may be built up to levels serious to human health. Most incidents of fecal contamination of shellfish production beds are attributed to 'rural non-point' sources of human and animal waste, such as poorly maintained septic systems, run-off from farms and illegal discharges from boats, but harbor seals contribute to fecal contamination at several shellfish growing areas in Washington State (Calambokidis et al., 1989); and they have been the principal cause of one site becoming 'restricted' (WDH, 1988). In this State no other marine mammal but the harbor seal has been implicated in fecal contamination, but studies only began a decade ago.

Because of such risks to human health, all shellfish beds have been rigidly monitored for decades, and are classified by individual state health authorities. In general, beds 'approved' for harvesting must not exceed specific levels of contamination, particularly threshold levels of fecal coliform bacteria. Other 'conditionally approved' beds meet standards but are subject to intermittent but predictable contamination, when they are closed. Other 'restricted' beds do not meet standards, but a commercial harvest can be relayed to approved areas for a period to make the shellfish safe; and they are closed permanently for recreational fishing. Others never meet standards, as fecal bacteria, pathogenic microorganisms, marine toxins and poisonous or deleterious substances are present in dangerous concentrations, and therefore all commercial and recreational fishing is 'prohibited'. In the State of Washington, for example, there are 77 commercial shellfish-growing areas classified as follows:

<table>
<thead>
<tr>
<th>Total shellfish-growing area</th>
<th>81,500 acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Approved' areas</td>
<td>52,000 acres</td>
</tr>
</tbody>
</table>
‘Conditionally approved’ areas
2600 acres
‘Restricted’ areas
15,000 acres
‘Prohibited’ areas
11,000 acres

Sessile shellfish farming is a major contributor to the seafood business in the USA, but the annual harvest continues to decline slowly. Coastal development and associated pollution have caused continuous devastation throughout the historic oyster industry in the country. Production of the native American oyster (*Crassostrea virginica*) along the length of the Atlantic seaboard and Gulf of Mexico is now about one-tenth of its peak in the 1920s, and production of the Pacific oyster (*C. gigas*) is only just holding its ground. Particularly worse hit have been the once-large oyster beds in Chesapeake Bay and San Francisco Bay. The small production of clams is mostly based on the indigenous hard clam (*Mercenaria mercenaria*) along the eastern and southern seaboards, and the accidentally introduced Japanese carpetshell or Manila clam (*Ruditapes philippinarum*) on the west coast, but the industry has not maintained the early steady growth. Mussel production is new and remains small, and is confined to the colder waters of New England and Washington State. Consequently, the weakening shellfish industry is not ready to face any new public health risks from growing numbers of seals around the coast.

2.2. *Enhanced or culture-based fisheries*

The business risks to the culture-based fisheries, which are almost entirely salmonid fisheries, are operational risks. Governments in the country at all levels collectively invest many millions of dollars annually on salmonid enhancement. Many of the cultured fish, both out-migrating juveniles and returning adults, are victims of many different predators, particularly other fish and birds. For example, Ruggerone and Rogers (1992) estimated that juvenile coho salmon in Chignik lake, Alaska, consumed an average of 59% of the sockeye salmon fry over a period of 3 years; and Wood (1987), working on the east of Vancouver Island, estimated that the mortality rate due to mergansers, which consume about 400 g of fish/day, was unlikely to exceed 8% for any particular stock of Pacific salmon during seaward migration.

The growing numbers of California sea lions, seals and otters in the near-shore waters of the Pacific coast unaccountably inflict additional losses in both wild and culture-based fisheries. A study (NOAA, 1997a,b) by a working group established by the National Marine Fisheries Service estimated the average biomass consumed each year by Californian sea lions in greater Puget Sound waters was 830 mt from 1986 to 1994. Because of the increased population the estimate for 1995 was 2064 mt, and in the lower Columbia River it was 390 mt. Similarly, the annual biomass consumption by harbor seals in inland waters of Washington State in 1993 was 5814 mt, and in the lower Columbia region it was 3851 mt. The study estimated that these two pinnipeds in all waters of Washington, Oregon and California consumed a minimum of 217,000 mt of prey species in 1993, which was almost half the total commercial fisheries catch of the three Pacific states put together (Fig. 2). Dolloff (1993) estimated that two river otters and their two young consumed 3300 juvenile salmon in a 6-week period.
Although pinnipeds are opportunistic predators, consuming a variety of fish and squid, the impact of their predation on a single fishery can be devastating. Studies at the Ballard Locks in Seattle revealed that California sea lions predated an estimated 2604 steelhead fish in 1986–1987. As this is a small fishery (an average of about 2500 fish return to Lake Washington each year), the sea lions took about 43% of the total combined run of wild and hatchery fish returning (Gearin et al., 1988). By 1989 it had reached 65%, giving concern that such a consistently high level would do unrecoverable damage to the winter steelhead run (Gearin et al., 1989).

In addition to the direct loss of salmonids to predators as they move through coastal waters, the fish suffer a further loss in the supposed safety of inland waters. This is the delayed mortality for one reason or another from wounds and scars inflicted by marine mammals as fish aggregate at specific sites, such as weirs, dams, locks and fish ladders. Because of the importance of Pacific salmon fisheries in North America, good statistics are maintained with the help of tags and automated recorders at reference points. For example, salmon returning to the Columbia and Snake River systems are counted through the Bonneville Dam; and steelhead entering Lake Washington are counted at the Ballard Locks. Park (1993) reported discrepancies between numbers of fish at reference points in the Columbia and in terminal areas upstream, and that 378,400 adult salmon and steelhead trout were unaccounted for above the Dam.

One explanation for the increasing numbers of ‘missing’ fish in inland waters may be the result of increased predation by pinnipeds. Harmon et al. (1994) recorded annual incidences of scarring from the teeth and claws of pinnipeds between 14.0% and 19.2% of spring–summer chinook and 5.45%–14.2% of steelhead returning to the Snake River from 1990 to 1993. Fryer (1998), recording abrasions (wounds or scars) on fish for the years 1991–1996 at the Bonneville Dam, reported increases in the numbers of adult sockeye abraded from 2.8% to 25.9%, and of spring–summer chinook from 10.5% to 31.8%. Similarly, data from nine hatcheries for winter steelhead in Oregon record incidences of between 10% and 53% (Fig. 3).

Furthermore, returning salmon do not escape continuing predation in inland waters. There are increasing reports of pinnipeds moving far upstream, and remaining in rivers...
throughout summer months when the adult fish are returning; for example, California sea lions are visible 145 miles up the Columbia River at the Bonneville Dam (NOAA, 1997a,b).

2.3. Net-pen fish farms

Almost every net-pen marine fish farm in the USA produces diadromous salmonids. Hence, such farms are confined to New England states and Washington State. However, research and development projects with marine species held in net-pens or sea cages are taking place around the coast (for example, flounders in New England, dolphinfish in Hawaii, abalone in California).

Current business risks to net-pen farmers from marine mammals are both production and market-related. The former concern lost production from predators and escapement; the latter concern lowering the quality and hence the value of the product. Production lost to marine mammals from net-pens occurs in several ways. Firstly there is direct predation, which is readily accountable. The higher freeboards and net strength of modern net-pens now make it more difficult for any marine mammal to get inside a net-pen to consume fish, but incidences still occur. Tillapaugh et al. (1993) (unpubl. data) observed the predators working in groups. They wait until fish are herded into a corner by the movement of the pliable net in the undulating waves, then they attack by pushing against the pliable net wall and pin fish against an opposite wall where they can be bitten. Mostly the larger fish in the populations (400–800 g and 1–3 kg) are attacked. The majority dies almost immediately, their livers and soft bellies eviscerated. However, the authors note the attacks are numerous and can be prolonged.

Secondly, lost production is in the form of lost body weight of the fish. The stress on a population of fish subjected to repeated attacks by predators shows itself in poor feed
conversion efficiency and hence the weight at harvest is not maximized. Stress may also manifest itself in exposure to disease. Surveys in farms in Maine in 1992–1993 (NMFS, 1996) reported that outbreaks of Hitra, a cold water bacterial disease, started and had the greatest impact on pens already being attacked by seals, and that such pens had a 4%–5% increase in disease-related mortality.

Thirdly, lost production is also in the form of escapement. Fish frequently escape from net-pens through holes in the walls made by marine mammals biting through the mesh fabric. Invariably they remain in the vicinity of the farm complex, waiting for feed, and become easy victims of predators.

Any one of these three types of losses can be disastrous to a producer. In the sea lion season in Puget Sound, for example, one farm lost 86,000 salmon in 1996 through bites alone (not escapees through holes), and another 114,000 fish in 1997. The farm later went into receivership. In Canada, salmon losses from predation mortality and escapes due to predator net damage accounted for nearly 200,000 fish in 1989 (Ruggeberg and Booth, 1989), or 1% of total production. By 1996, total predation costs were estimated as high as C$10 million (EAO, 1997). In Tasmania, Australia, 235 attacks by male fur seals were recorded in 4 months on 15 farms producing Atlantic salmon and rainbow trout, and one farm lost more than A$500,000 of fish in 1 year (Pemberton and Shaughnessy, 1993). More recently, the loss by the industry to pinnipeds has been estimated by the Tasmanian Salmonid Growers Association at 2% over a 6-month period, and predators accounted for between one-third and two-thirds of all losses from net-pens.

The difference between losses through predator mortality and escapes is important, as livestock insurance policies held by most farmers carry a large deductible. In the Gulf of Maine region, representatives of the Atlantic salmon industry made the unsubstantiated claim that 10% of farm-gate value of US$50 million was lost (NMFS, 1996). Records provided by an insurance broker for 1994 indicated that claims of predator-related losses amounted to just over C$1 million, of which about 25% was incurred in Maine. This would amount to less than 1% of the state’s production that year. However, the share of the insurance business by this broker was not known, and all claims are in excess of deductibles and claim thresholds. These can be as high as 80% of the value at risk in the cage. Therefore many small but regular losses, which are substantial in total but less than 80% of the number of fish in the cage, go unrecorded. Even so, about 50% of claims submitted to a major insurance broker since 1988 have been to cover losses attributed to predators (NMFS, 1996). Claims by BC farmers for holes-in-nets increased from 10% to 20% over the 3 years 1995–1997 (BCSFA, 1998), with predators as the main cause.

On the other hand, one insurance company in Norway paid only two losses due to predators in 1996 (NoK 1.2 million), and 1 in 1997 (NoK 0.52 million). Although many losses are either not claimed or not paid (T. Thorsen, Vesta Forsk, Norway, pers. comm.), as livestock policies carry a large deductible (about 20% of the value of the sum insured in the cage), the reason for the fewer claims is that licenses are not required for shooting gray seals or harbor seals in the hunting season, and only reports of kills are required out of season. In Canada, the killing of offending individual pinnipeds that cannot be deterred by non-lethal predator control methods (all of which must be
recorded is permitted by the Department of Fisheries and Oceans. Reported kills of the three most common predators (harbor seals, California sea lions and Steller sea lions numbered 3854 from 1989–1996, inclusive (Department of Fisheries and Oceans, Canada, unpubl. data).

The market-related risk is the lowering of the final quality of the harvested fish. Fish that have survived an attack, but are badly marked or scarred lose their full market value. The dress-out weight is lower than normal and the fish are processed as pieces instead of two prime sides for smoking.

Any factors that affect production and economic return are of fundamental importance to any business enterprise. In the salmon farming business they have recently become acute. With farm-gate prices of Atlantic salmon having fallen from over US$5/lb to well below US$3/lb (not dressed out), profit margins are now thin. Consequently, losses have become increasingly more significant, and additional operational expenses of US$50,000–100,000 annually for divers to repair nets damaged by marine mammals are not welcome.

2.4. Human safety

Finally, the last production-related risks from marine mammals concern the safety of the human resources working on aquaculture sites. These are classified here as technological risks as there is not the information available or the technological equipment for humans to deal with the behavior of marine mammals.

Firstly, many more California sea lions and seals throughout the Pacific coast of Canada and the USA are becoming less frightened of humans (NOAA, 1997b). The animals are becoming bolder, and Pemberton and Shaughnessy (1993) indicated that shooting was not an efficient deterrent. Anecdotal reports of increasing aggression are being given not only by fishers and employees in aquaculture enterprises, but also by people working in other water-borne activities in the vicinity of marine mammal populations. At net-pen fish farms, male sea lions have been known to attack divers working on nets. Mostly the sea lions bite or pull at the flippers of divers, but incidences of biting on the body have been reported, particularly once the predator is inside the net-pen.

The rapid population growth of sea lions and harbor seals is probably one reason for their changing behavior. Pinnipeds are known to establish social hierarchies for breeding behavior and dominating haul-outs, and the same may be true for males in a social group in a small feeding area. Salmon aggregating at fish weirs or locks, or concentrated in net-pens, are easy prey. This is again manifested in dominance by some individuals. NMFS (1992) described the dominance of a California sea lion, called Herschel by the media, at Ballard Locks in Seattle.

Fewer incidents of aggression towards divers and workers have been recorded around shellfish farms, although the numbers of seals at some oyster and mussel farms have increased. The seals use the floating rafts as haul-outs, and have been known to give birth to pups on them (G. King, Taylor Shellfish, WA, pers. comm.). Unlike salmon in net-pens, mussels are not a food source for the seals, and so this is probably the reason why their behavior is less aggressive.
Finally, marine mammals do accountable physical destruction to property wherever they are. In addition to the damage inflicted on nets and floats at farm sites, they haul-out on boats and docks at marinas and even sink small boats with their weight. At fish landings they are known to haul-out on the wharves ready to take fish and bait.

3. Managing and controlling the risks

3.1. The market-related risks

3.1.1. Public health and safety

With increasing populations of marine mammals in all coastal waters, it is possible that there will be more incidents where they are found to be secondary or possibly primary contributors of fecal coliform contamination of shellfish beds. This would result in downward reclassification of the beds and possible closure. However, in the present environment this is not likely to be allowed. Healthy shellfish beds are microbiological indicators of the health of coastal waters, and their harvests for human consumption are a political indicator of the concern and effort made by a government to protect the aquatic environment. A goal of many state health authorities, for example, is to restore growing areas of once-abundant shellfish to harvest condition, and any closure of the beds would be a failure of their policies.

The risks of contaminants in shellfish to public health and safety in the Pacific Northwest are currently handled simply and effectively by wet storage or relaying products through other approved zones. In Europe, on the other hand, many producers and consumers prefer the costly depuration process with chlorinated or ozonated water, but the process is not approved in most states. Any post-harvest handling adds to the production costs, and the low consumer demand for shellfish in the USA, compared with the large markets in Europe, makes profit margins thin. Therefore, the risk to the industry in Washington is the downward classification of the shellfish beds through fecal contamination from whatever source. Prolonged relaying of products, and costly monitoring, could quickly unbalance the national industry.

Unfortunately there is no simple solution for protecting recreational fishers from the increasing risk of coliform contamination from shellfish. Wet storage or relaying of each small harvest is not a practical solution, although in Europe (France and Italy), some depuration plants service recreational fishers. Therefore, for the most part, the risk to the general public who gather shellfish recreationally will be managed by the public health authorities. These vigilantly monitor coastal waters for many parameters and have the responsibility of keeping open the beaches and shellfish beds.

With the increasing incidences of coliform contamination in meats, poultry, fish and shellfish, which have caused serious illness and even death among young children and older people, research has made it possible to fingerprint coliforms and to identify the source. However, the accuracy of the identification depends on a historical database. This can only be built-up with effort and time, and so far attention has been predomi-
nantly in urban and inland regions, and not with animals and birds around the coasts. Therefore, this omission might be rectified to help resolve any problem with marine mammal coliforms in shellfish.

3.1.2. Product quality

The solution to avoiding the loss of product quality of fish, following wounding and/or scarring by the teeth and claws of marine mammals, is the physical separation of the two by well-engineered structures. Some ways to achieve this are described more appropriately in the following Section 3.2.

3.2. The production-related risks

3.2.1. Lost production

The fish farming industry, on its own, is gradually reducing production losses caused by marine mammals. Its success is being slowly achieved by a combination of deliberate measures to reduce the opportunities for predators to kill or wound fish, and the advances in technology characteristic of a growing industry.

The short-term solution for net-pen complexes and fish aggregation sites in the vicinity of marine mammal colonies is the engineering of improvements to guarantee separation of the prey from the predators. Such improvements include:

(i) tensioning net walls or barriers to make them as rigid as possible,
(ii) surrounding complexes or individual units or aggregation sites with improved predator nets, typically heavy-duty black nylon mesh,
(iii) using better deterrents around the floats and walkways (net, high freeboards, etc.),
(iv) redesigning the complex to avoid narrow passageways between tightly packed units, and where mammals may get trapped.

All these measures are becoming easier for farm enterprises to carry out as net-pen units have increased substantially in size with growing economies of scale. In some cases there is a saving in cost. With large and deep complexes (200 × 100 m), the cost per unit of predator barriers is reduced and, even if marine mammals get through this first barrier made of 3–6 mm diameter twine, the rigidly held walls of the net-pens do not flex as much and avoid exposing fish to danger.

The long-term solution is for net-pen farm complexes to move away from coastal haul-outs and rookeries of marine mammals. Ideally, a farm should move as far away as possible, although a complex of anchor-tensioned cages in New Brunswick located about 200 m from a haul-out experienced no predation (G. Loverich, Ocean Spar Technologies, WA, pers. comm.). Offshore relocation is now a more feasible solution, as the new generation of oceanic farms is moving away from gravity cages and sheltered water technology. The modern higher class cages are built around a system of spar-buoys and more rigid net panels. The buoyancy is therefore below the surface, replacing the need for large floating collars supporting the old net bags which flexed with the tide (G. Loverich, Ocean Spar Technologies, WA, pers. comm.). Fish farms in Norway are already moving further offshore in the search for high-quality seawater and to avoid the annual risk of algal blooms.
But moving net-pen complexes further offshore is extremely costly and high risk, and will not be for every investor. Net-pen farms remaining within the protected coastal region will depend on practical measures to deter predators. One option is to construct fencing entirely around the farm. This was done in Tasmania, with ca. 10 m pilings driven into the bay, to keep out Australian fur seals. Another option is to reduce the numbers of marine mammals in the vicinity of shellfish beds and aquaculture sites. This could be done, for example, by removing or fencing off haul-outs, relocating animals, licensed shooting of individual rogue animals, and a regional culling program.

Although the direct benefits of these options to the aquaculture and commercial fishing industries would be significant, such practices would not appeal to everyone. Some people think that relocation only spreads the health risk from coliform bacteria and others believe that populations of some species are still below strength. On the other hand, the data show that the numbers of marine mammals are increasing rapidly. For example, the population of California sea lions on the west coast of the USA (Fig. 4) has been growing at a rate of 8.3% per year (NOAA, 1997a,b). The minimum population estimate is over 111,339, according to the 1995 census (Beeson and Hanan, 1996). Similarly, the minimum population estimate of harbor seals in the inland waters of Washington State in 1993 (Fig. 5) is 15,349 (NOAA, 1997a,b). On the coasts of Washington and Oregon the estimated number for 1993 is 27,131. Between 1983 and 1992, the stocks increased at an annual rate of 5.5%. On the east coast, the US population of harbor seals was estimated to be 28,810 (NMFS, 1997a), together with 1200 gray seals. In Canadian waters the numbers are nearing historic levels (Olesiuk, 1995).

The numbers of predatory pinnipeds in the proximity of aggregations of fish are now too large to consider effective relocation. In Tasmania a system was managed by the

Fig. 4. California sea lion pup counts in Southern California.
Parks and Wildlife Service for a fee of A$500 per seal. But seals could return on average in 2 weeks over distances of 500 km, so the scheme has been abandoned (J. Purser, Univ. Tasmania, pers. comm.). Similar results were obtained with the relocation
of sea lions from Ballard Locks in Washington in 1988–1990. Twenty-nine out of 39 sea lions transferred to the outer Washington coast returned between 4 and 45 days later, and three out of six transferred to breeding areas off southern California returned between 30 and 45 days later (NMFS, 1992).

The direct interaction of marine mammals as predators in the fisheries in the Pacific Northwest is a relevant issue for future aquaculture development in the region. Within the last 20 years, the catch per unit effort for many of the fisheries of Puget Sound has rapidly declined (Fig. 6). These include the more popular targets of marine mammals, such as Pacific herring, Pacific salmon, Pacific hake, walleye pollock, lingcod and rockfish species (West, 1997). On the other hand, some species less appealing to higher predators, such as spiny dogfish, have actually increased in numbers. Similarly, among the more popular prey species, the decline of the vulnerable nest defenders (lingcod, cabezon and greenling) and the soft bodied species (herring, salmon, hake, lingcod) has been faster and more marked than the decline of hard-bodied spiny species (black, copper and quillback rockfishes). Recovery of these fisheries is exacerbated by their own predator–prey inter-relationships in addition to the growing populations of predatory pinnipeds. It is certain, however, that harbor seals and California sea lions, faced with declining natural resources of fish in the Pacific Northwest, will have to turn to other prey, such as cultured resources produced in hatcheries, or move to new areas.

3.2.2. Lack of information and technology

With the increasing interest in marine mammal behavior studies in recent years, particularly for cetaceans which have a large public following, it is possible that more will be learnt about the social behavior of sea lions and seals. Hopefully, this will lead to a better understanding of interactions within their own ecosystems and with human interventions in their environments.

Many marine mammals have been trained to respond to certain stimuli, particularly food, sound and modular behavior. Consequently, intense high-decibel acoustic deterrent devices (ADDS) were thought to be the best solution for keeping marine mammals away from net-pen farms and fish aggregation sites. In spite of their current sophistication and high cost (C$4000–16,000 per unit) they have not proved very effective (Norberg, 1998). Moreover, because the high frequencies might possibly injure some marine mammals, some ADDS are no longer advised in Canada and salmon farmers who bought them on the advice of the authorities may be compensated for their purchase.

Several non-structural deterrents have been used to keep away marine mammals, including explosives, firecrackers, bubble curtains, vocalized sounds of killer whales, models of predators and even aversion conditioning (NMFS, 1996). In theory, ADDS are the simplest and cheapest solution to the risks imposed by marine mammals on shellfish farms, net-pen farms and fish aggregation sites. In practice, however, like so many deterrents developed to keep wildlife away from food crops, their effectiveness is short-lived and mammals and birds quickly adapt their behavior around them.

3.3. The consumer-related risks

Although there are currently no risks to the industry caused by the consumer, there is the future possibility that certain management practices for controlling marine mammals,
such as the return of culling, might make certain consumers boycott seafood products. The influence of the consumer can be significant, currently illustrated by the decision of many European countries to ban or boycott genetically modified organisms.

4. Conclusions

1. In addition to their impact on wild fisheries, the growing populations of marine mammals around the coasts of North America are having an increasing detrimental impact on both culture-based fisheries and aquatic farming. The annual rate of population growth on the Pacific coast has been significant, and is estimated to be 8.3% for California sea lions, and 5.6%–7.5% for harbor seals depending on the state.

2. The impact is significant in terms of fish consumed by the California sea lion and harbor seal. The estimated consumption figure of 217,000 tons of fish (in 1993) has been compared to half the combined commercial fisheries of California, Oregon and Washington.

3. The impact is significant economically. Various authorities in different countries estimate the financial annual loss to predators by aquatic farms is between 2% and 10% of the total value of the national harvest.

4. The impact is significant environmentally. Small fisheries of endangered species and ESA-listed species are vulnerable to predators where they aggregate. Currently, the winter steelhead fishery in Lake Washington is losing 60% or more of the run each year to predators, and the fishery may become unrecoverable.

5. The aquaculture sector plays a significant role in the national economy. In addition to the production of US$736 million of seafood, the industry creates 180,000–200,000 jobs. The farming sub-sector, which is privately owned, is investing its own capital to identify solutions to the negative marine mammal interactions with shellfish beds and net-pen complexes. The enhanced (culture-based) fisheries sub-sector, which is largely publicly owned, is receiving virtually no assistance to resolve interactions with migratory stocks, other than information research.

6. The risks of negative interactions of marine mammals with several parts of the aquaculture industry (in addition to indigenous coastal fisheries) are real. Therefore, strategies for the management of both the aquaculture industry and marine mammal populations must include their increasing interactions.

References


Norberg, B., 1998. Testing the effects of acoustic deterrent devices on California sea lion predation at a commercial salmon farm. NMFS-NFWSC.


