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# Clam predator protection is effective and necessary for food production

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ABSTRACT

Shellfish aquaculture is a widely practiced way of producing food for human consumption in coastal areas. When farming intertidal clams, farmers commonly protect young seedling clams from predatory losses by covering farmed plots with netting or screening. Recent discussion of the effectiveness of protective nets or screens and their environmental effects has raised questions concerning the utility of the practice. We provide data based on a review of more than 35 peer-reviewed articles, as well as our own research that demonstrates the efficacy of predator protection for clam farms in various habitats around the world. In addition, we evaluate the effects of screening on temperature, and comment on ancient practices of clam gardening as conducted in the Pacific Northwest.



## 1. Introduction

We are faced with the global challenge of doubling food production over the next 25 years to support the future food needs of a growing global population (Foley et al., 2011; FAO, 2009). Approximately 40% of the global population lives on the coast, creating a strong pressure for sustainable food production practices, specifically aquaculture practices. Global aquaculture production has been expanding and now accounts for half of world food fish and shellfish production (Naylor et al., 2009). Shellfish aquaculture in particular is a widely practiced way of producing food for human consumption in coastal areas. When farming intertidal clams, farmers commonly protect young seedling clams from predatory losses by covering farmed plots with netting or screening. Recent discussion of the effectiveness of protective nets or screens and their environmental effects has raised questions concerning the utility of the practice (Bendell, 2015).

In this review, we provide evidence that shows the effectiveness of screening and examine some aspects of the environmental effects of the meshes. Shellfish aquaculture provides a sustainable means of producing food for human consumption in coastal areas. Properly installed and maintained predator protection is essential for successful clam culture in the Pacific Northwest, and along the Atlantic coast of the US and Europe (Table 1). Farming filer-feeding bivalves benefits coastal communities via ecological processes such as water filtration (Sorokin and Giovanardi, 1995; Newell, 2004), nutrient cycling (Magni et al., 2000; Nizzoli et al., 2006); and societal benefits including economic stimulus (Saurel et al., 2014). Concentrating clams and other bivalve crops in limited areas (farms) help to prevent disruption of large areas of habitat that would result from harvesting equivalent numbers of clams from the wild stocks. While it is the case that concentrating high densities of shellfish in aquaculture can result in locally enhanced nutrient concentrations (e.g., Cranford et al., 2007; Murphy et al., 2015), these effects are less pronounced than in aquaculture of higher trophic level species (crustaceans and fishes) and the net effect of bivalve aquaculture is a reduction in dissolved nutrients and phytoplankton. Plastics and other materials utilized by the shellfish aquaculture industry to prevent losses to predation can, if improperly managed, contribute to undesired debris to the marine environment. The solution to this issue lies in the development and implementation of industry-driven best management practices as discussed below, not in eliminating a critical predator control practice.

## 2. Efficacy of netting

As early as the 1970's it the importance of protecting seed clams was recognized: '*protection from predation is an absolute necessity when the clams are placed in the natural environment*' Menzel (1971). Nearly a decade later, Anderson (1982) concluded that the use of anti-predator netting is effective at increasing survival of benthic intertidal clam seed (i.e., small juveniles) on farms. Table 1 shows a partial list of studies showing conclusively that clam nets and screens provide important and

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**Table 1**
References that demonstrate protective netting performs better at protecting clams from predation than controls that do not use some type of screen protection. We limit our list here to only those studies specifically showing data from protected and non-protected controls. Not included are numerous references comparing performance of various types of nets or other predator protection.

| Reference | Region | Species |
|---|---|---|
| Anderson and Chew (1980) | Pacific Northwest | Manila clam |
| Anderson (1982) | Pacific Northwest | Manila clam |
| Anderson et al. (1982) | Pacific Northwest | Manila clam |
| Cigarria and Fernandez (2000) | Europe | Manila clam |
| Glock and Chew (1979) | Pacific Northwest | Manila clam |
| Glock (1978) | Pacific Northwest | Manila clam |
| Heath et al. (1992) | Pacific Northwest | Manila clam |
| Miller et al. (1978) | Pacific Northwest | Manila clam |
| Munroe and McKinley (2007) | Pacific Northwest | Manila clam |
| Peterson (1982b) | Pacific | Littleneck clam, Venus clam |
| Peterson and Quammen (1982) | Pacific | Littleneck clam |
| Spencer et al. (1992) | Europe | Manila clam |
| Spencer et al. (1991) | Europe | Manila clam |
| Spencer (2002) | Europe | Manila clam |
| Tezuka et al. (2014) | Japan | Manila clam |
| Toba et al. (1992) | Pacific Northwest | Manila clam |
| Beal et al. (2001) | US Atlantic | Softshell Clam |
| Beal and Kraus, 2002 | US Atlantic | Softshell Clam |
| Beal (2006a, 2006b) | US Atlantic | Softshell Clam |
| Castagna and Kraeuter (1977) | US Atlantic | Hard clams |
| Castagna (1970) | US Atlantic | Hard clams |
| Eldridge et al. (1979) | US Atlantic | Hard clams |
| Flagg and Malouf (1983) | US Atlantic | Hard clams |
| Godwin (1968) | US Atlantic | Hard clams |
| Haven and Andrews (1957) | US Atlantic | Hard clams, Southern Quahog |
| Kraeuter and Castagna (1977) | US Atlantic | Hard clams |
| Kraeuter and Castagna (1980) | US Atlantic | Hard clams |
| Kraeuter and Castagna (1985a) | US Atlantic | Hard clams |
| Kraeuter and Castagna (1985b) | US Atlantic | Hard clams |
| Manzi et al. (1980) | US Atlantic | Hard clams |
| Menzel and Sims (1964) | US Atlantic | Hard clams |
| Menzel et al. (1976) | US Atlantic | Hard clam |
| Menzel (1971) | US Atlantic | Hard clams |
| Walker, (1984) | US Atlantic | Hard clams |
| Peterson (1982a) | US Atlantic | Hard clams, dog clams |
| Walker and Heffernan (1990a) | US Atlantic | Hard clams, Softshell clams, surfclams |
| Walker and Heffernan (1990b) | US Atlantic | Hard clams, surfclams |
| Walne (1974) | Europe | Hard clam |
| Peterson and Black (1993) | Australia | Sand cockles |
| Loosanoff (1960) | US Atlantic | General |

effective protection for clam crops in a number of clam farming regions in the world, including the Pacific Northwest.

Smith and Langdon (1998) performed a study designed to test if habitat modification (addition of oyster shell) and/or use of predator protection can alter clam growth and survival such that otherwise unsuitable areas with high densities of burrowing mud shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*) could be farmed. The results were highly variable due to low replication of treatments, but showed clearly that the use of netting is not effective *within this habitat*. The experiment used predator exclusion cages (with all predators removed) in the second year of the study and was unable to prevent the nets and cages from becoming heavily inundated with sediment, likely due to burrowing shrimp bioturbation. Therefore, this study (Smith and Langdon, 1998) showed that clam nets are not useful to create farm-able habitat on otherwise unusable habitat (burrowing shrimp beds); however, it does not show that protective nets and cages are ineffective in habitats that are suitable for farming clams. Nor does it demonstrate that nets are ineffective at preventing loss of clam seed to shore crab (*Hemigrapsus oregonenesis*) predation. Smith and Langdon (1998) measured predation rates by shore crabs on unprotected small clams and found that very small clams (5 mm shell height) were consumed at a high rate (>100 clams crab$^{-1}$ day$^{-1}$), but that there is a size refuge of approximately 8 to 9 mm shell length above which predation rates are very low (see Peterson et al., 1995 for an corresponding example using size refuge to increase survival in hard clams). This is the reason that, as typical farm practice, very small clams are kept in nursery systems either on land or in some other form of full protective containment, before being planted in the intertidal at a size sufficiently robust to crab predation (Peterson et al., 1995).

A similar conclusion can be obtained from Table 6.3 in Kraeuter and Castagna (1989). It is very difficult to protect clams smaller than about 8 mm because interaction between the mesh size needed for protection and the clam size makes maintenance of the mesh very difficult in field situations. In addition, very small clams may be more vulnerable to other infaunal predators (e.g. *Cerebratulus*) that are not deterred by protective netting. Thus, any claim that nets allow crab predation by increasing predator habitat is unfounded. Predator exclusion nets have been shown to increase habitat for other species including some predatory crabs (Powers et al., 2007), and shore crabs can move into netted farm plots, but this is inconsequential because most clam seed is planted at a size that is larger than what can be eaten by these crabs (Peterson et al., 1995; Smith and Langdon, 1998). Spencer et al. (1992), Cigarria and Fernandez (2000), Beal and Kraus (2002) conclude that predator protection nets significantly increase the survival of clams beneath nets compared to locations without. We provide a number of additional references that show the effectiveness of the technique (Table 1). No claims are made in any of these papers that employing predator protection results in 100% survival; however, the loss of small seed (up to about 20 mm) in the control plots (those without nets) is so pervasive that most later studies focus on comparing various protection methods. Inclusion or immigration of small epibenthic or infaunal predators under nets can cause some level of predation mortality on farms using nets; however, this loss is much less than would be experienced if protective nets were not present. As an illustrative example, Fig. 1 shows that in randomized side-by-side comparison of manila clam survival and harvest between protected (netted) and unprotected control (non-netted) plots, clam survival and yield are consistently improved by the use of nets in the Pacific Northwest. We collectively note, that this is an observation that agrees with anecdotal information from individual farmers' experiences, as well as our own experimental observations. If protective screens are not used, heavy predation mortality on seed clams will occur.

Recently, one of us (Beal) conducted intertidal field studies examining effects of predation on soft-shell clams, *Mya arenaria*, in southern Maine that provides compelling evidence supporting the use of protective netting to enhance clam survival (Figs. 2 & 3). In addition, these field trials underscore results from earlier (1990's and early 2000's) studies conducted by Beal (2006a, 2006b), Beal et al. (2001), and Beal and Kraus (2002) in eastern Maine and others around the world (Table 1). In the Webhannet River (Wells, Maine; Fig. 2a), mean survival in experimental units protected (independent of tidal height) with any type of netting screen (71.0 ± 8.8%, n = 40) was nearly 22 times higher than in the open (control) units (3.1 ± 5.2%, n = 8). In the Fore River (Portland, Maine; Fig. 2b), no clams were recovered alive in open experimental units in the upper intertidal, and an average of only 2.8 ± 4.5% (n = 6) juveniles survived in the lower intertidal units that were unprotected. Conversely, survival in protected units was relatively high (77.9 ± 7.3%, n = 48), and did not vary significantly between tidal heights. In a separate study conducted near the mid intertidal at two mudflats in Freeport, Maine (Fig. 3), predator exclusion explained 55% of the variation in survival at one site (Fig. 3a) and 57% at the other site (Fig. 3b). At one site (Fig. 3a), mean survival in open units, pooled over all clam sizes, was only 1.7 ± 1.9% (n = 15), whereas survival in units protected with netting was 55.6 ± 11.3% (n = 30). At the other site (Fig. 3b), no clams survived in open units where green crabs, *Carcinus maenas*, and other predators were allowed unrestricted access to their prey, whereas survival in netted protected treatments averaged 45.5 ± 11.7% (n = 30).

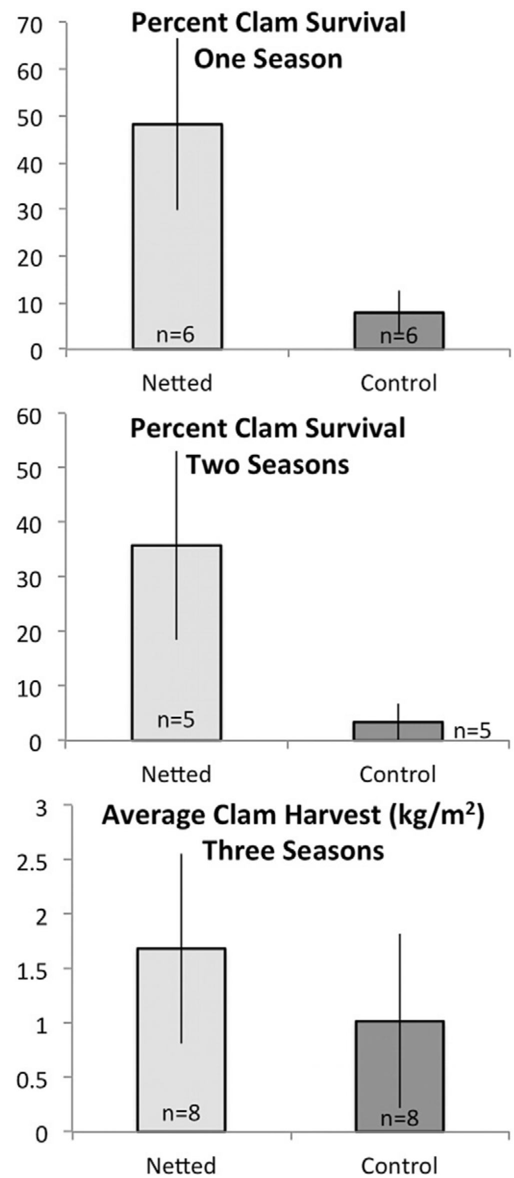


**Fig. 1.** Data replotted from Toba et al., 1992 and BCMAFF (1993). Difference in Manila clam survival (upper two panels) and harvest (lower panel) at side-by-side protected (netted) and control (non-netted) intertidal plots in the Pacific Northwest. Survival summary data are reported in Toba et al. (1992) from replicate sites in Washington. Harvest summary data are reported in BC Ministry of Agriculture (1993) and are harvest values for wild clams only (no seeding) demonstrating the efficacy of netting screens to reduce predation on all sizes of wild clams. Error bars represent 95% confidence interval, replicates (n) for each average value are shown on the figure.

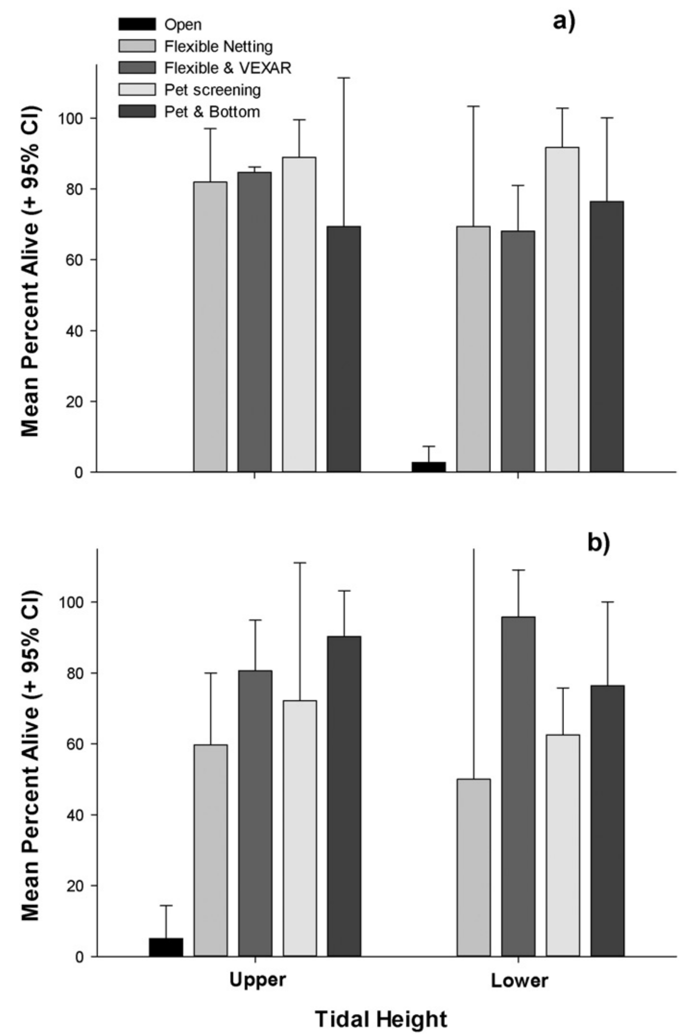


**Fig. 2.** Mean percent survival of cultured, juvenile softshell clams (mean shell length ± 95% CI = 12.9 ± 0.2 mm, n = 451), *Mya arenaria*, at two intertidal locations in southern Maine in 2014. a) Webhannet River, Wells, ME (12 May to 10 October — 151 days). b) Fore River, Portland, ME (13 May to 11 October — 151 days). Clams were produced in 2013 at the Downeast Institute (www.downeastinstitute.org), overwintered according to Beal et al. (1995), and deployed at two tidal heights at both field sites within plastic horticultural pots (experimental units) filled with ambient sediments (sensu Beal et al., 2001). Twelve clams were added to each experimental unit (stocking density ≈ 660 individuals $m^{-2}$) that included the following treatments: 1) open controls (unprotected) where predators had unrestricted access to clams; 2) protected with a piece of polypropylene, flexible netting (4.2 mm aperture) – OV 7100 – Industrial Netting (http://www.industrialnetting.com/ov7100.html); 3) protected with a piece of polyethylene, extruded netting (6.4 mm aperture – XV 1170 – Industrial Netting (http://www.industrialnetting.com/xv1170.html) held in place with a piece of flexible netting screen; 4) protected with a piece of pet screen (1.8 mm aperture — http://www.phifer.com/consumerdiy/product/62/petscreen-pet-resistant-screen); and, 5) protected with a piece of pet screen on the top and bottom of the experimental unit. Treatments 2 & 3 were designed to exclude large crustacean predators. Treatments 3 & 4 were designed to exclude large crustacean and nemertean predators (n = 5).

Poor husbandry can, in certain circumstances, reduce the efficacy of predator netting. Even a small lift or tear in the netting in the earliest stage of culture can greatly reduce seed survival. Peterson (1982a, 1982b) provides examples from the Atlantic and Pacific (respectively) of comparisons between properly installed complete nets (cages), and those with half-covering. It is often the case that clam survival on farms is better than on experimental plots because farmers visit the plots more frequently and thus do a better job insuring that the netting is maintained. The maintenance of the nets and the integrity of the seal around the edge are essential to obtaining good survival; therefore, farmers have a financial incentive to attend to and perform careful maintenance of their farms.

Infaunal predation rates can be high, and represents a source of farm mortality that is not controlled by netting. Unfortunately, there is very little scientific research on infaunal predation on clam seed, and the netting technology is clearly not designed to eliminate infaunal predators. Infaunal predation is a likely one reason that use of seed smaller than about 6 to 8 mm has generally been unsuccessful. The studies listed in Table 1 indicate that once seed are above the 6 to 8 mm size class, epifaunal predators – chiefly crabs – are the major source of seed loss (also Peterson et al., 1995). Similarly, clams can migrate within sediments, but if good husbandry is practiced (e.g. clam seed is large enough to be contained by the mesh and the mesh is kept in place by properly embedding the mesh in the sediments), very few clams emigrate from the plots. A study by Luckenbach et al. (*in prep*) at one of the largest clam farms in Virginia located in Cherrystone Creek, VA, reports densities of

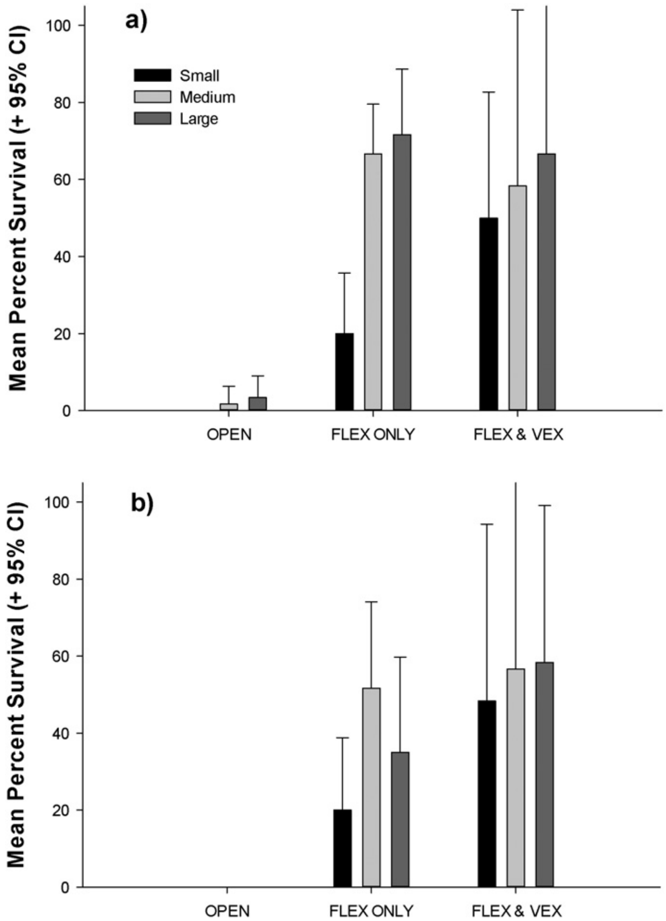


**Fig. 3.** Mean percent survival of three sizes of cultured, juvenile softshell clams (Small = 8.2 ± 0.45 mm, n = 30; Medium = 14.2 ± 0.54 mm, n = 29; Large = 19.4 ± 0.87 mm, n = 30) added to experimental units filled with ambient sediments (sensu Beal et al., 2001) near the mid intertidal at two intertidal mudflats in Freeport, Maine on 18 August 2013 (a = Little River Flat; b = Recompence Flat). Three predator exclusion treatments were incorporated into the fully factorial design (open controls; flexible netting screen; flexible plus extruded netting screen — as described for Treatments 2 & 3 in Fig. 2). The experiment was terminated after 90 days (16 November) (n = 5).

1 + year-old *Mercenaria mercenaria* under nets (N = 3 nets × 6 samples per net, mean = 523.7, SD = 293.7 clams $m^{-2}$) and no clams in adjacent rows between the nets (N = 3 rows × 6 samples per row, mean = 0 clams $m^{-2}$), indicating that at this site, little emigration of hard clams from under the nets occurs. In another experiment, Peterson (1982a, 1982b) showed that when predator exclusion cages are used properly with edges dug into sediments and nets fully intact, there is very little emigration from protected plots (see table 5 in Peterson, 1982a).

## 3. Temperature, plastics and protective netting

Munroe and McKinley (2007), show that screening can influence intertidal benthic temperature during tidal exposure. That influence acted to buffer low tide thermal extremes such that sediments exposed during cold nighttime low tides were slightly warmed by nets, and conversely sediments exposed during the heat of daytime low tides were slightly cooled by netting (summary data shown in Fig. 4). On average, the absolute value of the difference between side-by-side netted and control (non-netted) plots during tidal inundation (when under water) was zero, and while exposed during low tide was between 0.5–1.5 °C (Fig. 4). Intertidal sediment temperature during tidal exposure in this region can vary widely, ranging from freezing to ~35 °C, and the influence of nets during tidal exposure is small in comparison to the daily fluctuations and this natural range. Thus it is unlikely that screening has a significant environmental effect on the benthos.

At times predator protection screening can be lost, making its way on shore or fouling other marine habitats, especially during severe storm conditions and, in some areas, ice events. We note, however, that an estimated 80% of the plastic pollution entering the ocean is from terrestrial sources (Jambeck et al., 2015). In general, responsible farmers have operational methods that attempt to reduce these losses (such as removing mesh for the winter months from plots containing larger seed that cannot be consumed by ducks) and also have programs to identify and collect the majority of these losses and bring them to appropriate shore based disposal areas (Jensen and Zajicek, 2008). Best management practice guidelines for shellfish aquaculture have been developed either solely by industry or by industry in collaboration with government in most major shellfish growing areas in North America (e.g., Leavitt, 2004; Oesterling and Luckenbach, 2008; Flimlin et al., 2010; PCSGA, 2011; Dewey et al., 2011; BCSGA, 2013) and these plans all address the importance of waste management, including plastic screening. As a possible alternative to plastics, wire mesh could be used, but it too could be moved by storms, and it has an additional hazard in that corrosion or electrolysis of the mesh creates very sharp pieces that would be dangerous to humans and wildlife. It would be better if mesh was not needed, but there is no available substitute that would offer the same protection.

## 4. Clam gardens as an alternative

Could ancient clam gardening practices replace contemporary farming while maintaining production levels and business stability? We do not believe this is possible. We illustrate why with the following example. Studies on clam productivity on an ancient clam garden (Groesbeck et al., 2014) showed that these gardens produce about 2 kg wet weight of clams per $m^2$ of beach surface area. This is the sum of two species, and includes sizes below those that are harvestable and is thus an overestimate of clam biomass available to harvest from a garden. A study at a contemporary clam farm (Munroe, 2006), showed that on average netted manila farm plots contained 4 kg wet weight of clams per $m^2$ of harvestable biomass. This 4 kg, does not include other species and is

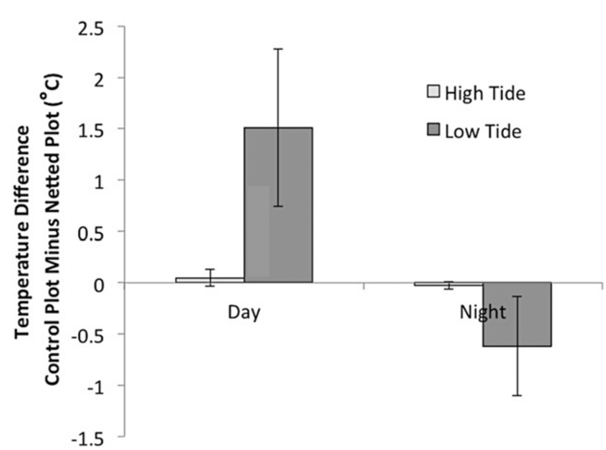


**Fig. 4.** Average sediment surface temperature difference (control plot temperature minus protected plot temperature) between paired (side-by-side) control and netted plots on 4 intertidal beaches. Daytime observations are the average temperature difference taken over one hour at 1 min intervals during the lowest or highest tide at midday (between 11:00 am and 2:00 pm). Nighttime observations are the average temperature difference taken over one hour at 1 min intervals at the lowest or highest tide at night (between 2:00 am and 4:30 am). All data were collected in Baynes Sound in September 2005 (Munroe, 2006). Temperature differences are not significantly different than zero during high tide (inundation), whereas there is a strong and significant interaction in the temperature difference observed during low tide (exposure) on daytime versus nighttime low tides.

thus a conservative estimate of harvestable biomass relative to the clam garden estimate above.

The fact that a contemporary farm conservatively carries twice the harvestable biomass per area than a garden suggests that to 'garden' rather than farm using predator protection, the leased bottom in use for clam aquaculture in BC would have to be expanded to at least double the current footprint to maintain the same production. We expect this would be infeasible given federal and provincial regulations preventing the alteration of intertidal areas (installation of gardens would require large alterations of foreshore areas by terracing and building rock walls on natural beaches). Our estimate of a requisite doubling of intertidal to garden rather than farm is a highly conservative estimate because it does not account for the fact that the unprotected, and unseeded garden plots on terraced clam gardens will be subject to high variability in the abundance of clams recruiting into the population each year (Munroe and McKinley, 2007 show recruitment in this region can vary over several orders of magnitude among years). This high variability in recruitment is overcome on contemporary farms by the use of hatchery-reared seed clams that provide a stable input of new stock each year. Gardens that are harvested to remove nearly all of the available biomass, as estimated above, would experience annual depletion that would rely on wild recruitment to replenish. This uncertainty in recruitment would mean that the garden footprint would have to substantially increase to compensate for recruitment variability and harvest population recovery time. The uncertainty in both recruitment and population recovery will additionally create instability in business models. Considering the amount of intertidal area that would be required, the inter-annual variability in crop due to recruitment fluctuations and the limitations in permitting the necessary alteration of foreshore areas, we believe that gardens do not represent a feasible alternative to contemporary clam farming.

## 5. Conclusion

We have provided an extensive list of literature that unequivocally shows that properly installed and maintained screening is essential for successful clam culture of clam species in the Pacific Northwest, and along the Atlantic coast of the US and Europe. We provide evidence that predator netting is an effective environmentally acceptable means of farming clam crops, and that these practices increases the harvestable density relative to practices that greatly alter the intertidal zone such as ancient clam gardens. Predator protection measures such as nets, screens, or cages are necessary for farmers to conduct their businesses, and they do not pose an obvious or great threat to coastal ecosystems.

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