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Viewpoint

Favored use of anti-predator netting (APN) applied for the farming of clams leads to little benefits to industry while increasing nearshore impacts and plastics pollution

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ABSTRACT

An overview of the efficacy of anti-predator netting (APN) used by the shellfish industry is presented. There is little support that the currently favored APN effectively protects farmed clams from predators. Evidence does suggest that APN leads to impacts and pollution. APN is an attractant for predators, e.g., crabs, by providing a refuge within *Ulva* sp. which attaches onto the surface of APN. APN entrains silt and organic matter and increases sediment temperatures degrading habitat underneath the APN. APN present hazards to fish and wildlife and is a source of plastics to the marine environment. The continued use of ineffective APN does not serve either the environment or industry well, and many of these issues could be addressed through the alternate use of "ancient" technology used by aboriginal people to maintain clam gardens; building of rock walls optimizing the amount of clam habitat thereby increasing numbers without the use of APN.

1. Introduction

The world's population is now at 7.2 billion and projected to reach 10.85 billion by 2100 (http://www.worldometers.info/world-population/). The recently released Global Ocean Commission Report (2104) clearly states that the high seas can no longer provide an ever growing population with a reliable source of protein. Hence, we look to finfish and shellfish aquaculture to meet that demand. At no time then, is it more important to establish environmentally sound aquaculture practices that will help meet the ever increasing demand for protein while maintaining healthy, functioning ecosystems.

Of the two, shellfish aquaculture takes a distance second to finfish aquaculture in terms of biomass produced. However, it still contributes significantly to the world's sources of protein through the farming of oysters, mussels and clams. Of the three bivalves, only the clam, *Vernerupis philippinarum* (*V. philippinarum* is also referred to as *Tapes philippinarum* and *Ruditapes philipiinarum* and goes by the common names of the Japanese carpet shell and Manila clam. Manila clam shall be used herein.) has seen a steady increase in production with global production nearly tripling from 2003 to 2011 and six fold since 1991 (FAO, 2014). By far the main producer of the Manila clam is China (97.4% in 2002). Korea, Italy, USA, France and Canada make up the remaining 2.6% (FAO, 2011). Hence, clam culture in North America is a small enterprise which contributes marginally to the global production of this source of protein. Despite this small contribution, the shellfish industry in both Canada and USA hope to increase production of the Manila clam and in doing so provide economic opportunities to the coastal communities within the Pacific Northwest coast.

The Manila clam is a subtropical to low boreal species of the western Pacific and is distributed in temperate areas of Europe (FAO, 2012). It has been farmed (or grown) intentionally for aquaculture purposes (e.g., Humphreys et al., 2007; Bendell, 2013) and unintentionally introduced to the North American Pacific and along the European coastline from the United Kingdom to the Mediterranean Basin (FAO, 2012). Concerns have since been raised as to the threat the Manila clam presents to local bivalve diversity as it continues to spread and increase in abundance (e.g., Bendell, 2013; Humphreys et al., 2007).

Production of the Manila clam is the spreading of clam "seed" when the clam is 10–15 mm in length onto the intertidal substrate at a density of 200–700/m^2 and then covering the seeded area with APN thought to protect the seed from excessive predation (FAO, 2012). APN is typically a plastic mesh of 1–2 cm aperture diameter. Correct husbandry practices include the cleaning of the nets to avoid fouling and siltation and monitoring for predators such as crabs. In China, where the majority of clams are produced, nets are not used. Nets are used however in France and Spain, on the

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Pacific Northwest of Canada, and the USA including Alaska ostensibly to prevent predation from clam eating sea ducks as well as invertebrates such as crabs (Toba et al., 1992).

Along the Pacific Northwest shellfish aquaculture is clustered in those regions that are conducive to farming activities. Thus, the quiescent bays and protected inland seas have mostly been developed for the farming of primarily oysters and clams, although now geoducks are becoming a major product farmed. Within coastal BC, arguably one of the most sensitive ecosystems along the coast (DFO, 2013; Bendell et al., 2014), Baynes Sound, is now subject to aggressive expansion of the industry, including extensive use of APN. Shellfish farming practices that include seeding and the application of APN have never been comprehensively evaluated for their effectiveness, a result of research not keeping pace with the rapid expansion of the industry along the Pacific Northwest.

Here I present an overview of the literature with respect to the use of APN for the purposes of decreasing predation of the Manila clam thereby increasing farm productivity with the objective of determining if there is evidence that supports the use of APN for this purpose. Although the focus is the Pacific Northwest, due to the paucity of studies available for the Pacific Northwest, this review draws on studies conducted in Europe and elsewhere to assess APN efficacy. The review is organized under the following headings; (1) the use of APN in shellfish aquaculture: net effectiveness, (2) influence of APN on intertidal biological attributes, (3) the influence of APN on intertidal geochemical/geophysical attributes, (4) other environmental impacts, (5) a sustainable alternative, clam gardens and (6) conclusions.

2. The use of APN in shellfish aquaculture: net effectiveness

APN is used as a standard aquaculture practice along the Pacific Northwest in regions such as Puget Sound, Baynes Sound and Alaska. Within these regions there can be extensive coverage. For example within Baynes Sound in 2001, 27% or 1.2 km^2 (ca. 225 American football fields) of the mid- intertidal area was covered by APN (Bendell and Wan, 2011). Despite its extensive use no studies have assessed net effectiveness at such large scales within the Pacific Northwest. Rather, the few studies that have assessed the effectiveness of APN for increasing clam productivity have been conducted at the experimental plot scale of m^2 (e.g., Miller, 1982; Anderson, 1982) rather than km^2 as currently practiced by the shellfish industry.

The first studies to assess APN effectiveness within the Pacific Northwest were those of Anderson (1982). Within 6 regions of Puget Sound, Anderson (1982) compared the survival of 2–4 mm Manila clam seed on netted versus non-netted plots. Nets used had an aperture of 0.25–0.5 in. Of the 6 sites, over two growing seasons, 3 showed greater survival under nets as compared to exposed, with one site having no difference, and a second with marginal increased survival. A third site had data for only one growing season. No measure of statistical variability was reported (in contrast to the studies of Smith (1996) reviewed below). These findings became the basis of a "manual" first published in 1982 by Anderson et al. (1982) and then by Toba et al. (1992), on how to farm Manila clams within Puget Sound and Washington State.

Smith (1996) determined the ability of raise Manila clams within shrimp-infested Mudflats in Yaquine Bay, Oregon. Rather than predation, the burrowing shrimp creates muddy substratum unsuitable for clam culture. Thesis objectives were to determine if using a combination of substrate modification (addition of oyster shell) and predatory exclusion devices (cages and netting) whether clam aquaculture would be feasible within Yaquina Bay. Unlike Anderson (1982), Smith (1996) found that predator netting was ineffective in protecting juvenile clams from predation and recommended the use of in-ground cages. No statistical difference was found among treatments which included the plots covered with 6.25 mm Vexar ® netting and unnetted plots. This was despite the anchoring of the nets with sand-filled PVC pipe and with mud applied to the perimeter of the nets. Smith (1996) concluded that densities of hairy shore crab (*Hemigrapsus oregonensis*) at Yaquine Bay would explain the high losses of Manila clam seed that occurred throughout the study plots (see also Bendell, 2014). Other reasons suggested for the loss of clam seed included the displacement of clams by wave and current action (passive movement), sedimentation and natural mortality.

Spencer et al. (1992) addressed the effectiveness of plastic APN in protecting Manila clam seed specifically against shore-crab predation and found that deploying nets of heavy weight (500 g plastic per square meter of net) was an effective means of preventing predation. However, considering the cost of the heavy APN material, the authors also recommended using double layers of cheaper lightweight nets to protect the clams. Double the work effort would be required to apply lighter nets and the cheap plastic nets would also be a source of plastics to the marine environment (see Section 4). Cigarria and Fernandez (2000) addressed the role of APN in the management of Manila clam beds in the Eo estuary of NW Spain. Over a 5 year period a significant effect of size on mortality in both protected and unprotected beds was observed; even with predator control, smaller seed showed poorer survival when planted in the field. As with Spencer et al. (1992) these authors note that in European clam culture, green crabs (*Carcinus maenas*) are one of the most significant predators on juvenile clams with these predators having a preference for smaller sized prey. Reasons for the observed mortality of protected beds included that the net on the intertidal surface is ineffective against infaunal predators such as nemertean worms or polychaetes, although their importance as predators is unknown and crab predation persists due to net inefficiency. Cigarria and Fernandez (2000) concluded that although smaller seed is less expensive, they are more vulnerable to predation. Larger seed would provide greater survival, but at a greater cost and less seed availability. Also recognized by Cigarria and Fernandez (2000) was the dearth of knowledge on the basic biology of the clam such as habitat selection, the effect of infaunal and epibenthic predators and the development of effective protective devices. Beal and Kraus (2002) assessed the interactive effects of initial size, stocking density and type of predator deterrent on the survival and growth of juveniles of the soft-shell clam in eastern Maine. They found that protecting clams <12 mm shell length with APN increased survival a modest 13% with no difference in survival found for clams planted at 15 mm shell length. In this case, no crab predation was observed; rather clam loss appeared to be caused by the spotted wrymouth eel (*Cryptacanthodes maculatus*).

While there are studies which have addressed the effectiveness of APN in the exclusion of crabs, there are few that have addressed the effectiveness of APN in preventing clam predation by sea ducks and shore birds. In Puget Sound, Taylor Shellfish report that significant losses would occur without the use of APN (Bill Dewey, pers comm. April 2014). But, the lines of evidence for Baynes Sound, BC and clam farming regions in Europe suggest differently.

Whiteley (2005) conducted a field scale experiment to examine any possible short term effects of APN on the intertidal bivalve community which included whether prey depletion by wintering shore birds occurred in non-netted control plots as compared to netted plots. The experimental design consisted of three paired (netted and non-netted) plots of 5 × 5 m (25 m^2) at three locations on the east side of Vancouver Island within Baynes Sound, BC. Each plot was sampled three times, time 0, prior to the application of the APN to set baseline, at 7 months and again at 9 months. Timing of sampling coincided with the arrival (fall) and departure (spring) of wintering sea ducks, such as the white winged or velvet scoter

(*Melanitta fusca*) which are thought to be the cause of the depletion of clam beds during the wintering stage of their lifecycle. Plots were sampled for infaunal densities as described in Whiteley (2005). Clam densities varied little through time and no decrease was observed even within the control plots where depletion was expected. Whiteley and Bendell-Young (2007) in a comparison of farmed and reference beaches from three regions of coastal BC found that despite seeding and APN, there was little difference in clam density between farmed and reference sites. This was contrary to what was expected in that it was thought that farming practices would significantly increase the abundance of clams within the intertidal relative to non-farmed intertidal sites.

Godet et al. (2009) assessed the effects of the degradation of a key diet item, *Lanice conchilega* by Manila clam farming on the spatial distribution of shorebirds, notably the Oystercatcher (*Haematopus ostralegus*) , in the Chausey archipelago (France). In this region of Europe clam production is done in 3 years and nets are applied only in the first year to prevent crab predation. Godet et al. (2009) note that potential predation of the Oystercatcher on Manila clams is size dependent with clams greater than 16 mm being preferred which occurs in the second year of production when no nets are present. Despite having access to the clam beds, Godet et al. (2009) did not find any differences between the three years in terms of attractiveness as forage sites for the birds, that is, no one year of the production cycle was more or less favorable. Lewis (2005) determined the foraging behavior and prey depletion by wintering shore birds in Baynes Sound, BC and found that despite the presence of nets, Baynes Sound remained a high-quality habitat for wintering scoters. Two factors, the recent invasion of the varnish clam increasing overall clam abundances within the region and the spread and spawning of aquaculture-planted Manila clams were suggested as reasons for the high-quality. Whiteley (2005) as previously noted addressed the role of predation on clam density and found no difference between his control and netted plots over three sampling periods, fall, prior to bird arrival, during wintering and spring, and after bird departure. Availability of high quality habitat elsewhere in the sound as suggested by Lewis (2005) could possibly explain the absence of any evidence of predator depletion.

Integrating the above studies, there is limited evidence in support of APN in combination with seeding increasing the density of Manila clams relative to regions of the intertidal that are not farmed. Possible explanations for this include;

(1) Nets do not effectively exclude epibenthic predators such as crabs and fish. Indeed the findings of Bendell (2014) indicate that seeding is acting as an attractant for bivalve predators such as small fish and crabs.
(2) Poor husbandry of the nets results in gaps in the APN allowing for predation. Nets are often in disarray and not firmly attached allowing easy access to clams by crabs and small fish (Fig. 1).
(3) Infaunal predation rates are high and infaunal predators would not be excluded by APN (e.g., Cigarria and Fernandez (2000)).
(4) Clam migration. Both Whiteley (2005) and Lewis (2005) have suggested that clams can migrate out from under the nets to other areas. Miller (1982) also notes that "clams do not always stay where you put them". Reasons for this mobile behavior are unknown but it could be related to density effects that is, clams are able to optimize their density to numbers that optimize food availability thereby reducing direct competition for the same food source.

As noted by Cigarria and Fernandez (2000) nearly 15 years ago, much more research is needed to understand the basic ecology of bivalves such that applied farming practices can be as effective as possible.

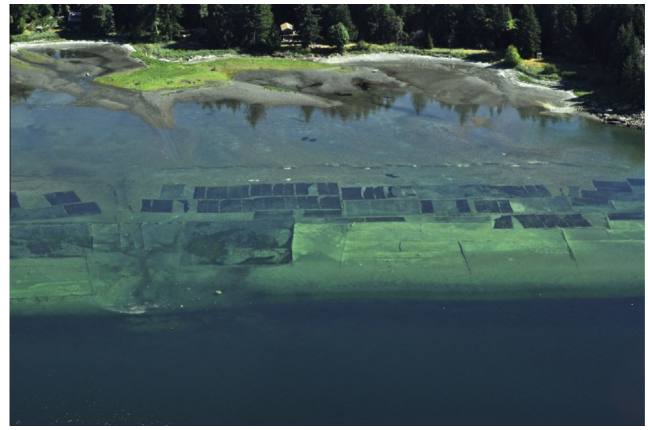

Fig. 1. Aerial photograph of APN on the intertidal region of Baynes Sound, BC. Photo Credit Janet Thomas.

3. Influence of APN on intertidal biological attributes

Although not effective as a predator deterrent, APN does change the nature of the intertidal coastline. As noted by McKindsey et al. (2007), APN can increase the three dimensional structure of the aquatic environment and hence the abundances and types of organisms. Such habitat modification has its most profound effect on regions of minimal habitat heterogeneity (e.g., flat sand substrate). In some cases then, shellfish aquaculture could in turn through the increase in three dimensional structures, also too provide an ecosystem service, rather than just capitalize on the existing functioning of an ecosystem. Powers et al. (2007) suggest that at local scales APN does serve to increase organism abundance and provides refuge and nurseries for small fish. Based on a comparison of two leased sites with a seagrass bed and a sandy beach, these authors concluded that the ecological role for structural habitat rising above clam aquaculture leases is consistent with a broader recognition that artificial reefs, plastic seagrass, oyster shell mounds, and other emergent bottom structures provide habitat services.

Recently Bendell (2014) assessed for possible impacts of shellfish aquaculture, specifically the use of APN in combination with seeding on intertidal community composition within coastal BC. Twenty-eight farm and reference sites from 3 geographically distinct regions of BC were surveyed in each of two years and their epibenthic, endobenthic and macroflora communities compared. The three regions differed in their intensity of industry from low (Barkley), medium (Desolation) to high (Baynes). Marked regional differences in intertidal community composition were observed. Of the three regions Baynes Sound which has 101 tenures, was the most altered with the greatest numbers of Batillaria sp_, an invasive species, and the shore crab, *H. oregonensis*. Of note was the finding that within Baynes Sound, the farming practice of seeding appeared to be acting as an attractant for crab predators with farm sites having on average 3-fold greater numbers as compared to reference sites. Farming practices which used APN were also found to encourage growth and biofouling of the intertidal with *Ulva* sp_ providing refuge for crab predators thereby facilitating increased numbers on the farmed site and hence increased predation rates. Powers et al. (2007) also note that nets with their coverage of algae provides refuge for mobile invertebrates and fish and it is likely that it is these organisms that prey upon small clams and other benthic invertebrates on netted sites. Hence rather than affording protection from predators, APN, especially when biofouled acts as a refuge for the very species it is supposed to exclude.

Walton et al. (2002) have shown the devastating impact that crabs can have on clam farming notably invasive species such as the green crab, *C. maenas* (also recognized by Cigarria and Fernandez (2000)). These authors experimentally determined the effect of the green crab on the stepped venerid clam, *Katelysia scalarina*, the basis of the beginning clam fishery in Tasmania, Australia. Among their findings was that the smallest size class of *K. scalarina* (6–12 mm shell length) was the preferred prey and that *C. maenas* had much higher predation rates that any native predator tested and that predations rates of *C. maenas* increased with increased densities of juvenile *K. scalarina*. These authors concluded that the invasion by *C. maenas* may reduce the average abundance of *K. scalarina*, potentially below the point of economic sustainability.

In addition to providing a refuge for predators, other changes in intertidal community composition include lower species richness (Beadman et al., 2004; Bendell-Young, 2006) and changes in species composition toward domination of netted regions of foreshore by deposit feeding worms (Kaiser et al., 1996; Spencer et al., 1997).

4. Geochemical and geophysical attributes

The physical presence of APN is associated with accumulation of fine silt and organic matter directly under the net (Simenstad et al., 1993; Spencer et al., 1997). The build-up of organic material in parts of the Sacca di Goro (Italy) subject to intense clam farming practices has led to dystrophic events causing anoxia and massive mollusk mortality in cultivated areas (Bartoli et al., 2001). Bartoli et al. (2001) recommended that shellfish farmers should carefully consider sustainable densities of clams (*T. philippinarum*) to prevent the risk of sedimentation and water anoxia, a recommendation relevant to farming practices currently practiced on the west coast of Canada.

More recently, Munroe and McKinley (2007) assessed the effects of APN on intertidal sediment characteristics within one region of coastal BC. While these authors did not observed a statistical difference in percent silt (although while not significant in the first year of study netted beaches all had greater levels of silt as compared to non-netted, in the second year of study 2 of 4 had greater levels), levels of organic matter were significantly higher on netted plots. A unique finding was increased temperature under the nets, the nets acting as an insulator keeping intertidal sediments warmer as compared to those intertidal regions without nets. Bendell et al. (2010) compared sediment characters of netted versus non-netted intertidal areas across three geographically distinct regions of BC. A total of 16 paired farm and reference sites were sampled for both surficial (0–3 cm) a bulk (0–10 cm) sediments and analyzed for % silt, organic matter, ammonium, phosphorus, iron and manganese. In agreement with the studies of Sorokin et al., 1999; Bartoli et al., 2001; Beadman et al., 2004 and Bendell-Young, 2006; Bendell et al. (2010) found that all geochemical attributes and ammonium sorption coefficients were greater in either surficial and/or bulk sediments of farmed as compared to reference beaches. A possible explanation for the different outcomes of the study by Munroe and McKinley (2007) is that the region they chose for field manipulation has been intensively used for shellfish farming since 1940. It is likely that beaches within this region have all been highly altered making it difficult to detect additional anthropogenic influences on sediment characteristics.

5. Other environmental interactions: a source of plastics to the oceans

The application of APN on intertidal regions on the Pacific Northwest has more far reaching effects than just altering intertidal community and sediment characteristics. They present real environmental hazards by providing a source of plastics to the marine environment. Recent research on the distribution of microplastics in the subsurface seawater of the Pacific Northwest found that concentrations ranged from 8 to 9200 m^{-3} with concentrations of approximately 4000–5000 m^{-3} of which 80% were fibrous occurring within Baynes Sound where 50% of British Columbia's shellfish industry is located (Desforges et al., 2014). That the shellfish industry is a major source of plastics to the marine environment has been demonstrated by local community groups who have been conducting beach clean-ups within Baynes Sound for 10 years. Each year 3–4 tonnes of debris are collected, 90% which are plastics and Styrofoam originating from the shellfish industry (Bendell et al., 2014). Examples of plastics collected include "oyster blue" plastic rope, which likely contributes to the high fibrous composition of the microplastics determined by Desforges et al. (2014), plastic net shell bags, and plastic oyster pouches and baskets (Fig. 2).

We are just beginning to appreciate the magnitude by which we have contaminated the oceans with plastic pollution. With that realization, the last 10 years has seen an increased research emphasis on the possible impacts of microplastics within the marine environment. A recent review of Ivar do Sul and Costa (2014) reports that microplastics can transport pollutants over large ocean areas and can contaminate marine biota when ingested. Perhaps of greater concern to the shellfish industry are the findings of Van Cauwenbeghe and Janssen (2014) who determined that *Mytilus edulis* (the blue mussel) and *Crassostrea gigas* (Pacific oyster) contained on average 0.35 and 0.47 particles of plastics $g\,ww^{-1}$ respectively. Van Cauwenbeghe and Janssen (2014) estimated that this would translate into an annual dietary exposure for European shellfish consumers of 11,000 microplastics per year. In a similar study, Mathalon and Hill (2014) determined that farmed mussels sampled from Halifax Harbor, Nova Scotia contained ca. 75 microplastics $mussel^{-1}$ or 10 microplastics gww^{-1} (assuming a mussel meat wet weight of 7 g (Karayucel et al., 2010)) which would translate into the ingestion of ca. 1700 microplastics per average restaurant serving of 24 mussels. Hence, not only is the shellfish industry contributing to the global issue of marine plastic pollution, but also contaminating the very product they are farming. Further impacts include nets not being properly attached which then wash up on shore providing hazards to humans and wildlife alike (Fig. 3). APN also entrains wildlife and poses a real threat to forage fish such as herring which use the intertidal regions for spawning (Fig. 4).

Fig. 2. Examples of plastics collected during the annual beach clean-up within Baynes Sound. Between 3–4 tons of plastics attributed to the shellfish industry are collected within one day of clean-up. Photo credit ADIMS (Association of Denman Island Marine Stewards).

Of real concern is that as the shellfish industry continues to expand, it does not appear to be responsive to the role they play in contributing to plastics in the marine environment. The industry is now looking to the farming of geoducks (*Panopea generosa*) within the Pacific Northwest to meet demand from the Asian market for this product. The farming of geoducks involves the drilling of holes into the intertidal substrate and inserting approximately 18 inch polyvinylchloride (PVC) pipes into which the juvenile geoduck seed are placed. A typical one acre area of geoduck tenure within Puget Sound, Washington, USA, contains approximately 43,500 pipes or approximately 16.5 tons of plastics (Bendell et al., 2014). Cole et al. (2011) reviewed the role of microplastics as contaminants in the marine environment. These authors note that although plastics such as PVCs are considered "inert", plastic additives used to change the properties of the PVC (e.g., softening) may leach presenting hazardous chemicals to marine biota. The example provided by Cole et al. (2011) is the presence of phthalates which can comprise 50% of the plastics weight. Key knowledge gaps identified by Cole et al. (2011) included "determining the impact of leached plastic additives and adsorbed waterborne pollutants to biota, transferred via microplastics, on marine biota. Most worrisome is that the shellfish industry continues to expand without this knowledge.

6. An alternative approach to increasing clam productivity on the intertidal; Clam gardens

In 1995, unusual coastal features were identified in the intertidal zone of the Broughton Archipelago, BC (Harper et al., 2005). The features were boulder-cobble walls (ridges) parallel to the shoreline positioned at the low-water line. Harper et al. (2005) mapped the features on coastal BC and found over 500 spread along the BC coast from Bella Bella BC to Victoria BC. These researchers noted that clam gardens were a significant part of the natural landscape for aboriginal peoples and indicated that clam mariculture was wide-spread in the pre-contact cultures of BC. Williams (2006) also reports on the wide spread occurrence of clam gardens along coastal BC. In her book, *"Clam Gardens; Aboriginal Mariculture on Canada's West Coast"*, Williams recounts how first nations did clam mariculture first and better than as currently practiced by the BC shellfish industry. She notes that the basic structure of a clam garden is simple but elegant: a wall of stones and boulders set at low tide. The wall serves to retain sediment and nutrients that provide an environment conducive to bivalve growth. More recently Groesbeck et al. (2014) were able to experimentally demonstrate that clam gardens increased clam productivity by altering the slope of soft-sediment beaches, expanding optimal intertidal clam habitat thus enhancing growing conditions for clams. These authors found that juvenile *Leukoma staminea* grew 1.7 faster and occurred at twice the density within clam gardens as compared to those not within the modified intertidal regions.

Fig. 4. Hazards presented to wildlife and forage fish by APN within the intertidal region of Baynes Sound BC. Photo credit Liz Johnston.

Fig. 3. Unsecured APN on intertidal region of Baynes Sound BC. Photo credit Liz Johnston.

In contrast to netting, application of an ancient means of increasing bivalve productivity could provide an environmentally benign approach to shellfish aquaculture. Although some beach modification is required, i.e., the building of stone walls to create optimal habitat, negative attributes such as entrapment of wildlife, creation of anoxic conditions and the introduction of plastics into the marine environment caused by the presence of APN would not occur. The refuge created by the accumulation of *Ulva* sp. on the net would no longer occur possibly then leading to a decrease of clam predators, notably crabs that feed on the small seed.

A final consideration is the ever increasing threat of ocean acidification on the shellfish industry. Svanhill (2012) notes that seed security is critical for any aquaculture project with clam seed available from 3 hatcheries in BC, a few in Washington State and Hawaii. However hatcheries are having difficulty keeping up with demand and are also seeing increased mortality rates due to ocean acidification (Svanhill, 2012). Indeed, Narita et al. (2012) assessed the economic costs of ocean acidification on shellfish production and concluded that the costs for the world as a whole could be over 100 billion USD. Clam gardens may provide an alternative means of increasing productivity without having to rely on hatchery sources. By building up the lower region of the intertidal, the enclosed area would act as "larval settling basins" increasing numbers of clams without the need for purchasing seed.

7. Conclusions

Rather than being a means of increasing beach productivity APN provides a refuge for clam predators and degrades the intertidal sediment geochemical characteristics. The nets also present hazards to wildlife and humans alike. Ancient methods of clam farming, the building of rock walls which serve to expand and enhance the intertidal habitat such that it is conducive to clam productivity may provide an alternate approach. No hazards are presented, no plastics are introduced into the marine environment and no physical changes to the sediment need be made. In this time of climate uncertainty, finding alternate means of ensuring food security are international and national priorities. This is a unique opportunity in the development of shellfish aquaculture in the Pacific Northwest and it would be unfortunate if the shellfish industry does not embrace this opportunity.

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