

Association For Responsible Shellfish Farming

As of October 2009

Items 1 – 32 below are excerpts from various reports and articles of relevance to shellfish farming in British Columbia and other regions in the United States and the rest of the world.

Following item 32 are studies and reports presented from Protect our Shoreline (USA) and the Pacific Shellfish Institute.

1. Alaska Coastal Zone Management Program, 1986. Annual Report.

79/...Conflict over mariculture siting has resulted in development of siting criteria and zoning in both Washington and British Columbia...guidelines are for “all aquaculture proposals involving floating structures and improvements” in British Columbia (BC Ministry of Forestry and Lands 1987)

80/...To minimize adverse impacts on productive benthic habitats: ...

- 1a...determine flushing regime, benthic community composition
- 1b...avoid siting in small embayments with sills, natural restrictions to tidal exchange, or existing water quality problems.
- 1c ...Site floating facilities ...in areas with least productive benthic habitat. Avoid shallow areas (less than 40 feet deep)
- 1d...detailed site analysis including a dive survey should occur prior to siting...Information on the existing benthic community
- 1e...Avoid siting within 300 feet of herring spawning areas, clam concentration areas, and eelgrass and kelp beds.
- 2b...Avoid siting within a 300-foot radius of fish streams
- 2c...Avoid siting within one mile of: harbor seal haul out, sea otter concentration areas, and seabird colonies.

2. Anon: 1983 “Pollution” [translation from Japanese of a brochure issued by the National Division of Fisheries, Institute of Environmental Protection].

...Both urine and feces are excreted. After a time, very bad effects on water quality and the substratum occur, which constitute pollution, which results in loss of production of the aqua cultural effort. Pollution of this type results not only from fish aquaculture, but also from shellfish aquaculture, in which feeding is not necessary. Oyster and pearl oyster feces adversely affect the fish environment....

- Feces contain much nutrient...which induce red tides...
- The sediment on the substratum becomes degraded, consuming much oxygen, creating an environment in which no fish live....
- Oxygen lack and red tide kill many fish in aquaculture...
- In the small-enclosed bay, with little natural recovery, pollution proceeds very rapidly...

3. Bartoli, Marco, et al. 2001. "Impact of *Tapes philippinarum* farming on nutrient dynamics and benthic respiration in the Sacca di Goro." *Hydrobiologia* 455:203-212.

<http://cat.inist.fr/?aModele=afficheN&cpsidt=13421924>

203/...The introduction of the short-necked clam into the Sacca di Goro made this coastal environment one of the top European clam production sites...this activity has been seriously impacted due to the appearance in the lagoon of large macro algal beds and the occurrence of dystrophic events causing anoxia and massive deaths of molluscs in the cultivated areas....cultivation sites now cover more than one third of the lagoon surface...Oxygen, carbon dioxide, ammonium, reactive silica and phosphorus fluxes were stimulated several fold by the presence of *Tapes* due to the clams' respiration and excretion activities, but also to the reducing conditions in the surface sediments. On average, the whole lagoon dark sediment O₂ demand and CO₂ production were stimulated by a factor of respectively, 1.8 and 3.3, whilst nutrient release was 6.5 times higher for NH₄ and 4.6 times higher for PO₄...clam farmers should carefully consider sustainable densities of *Tapes* in order to prevent the rush of sediment and water anoxia.

204/...The study of their [molluscs such as oysters or mussels] impact on the environment due to increased organic matter deposition on sediments is relatively easy (Boucher & Boucher-Rodoni 1988; Cheng et al. 1993; Hatcher et al 1994; Kemp et al. 1997)

...Clam culture enhances sedimentation and concentrates feces and pseudo feces in the farmed areas. This results in an accumulation of organic matter which stimulates sulphate reduction and leads to the accumulation of sulphide in the surface sediments....the dominance of clams within the benthic community results in the displacement of other organisms and the loss of their associated functions.

205/...clam farming has suffered serious setbacks due to massive clam mortality in the summer. The appearance of the macro algae *Ulva rigida* and the occurrence of dystrophic events triggered by macro algae decomposition....Dystrophic events occur in the summer when huge mats of *Ulva* (up to 800 g dry weight m⁻²) suddenly collapse; decomposition processes turn the water column anoxic and allow sulphide diffusion from the sediments with catastrophic effects for the benthic fauna (Viaroli et al. 1996).

209/ ...clams produce large quantities of feces and pseudo feces which represent an ideal substrate for bacteria and shift the sediments towards a rapid consumption of oxygen (Sorokin et al. 1999)...In areas close to the farmed sites, increased densities of opportunistic polychaete is a good indicator of organic matter enrichment.

...most of the sediment oxygen demand in the farming area was due to the respiration of the clams, up to 20 mmol per square meter per hour. In eutrophic coastal lagoons, oxygen respiration never exceeds 10-15 mmol...If a drifting *Ulva* bed becomes stranded on the sediment of a farmed area, respiration up to 30-40 mmol would be expected. Such oxygen demand could turn a water column of 50 cm completely anoxic in a few hours...

...Carbon dioxide, ammonium, reactive phosphorus and silica fluxes were all strongly stimulated by the presence of the clams. This is due to the reducing conditions that establish at the surface sediment, to the clams excretion and to the rapid degradation of the organic matter (fecal pellets, feces or pseudo feces) produced by the clams...fluxes were 10-fold higher than cores without clams.

210/...The need for large volumes of water for respiration results in the production of large quantities of pseudo feces which represent an easily

degradable material deposited on the sediment surface. This explains the extreme reactivity of this sediment horizon in the farmed area and the rapid regeneration rates for C, N, P and Si coupled to high oxygen consumption. Similar results have been obtained for oyster beds, mussel and clams.

The rapid circulation of nutrients can promote new phytoplankton blooms which is a positive feedback for clams but can also sustain macro algal growth, in particular in the warm season...the consequences of dystrophic events associated with macro algal bloom collapses are a negative feedback for clam culture.

...in the core with the highest biomass of *Tapes* ammonium fluxes were 20 times higher than in the controls, while the oxygen flux was 7 fold higher.

...clam harvesting activities are disruptive for the surficial sediment and result in sudden and localized deficits of oxygen in the water column which could affect the benthic fauna.

211/... the hypothesis that clam farming acts as a control for eutrophication processes seems not realistic for the Sacca di Goro.

4. Beadman, H., M. Kaiser, M. Galanidi, R. Shucksmith, and R. Willows. 2004. "Changes in species richness with stocking density of marine bivalves." *Journal of Applied Ecology* 41:464-475.

464/...The presence of mussels significantly changed the occurrence of some species of the infaunal community within the cultivated area. The infaunal communities supported fewer individuals and species than control treatments at all but the lowest mussel cover... Species richness and the abundance of individuals per unit area also declined with increased area of mussel cover....but the effects were localized (0-10 m) and not detectable at larger scales (10-100 m).

474/... changes in benthic community composition could be reduced by proportional lowering of the stocking density of mussels within mussel beds or by restriction of the final surface area of coverage of the seabed...Therefore, controlling the area available for cultivation would be an effective management measure to reduce impacts on benthic fauna.

5. Bendell-Young, L. 2006. "Contrasting the community structure and select geochemical characteristics of three intertidal regions in relation to shellfish farming." *Environmental Conservation* 33:21-27.

21/...shellfish aquaculture, is in its fledgling stage facing increasing concerns as to the environmental sustainability of existing practices (Simenstad & Fresh 1995; Kaiser et al. 1998; Sorokin et al 1999; Bartoli et al. 2001).

...The region to be used for shellfish farming is first cleared of all surface species and competing bivalves. The area is then seeded with hatchery-reared seed....the seeded region is covered with fine plastic mesh anti-predator netting. Currently, there are no regulations as to amounts of the intertidal region that can be covered by netting; as a result, substantial regions of the intertidal can be subject to cover (Jamieson et al 2001). Other practices include the use of vexar netting and substrate modification for beach stabilization, use of vehicles on the intertidal region for accessing farm sites, as well as dense coverage of the intertidal with the Pacific oyster... use of anti-predator netting is the most invasive. In addition to habitat loss, nets become covered in a dense layer of algae...

26/ ...Other studies have reported intensive shellfish farming leading to loss of benthic diversity, increased sedimentation and anoxia (Sorokin et al 1999; Bartoli et al. 2001; Beadman et al. 2004) and change in species composition towards domination of netted regions of foreshore by deposit feeding worms (Spencer et al. 1997). Loss of species richness could have important consequences for the ecological functioning of the intertidal zone (McCann 2000; Tilman 2000).

...current shellfishery practices which reduce species richness could decrease intertidal ecosystem stability that in turn could affect the overall productivity of these systems.

...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 mollusc mortality in cultivated areas (Bartoli et al. 2001).

...Unlike the farmed beaches where the shellfish farmers remove this predator [the moon snail], there is no such practice on beach A. Large moon snail densities occur there.

...Given the importance of Baynes Sound as an internationally recognized bird area, and staging and wintering area for many migratory species (Daw et al. 1998), Vermeer and Butler (1989) have recommended that Baynes Sound and surrounding areas of critical bird habitat be protected so that existing bird populations can be maintained. Despite this, the expansion of the shellfish aquaculture continues in this ecologically sensitive region of the west coast of British Columbia.

...Anti-predator nets could restrict access of shore birds and sea ducks to the intertidal region, possibly during key periods of the life history, such as before and after breeding and during migration. This could prove detrimental to existing populations where are already in decline (Goudie et al. 1994).

....Surface species that are absent from the farmed beaches include filter-feeders such as the blue mussel (*Mytilus* spp.) and barnacles (*Balanus* spp.) that engineer benthic-pelagic coupling. In the absence of these surface species, the two-way movement from the overlying water column to the surface sediments could be much reduced, possibly limiting the flux of much needed nutrients to the benthic community.

Very little is known about the ecological importance of the intertidal zone. It is important for example as nurseries and feeding grounds, however, comprehensive understanding of which species use the intertidal for what purposes and when is still limited.

6. Black, K.D. 2001. "Sustainability of aquaculture" In *Environmental Impacts of Aquaculture*, edited by K. Black. Sheffield Academic Press, CRC Press. Pp. 199-212.

199/...definitions of sustainability...condense around concepts relating to stewardship. It is perfectly acceptable to exploit the environment, provided that this is done in a way which:

- a) Does not significantly interfere with the commercial or amenity use of that environment by others
- b) Does not reduce the scope for future users to benefit from the environmental resource
- c) Does not significantly alter or diminish environmental quality and biodiversity per se.

...Many environmentally-minded bodies, especially in the last few years, turned their attention to aquaculture...Intensive aquaculture...is the form of culture most questioned in terms of sustainability...The culture of seaweeds and filter-feeding shellfish leads to a net reduction of nutrients and energy from the ecosystem and, unless practiced in some extreme sense, is unlikely to have sustainability consequences beyond the purely local scale. These forms of aquaculture are, however, commonly spread over quite large areas of relatively important habitat in the intertidal zone or on the coastal fringe, and may seriously interfere or conflict with other users.

200/...Therefore, even where the culture type tends towards sustainability, management of resource use will always be required in order to ensure the protection of all legitimate users...Clearly aquaculture practices that are unsustainable will not be sustained. The question is, will they do serious and/or irreversible environmental or socioeconomic damage prior to their decline?

204/...'Eutrophication (noun)--an increase in the rate of supply of organic matter to an ecosystem.'

...whether eutrophication is of significant consequence to the ecosystem will depend on a number of factors, including its intensity, its duration and, importantly, the trophic status of the receiving environment...if an ecosystem is already under pressure, a small addition may result in system collapse.

It has been argued that the input of nutrients from marine cage culture in the coastal zone has reached unsustainable levels in many areas, as severe ecosystem perturbation is now occurring or is likely.

205/...Nutrient levels from marine cage culture have been compared to sewage effluents...dilution is not the answer for pollution.

206/...In addition to eutrophication, alterations of nutrient ratios are often held responsible for changes to pelagic ecosystems that may lead to increased occurrence of harmful blooms (ref)...further experimental study and fieldwork is urgently required. Folke et al assert that, as a link between nutrient ratios and harmful blooms has not been disproved, the precautionary principle should be invoked. This would involve a moratorium on future expansion in areas where there was any suspicion that nutrients from fish farms contributed to algal toxicity.

208/...in most cases it is difficult to establish causal relationships but , where the circumstantial evidence convinces a significant number of informed experts, perhaps it is necessary to invoke the precautionary principle.

209/...Unfortunately, because of low profit margins, there is a tendency for companies to merge and for control to be removed from the local area along with any profits but with only some of the risk... governments...as do regional development organizations...may often be influenced by short-term economic benefits.

210/...[discussion of idea of increased environmental controls with improvements in economy and how this is a fallacy]

Arrow et al argue that exploited ecosystems might show resilience up to a point before irreversibly flipping to a new degraded stable state...Economic growth is not, therefore, a substitute for environmental policy. Such policies must ensure incentives to protect the resilience of the environment, particularly when related to use of a resource stock.

7. Carlton, James, G. Ruiz, and R. Everett. 1991. "The structure of benthic estuarine communities associated with dense suspended populations of the introduced Japanese oyster Crassostrea gigas: Years 1 and 2." Report for South Slough National Estuarine Research Reserve, US Department of Commerce, National Ocean Service.

1/...Stake culture resulted in increased sediment deposition, the formation of dense algal mats, and trends toward increases in both the percentage of silt-clay particles and sediment organic content... Both stake and rack cultivation methods led to a distinct decline in the abundance of the native eelgrass....Stake culture resulted in lower recruitment and survivorship of tellinid clams (an important prey item for many fish, birds, and crustaceans including juvenile Dungeness crabs)...

2/ ...Stake culture occurs in the mid to low intertidal zone, while rack culture occurs in the extreme low to shallow subtidal zone...the degree and rate of eelgrass decline appear to be more complete and rapid in rack rather than stake plots.

8. Comeau, Gerald (Chairman). 1988. Aquaculture in Canada: Report of the Standing Committee on Fisheries and Oceans. House of Commons, Issue No. 40. Ottawa

21/... "the effects of aquaculture on the environment...requires mandatory environmental data monitoring programs, public liability insurance and substantial site clean-up bonds as conditions of tenure...to minimize the opposition of other resource users to aquaculture development the density of farms must be kept low and their visual impact minimized. In addition, a control of the density of farm units is likely to be found to have a positive effect on pollution levels and fish health."

9. Elston. R. 1987. Mollusc Diseases. Washington Sea Grant Program. U. Washington Press.

246/... Description of Denman's disease among oysters.

[Bill Heath confirmed that Denman's Disease has been observed among oysters on Marina island. DSO originates from Denman's Island.

10. Fent, Karl. 1996. Organotins in municipal wastewater and sewage sludge. In M. Champs and P. Seligman (eds.) Organotin: Environmental fate and effects. Chapman & Hall: London. Pp. 581-600.

594/...principal commercial use of organotin is as a PVC stabilizer; the possible route by which organotin compounds may enter the wastewater is leaching and weathering; also used as a biocide in wood preservation, added to dispersion paints, as a protection against microbial attack by incorporation of TBT in PVC, polyethylene, polyurethane, and silicone

595/...toxic effects on the immune system of fish (thymus atrophy) at 320 ug per liter DBT, at 0.8 ug per liter TBT; also affect mitochondria and metabolism and induce thymus atrophy in rats. Accutely toxic to molluscs and gastropods, zooplankton and algae. Organotins are predominantly affect filter feeders and benthic organisms. "a few nanograms per liter (of TBT)...elicit chronic toxic

effects on molluscs and gastropods.. the most susceptible organisms such as oysters, dogwhelks and other gastropods.

11. Griffin, Kerry. 1997. "Eelgrass ecology and commercial oyster cultivation in Tillamook Bay, Oregon: A literature review and synthesis." Tillamook Bay National Estuary Project.

1/...Eelgrass beds are critical elements of the ecology...They provide habitat for juvenile fish and shellfish, food for waterfowl, spawning areas for fish, and play an important role in nutrient cycling. Recent investigations suggest that commercial oyster farming has a negative impact on eelgrass meadows in Pacific Northwest estuaries.

11/...Past research indicates that all types of oyster culture, including ground culture, negatively affect eelgrass density and percent cover... in areas of commercial oyster culture, eelgrass was absent or rare, while areas immediately surrounding these plots support dense beds.

10/...In Washington, the burrowing shrimp problem is addressed with the application of the pesticide carbaryl (trade name Sevin), which has been used for over 30 years to rid the oyster beds of shrimp. It is currently illegal to use carbaryl for shrimp control in Oregon.

[NOTE: Fred Zwickle told me that there are laws in Oregon prohibiting the siting of oyster farms within certain distances of eelgrass beds. There appear to be eelgrass beds in the Gorge, but I do not have details. Sabina Mense apparently has information on this].

12. Hatcher, A., J. Grant, and B. Schofield. 1994. Effects of suspended mussel culture (*Mytilus* spp.) on sedimentation, benthic respiration and sediment nutrient dynamics in a coastal bay. Marine Ecology Progress Series 115:219-234.

<http://www.int-res.com/articles/meps/115/m115p219.pdf>

219/...Many studies show that the primary effect of shellfish culture on nearshore marine systems is enhanced sedimentation.

--increased chlorophyll is associated with increased sedimentation, especially under mussel lines

--most of the carbon and nitrogen falling to the bottom was not incorporated into the sediments.

--the largest impact of suspended mussel culture was the release of ammonium by sediments (higher ammonium under mussel lines at all times of the year). Phosphorus was not affected.

--sediments under mussel lines were a source of dissolved nitrogen, while off-site areas absorbed dissolved nitrogen.

13. Huxel, Gary. 1999. Rapid displacement of native species by invasive species: effects of hybridization. Biological Conservation 89:143-152.

- 143/...species replacement can occur very rapidly
--need more empirical studies on the immigration patterns of invasive species, genetic structures, and their potential for interbreeding with natives (151).
--suggested that interbreeding increases the threat of extinction for a number of species due to hybridization introgression; can also lead to introduced taxa dying out, co-existence, new hybrid species.
- 146/... hybrid vigor can occur
- 149/... near-shore temperature is a major limiting factor in species distribution. increased temperature will facilitate dispersals. Interaction between *M. galloprovincialis* and *M. trossolus* may be further complicated by warming of northern Pacific waters allowing *G. provincialis* to spread northward. (see Suchanek et al . 1998)
- 151/... increased frequency of hybrids with introgression heavily impacts native sp. and the likelihood of extinction is greatly increased.
--species most threatened by introgression and hybridization have low population sizes and restricted ranges. This includes the potential loss of genetic integrity of native populations through selective stocking of non-native individuals.
--due to the rapidity of displacement, it is best to prevent biological invasions from occurring when possible.

14. Inglis, Graeme, B. Hayden, and A. Ross. 2000. An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. New Zealand Ministry for the Environment, National Institute of Water and Atmosphere, Client Report CHC00/69, Project No.: MFE00505.

http://www.aquaculture.govt.nz/files/pdfs/Mussel_farms_-_carrying_capacity_of_coastal_embayments.pdf

Exec. Sum.: ecological and social impacts of mussel culture have been limited to relatively small (c. 3-5 ha), single farms. Direct ecological effects are relatively minor and, with good management, can be restricted to the immediate footprint. Effects include: organic enrichment of sediments by mussel feces, shading of benthic habitats, deposition of shells and farm debris, local depletion of phytoplankton. "There is, however, a critical lack of strategic information on the environmental changes that might occur with increase in stocking density, farm size and farm number. Potential diffuse and cumulative effects of shellfish culture could include shifts in primary production within sheltered embayments, changes in predator behavior and abundance, off-farm effects on natural assemblages and changes in the abundance and distribution of "problem" species. Potential social impacts include displacement of other stakeholders, decreased satisfaction and enjoyment of other users...and diminution of future opportunities."

Recommended approaches:

- monitoring of new farm developments and reference areas
- sampling and experiments along a gradient of intensity of existing marine farm development
- comparison with reference areas that remain unaffected

- use of archival information to reconstruct historical baselines for natural assemblages in farmed embayments (see p. 25)
- 3/... ecological carrying capacity vs. economic carrying capacity.
- 4/... production capacity vs. social capacity
- 7/... 33% of the nutrients ingested by mussels is deposited on the seafloor
- 8/ ...“established culture sites have...shown that some adverse effects of mussel culture are possible. These include:
 - organic enrichment of sediments
 - shifts in benthic food webs to deposit-feeding faunas
 - shading of submerged plants and animals
 - drop of shells and other waste
 - local depletion of phytoplankton
 - attraction of predators.

The severity of these environmental effects and their ecological significance varies with the size and configuration of the farm “

Rates of sedimentation at farm sites range from 3-945 g. per sq. meter per day; this material has a high organic content

9/... In well-oxygenated sediments, where there is good water movement, full degradation of biodeposits occurs quite rapidly...In poorly flushed areas, limited exchange of oxygen within the surface sediments can rapidly lead to anoxic conditions...benthic metabolism becomes increasingly anaerobic... characterized by films of cheoauthtrophic sulphur bacteria...The by-products of anaerobic metabolism form h₂S and ammonium, build up in the sediments... sulphide concentrations can be up to 100 times greater than elsewhere. Ammonium efflux can also be an order of magnitude greater below mussel farms...effects can be detectable up to 3 years after the culture system has been removed.”

11/...“Only limited research has been done on the effects of mussel culture on the soft-sediment fauna...Organic enrichment of the sediments beneath mussel farms is frequently accompanied by a decline in the abundance of large, deep-burrowing species of molluscs, echinoderms, crustaceans and polychaetes, and an increase in the relative abundance of surface-feeding gastropods and small, opportunistic species of polychaetes, meerteans and crustaceans...Less consistent changes include a decline in species diversity and overall faunal abundance...The loss of active burrowing infauna that turn-over and oxygenate the sediments exacerbates the anoxic conditions caused by organic enrichment.”

The accumulation of mussels, mussel shells, and other debris attract large numbers of predatory fish, starfish, crabs, sea urchins and other echinoderms

12/...“There have been no direct studies of the cumulative and diffuse effects of mussel culture on sheltered waterways. Such effects may be associated with the gradual accumulation of large numbers of small farms or the development of very large blocks in areas of limited water flow....”

13/...It is possible that changes in the composition and abundance of zooplankton associated with intensive mussel rearing could effect long-term changes in benthic fauna...unlikely to be detectable at low levels of farm development, but may become increasingly important as the number of farms increase. Changes in the pattern of nutrient cycling have been linked to outbreaks of toxic red tide organisms...in Japan blooms of the red tide dinoflagellate are stimulated by increased release of ammonium and other

micronutrients from the sea floor...Ammonium efflux from the sediments is often greater in areas affected by the biodeposits of mussel farms.”

14/...As an extreme example of ecosystem-level effects that large densities of suspension-feeding bivalves can have on coastal embayments was provided by the catastrophic elimination of intertidal mussel and cockle beds in the Dutch Wadden Sea in 1990 (Dankers and Zuidema 1995)... Mortality was subsequently followed by exceptional blooms

...fouling species on mussel culture systems may be as high as 67% of the mussel biomass

15/...“Shelby and Heberlein (1986) proposed three ‘rules’ for determining the social carrying capacity of an area:

1. There must be a known relationship between the level of the activity and social impacts.
2. There must be agreement among relevant groups about the different types of opportunities to be provided in the area.
3. There must be agreement among relevant groups about appropriate levels of impact.

25/ ...“Direct evidence of past cumulative effects is not possible, but a case may be built by using several lines of inquiry concurrently (Wiens and Parker 1995). These could include:

- Development, testing and monitoring of indicators of regional ecosystem condition
- Use of archival information to reconstruct historical baselines

15. Kaiser, M.J., 2001. “Ecological effects of shellfish cultivation.” In, *Environmental Impacts of Aquaculture*, edited by K.D. Black. Sheffield Academic Press, CRC Press. Pp. 51-75.

51/ ...the lure of high financial returns and government subsidies has led to the uncontrolled expansion of crustacean and molluscan cultivation in some areas. This in turn has led to problems with over-exploitation of juveniles and seed, the spread of pathogens and alien species, destruction of coastal environments, pollution and outbreaks of disease.

53/ ...adverse effects have been associated with mussel and oyster farms on the continent of Europe (refs)

54/...Mussel seed are vulnerable to heavy predation by starfish and crabs.

57/...Introduced species may compete with native species for the same resources, and they may carry pests, predators and disease to which native species are more vulnerable.... Introductions of algae, including toxic dinoflagellates, blooms of which can have a significant impact on commercial bivalve mollusc culture.... transport of shellfish stocks from one area to another followed by relaying or storage in open basins, can provide another mechanism of transfer. The feces and digestive tracts of bivalves can be packed with viable dinoflagellate cells or can contain resting cysts.

58/...on-growing usually requires the introduction of structures into the marine environment on or from which the bivalves are either supported or suspended. The introduction of such structures has an immediate effect on local hydrography and provides a new substratum upon which other epibiota can settle

and grow. In addition, the introduction of high densities of cultivated organisms increases local oxygen demand and elevates the input of organic matter into the immediate environment. At high stocking densities of bivalves, the larval settlement of other benthic species may be reduced as their larvae are filtered and digested or become entrained within pseudo feces.

59/...Castel et al (1989) found that the presence of densely-stocked oyster parks elevated organic carbon levels in the local sediments, which increased oxygen demand and produced anoxic conditions in the underlying sediments. As a result, ...macrofaunal abundance decreased by nearly 50%....Water currents were significantly reduced in close proximity to oyster trestles, which in turn doubled sedimentation rate and increased the organic content of the underlying sediments, leading to a reduction in the depth of the oxygenated layer of sediment ...at low stocking densities, the effects of oyster cultivation are relatively benign and highly localized. ...environmental effects are exacerbated as the carrying capacity of enclosed systems is approached and the extent of cultivated areas is increased.

60/...In some areas...the insecticide, carbaryl, is sprayed on intertidal areas to kill populations of burrowing shrimp.
[+ discussion of adverse effects of using netting on beaches & harrowing beaches]

61/...Relaid mussels lead to the development of 'mussel mud' beneath the mussel bed, as the filtration and feeding activities of the mussels increase the rate of sedimentation. These deposits are composed of dead shells, silt, and pseudo feces, which persist in excess of 18 months after the mussels have been removed. The cohesive nature of the 'mussel mud' is degraded by a combination of bacterial activity and wave erosion...the formation of 'mussel mud' and the use of protective netting induces localized change in the sedimentary environment and composition of the benthic community.

62/...The bivalves provide a surface on which many epibiotic organisms attach and grow. Thus, a large biomass of biota develops in suspended culture systems and this, in turn, has a major effect on phytoplankton, benthic, and hydrographic processes in close proximity to the cultivation site...over 100 species can develop...

Mussels excrete high levels of ammonia (refs), which promotes increased levels of productivity in algae attached to mussel lines...

Cultivation sites that are well flushed by tidal currents...do not encourage the accumulation of pseudo feces beneath mussel rafts, which can lead to the development of anoxic conditions (refs)... In Sweden, they demonstrated organic sedimentation rates of 2.4-3.1 g organic carbon per square meter per day beneath mussel longlines, which was twice as much as found in adjacent uncultivated areas. This excessive organic enrichment led to the development of anoxic sediment conditions. Mats of bacteria, *Beggiatoa* spp., then developed beneath the longlines at their study site. In this situation, the benthic infauna had low diversity and biomass, which is a well-documented response to excess organic enrichment (ref). Similarly, the productivity of densely-stocked Japanese oyster grounds was detrimentally affected by the generation of large quantities of pseudo feces and high filtration rates (refs). Pseudo feces production was so great beneath oyster cultivation rafts that it was at least equivalent to natural sources of sedimentation (ref).

64/...[discussion of effects of beach harvesting on birds & sediments & seagrasses & changes created by repeated trampling & harvesting.

70-1/ ...Technological advances are improving the efficiency with which marine organisms are bred and grown...The financial success of shrimp farming has led to a gold rush mentality, with little environmental planning. The disastrous consequences of environmental mismanagement have severely hampered this sector of the aquaculture industry from reaching its full potential and sound a warning shot to other sectors of the industry.

16. Kelly, Jennifer. 2005. Effects of non-native oyster (*Crassostrea gigas* Thunberg) on native eelgrass (*Zostera marina* L.) in the Strait of Georgia, British Columbia. M.A. thesis, Biology Department, University of Alberta.

13/...presence of farmed oysters is correlated with decreased eelgrass abundance (Waddell 1964, Everett et al. 1995, Griffin 1997).

14/...oysters affect eelgrass through accumulation of toxic levels of sulphide in sediments, more than 100 times higher than at reference sites.

17. Massachusetts Aquaculture White Paper--Shellfish Bottom and Off-Bottom Culture

"Shellfish culture is associated with nutrient-loading, but nutrition is obtained from indigenous phytoplankton and particulate matter, rather than from any external food source. Thus, the culture operation does not introduce any "new" nutrients into the marine environment, but promotes the recycling of those which are already present. There is actually a net decrease in nutrient levels in the system, since about only 40% of the total nutrients removed by mollusk culture is released directly to the water column; 30% fall to the bottom as particulate material and 30% are removed in the harvest."

"Shellfish generate solid waste in the form of feces and pseudo feces. Shells which fall from the culture structure also accumulate on the bottom immediately under the raft or longline. Studies of oyster culture in Japan indicate that the amount of solid waste produced by shellfish culture can be considerable. A raft of oysters in Hiroshima Bay holds 350,000-530,000 oysters. During a nine month culture season a single raft will produce 16 metric tons of feces and pseudo feces, with an additional 4.5 tons attributable to feces of fouling organisms growing on the rafts. Approximately 20-30% of this material is deposited on the bottom."

18. Molnar, Jennifer, R. Gamboa, C. Revenga, and M. Spalding. 2008. Assessing the global threat of invasive species to marine biodiversity. *Frontiers in Ecology and Environment* 6(9):485-492.

489/..."The most common pathway for marine species was shipping...The aquaculture industry is the next most common pathway (134 species, 64% of which are harmful)"

490-1/...“We also confirm earlier studies describing the role of aquaculture operations in marine invasions (e.g Naylor et al 2001)...in the two eco-regions that extend along the coastlines of Oregon and Washington State...aquaculture has been the most common pathway for introduction (71% of non-native marine species documented in these eco-regions were introduced by aquaculture)...Of the 33 species known to be associated with oyster farming, 55% are harmful, and most are difficult if not impossible to remove or control.”

The Pacific oyster...can dominate native species and destroy habitat

Species are often introduced to new habitats for economic benefits...can cause serious, unforeseen economic and ecological damage.

19. National Geographic, March 2005. “100 least wanted species.”

114/... Mediterranean mussel (*Mytilus galloprovincialis*) is one of the 9 worst invasive exotic species of aquatic invertebrates (only 2 other molluscs are on the list).

115/...Like wolves, other predators are keystone species whose removal causes a trophic cascade all along the food chain. In a classic 1966 study, biologist Robert Paine intentionally eliminated *Pisaster* sea stars in a Washington intertidal zone. Mussels, which are *Pisaster*'s prey, exploded and pushed other species out.

[Note: This Medit. mussel is the species that shellfish growers have introduced into the Gorge. Fred Zwickle has documented its presence now in Manson's Lagoon, so in addition to infesting the Gorge, it is spreading out of control.]

20. Naylor, R. S. Williams, and D. Strong. 2001. Aquaculture—a gateway for exotic species. Science 294: 1655-56.

Ombudsman of British Columbia. 1988. Public Report No. 15: Aquaculture and the Administration of Coastal Resources in British Columbia.

29/...Recommendation 4.5.2 of the Gillespie report is that “ the government should establish a mandatory environmental monitoring and data gathering system for each aquaculture site and surrounding area, the results of which should be submitted on a regular basis for review of changes in environmental quality.”

32-3/...Recommendation 4.5.4 is: “ The government should continue the use of a distance guideline to separate fish farms” comment: ...”a distance guideline has been established at 3 km between farms....Spacing of fish farms relative to residential settlements or biologically sensitive areas is another matter in which legislated avenues of public or expert involvement, and an independent appeal process, would be useful in securing administrative fairness to local governments, land owners, and the aquaculture industry...”

Recommendations 4.6.1 to 4.6.6 also recommend the discontinuance of aquaculture tenures adjacent to provincial parks and recreation areas

36/...Recommendation 4.10.1: "To be effective, the single window agency would have to be a neutral, rather than an advocate agency." Comment: individuals with influence might be ignoring the rights of certain individuals or communities with legitimate interests. As the industry grows, it is conceivable that the situation might worsen given advantages of economies of scale near populated areas, which are often the scenes of greater user conflicts."

52/...In B.C., municipalities and regional districts have the right to zone the foreshore, including the water surface within their boundaries, for particular activities. While the province has the authority to override the expressed desires of local government and issue a license, the license is always issued subject to the requirements imposed by local governments...residents of Cortes Island have developed a comprehensive set of policies dealing with coastal protection, economic development, public, access, private property interests, and public participation in consideration and approval of applications for aquatic land tenures."

96/...Ombudsman Recommendation 1: "Conflict is likely to be substantially reduced if the aquaculture industry can be clearly seen to be the subject of impartial regulation."

97/ ...1.a.ii: "siting and operational requirements consistent with high standards of environmental integrity with provision for effective environmental monitoring

1.a.iv "explicit recognition of the authority of local or regional governments to establish areas in which specific aqua cultural activities may be limited

1.a.vi. "provision for the office of an Aquaculture inspector to enforce the legislative requirements

98/ ... 1.d. "A neutral impact assessment mechanism should be integrated into the overall aquaculture facility licensing and permitting structure

1.e. "Visual impact and site-specific facility design criteria should be developed

1.f. "Internal and external appeal processes relating to facility siting...The external appeal body should be independent and expert

99/...Recommendation 2: "A framework for integrate management of resources and activities in the coastal zone should be created.

100/...2.e. The concept of "highest and best use" ... should be abandoned and replaced with sound integrated resource management criteria. "Highest and best use" most often is equated with maximum economic yield , and may therefore conflict with values advanced by other Ministries, conservationists, environmentalists, tourism and recreational interests, or Native Indian bands..

101/...Recommendation 3: "Consensual dispute resolution...should be applied as official policy...should be available for the resolution of aquaculture-related disputes which may occur at any stage..."

21. Puget Sound Partnership, Discussion Paper: Species and Biodiversity Topic Forum 2008.

23/...“New species such as lingcod or geoduck are being cultured or considered for culture without extensive research into potential impacts, while cultured species continue to be a vehicle for introducing invasive species.

“At an average rate of entanglement, each of the estimated 4,000 nets in Puget Sound could entangle 92 invertebrates, 13 fish and 7 seabirds each month.”

“the Puget Sound ecosystem has continued to decline...between 2002 and 2004, 14 species were added to these lists (of concern)...The total number of species on the combined lists—63—is indicative of ecosystem decline.”

24/...“To arrest this decline, many scientists suggest focusing on ecosystem-based management, which accounts for the linkages between species and addresses system-wide factors of decline...a shift away from single-species or single-issue management...The U.S. Ocean Policy Commission and the Pew Ocean Commission both called for a shift to ecosystem-based management, and NOAA is following their lead by conducting an Integrated Ecosystem Assessment (IEA) of Puget Sound, with plans for a future U.S. West Coast IEA...Ecosystem management is designed to protect ecosystem structure, functioning and key processes...Ecosystem –based management has been implemented only rarely.

25/...The precautionary principle: Kriebel et al. (2001) describe the precautionary principle to have four central components...The State of California has adopted the precautionary approach as a starting point for addressing 19 fish species.”

Adaptive management occurs when: “management approaches are developed and applied, their impacts are monitored and assessed, and management approaches are modified based on findings. ...it may take years for adaptive management of a given ecosystem to accurately measure and document the effectiveness of management techniques... in practice it is often less effective than expected.”

26/...“Management approaches that “effectively protect and promote species, biodiversity, and food webs include aggressively preventing species invasion, taking an ecosystem approach to management, and prohibiting or limiting harvest in set-aside areas...”

derelict gear removal has been shown to be cost-effective in Puget sound”

31/...WDFW (Washington Dept. of Fish and Wildlife) “manages aquatic nuisance species, focusing on non-native invasive mussels... the Washington Aquatic Nuisance Species Committee, Washington Tunicate Response Advisory Committee

41/...Where should we start?

- enforce existing regulations
- prevent introduction of invasive species, and remove them where already established;

- remove pollutants (including debris and derelict gear from water and sediments and thus from the food web);
- develop an understanding of species, biodiversity, and the food webs;
- protect the marine areas of Puget Sound that support high levels of biodiversity
- ongoing research activities into the effects of harvest and culture, such as the current focus on geoduck aquaculture...Current harvest practices protect their target species, but don't consider the links between those species and other species in the food webs... culture practices ensure the propagation of target species but don't consider their effects on the food webs."

22. Quayle, D. 1988. Pacific Oyster Culture in British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 218

166/...If a raft is left too long (3-5 years) in one place there may be a decline in productivity...This is believed due to the deposition and accumulation of oyster feces and pseudo feces that amount to 0.6-1.0 t (dry weight) of material per year from a raft 10m x 6 m, holding between 60 000 and 100 000 oysters. This deposition is rich in organic material and when stirred by wave action, may create a suspension of silt accompanied by a release of hydrogen sulphide gas, both of which are detrimental to the well-being of oysters.

23. Quesada, Humberto, R. Wenne, and D. Skibinski. 1995. Differential introgression of mitochondrial DNA across species boundaries within the marine mussel genus Mytilus. Royal Society of London, Proceedings B, Biological Sciences 262:51.

--Mytilus taxa are very closely related and no single morphological or genetic character is perfectly diagnostic. There is variation in the extent of hybridization with contact.

--mussels can maintain their morphological integrity despite extensive hybridization

24. Rensel, John, R. Horner, and J. Postel. 1989. Effects of phytoplankton blooms on salmon aquaculture in Puget Sound, Washington: Initial research. The Northwest Environmental Journal 5:53-70.

Salmon losses due to phytoplankton blooms persist and fish-farming industry officials consider this to be their number one problem.

25. Rosenthal, Harald, Donald Weston, Richard Gowen and Edward Black. 1988. Environmental Impact of Mariculture. International Council for the Exploration of the Sea, Report. Plagade 2-4,1261 Copenhagen K.

10/...A good example of the effects of mariculture on the benthos is provided by studies of a Swedish mussel site where the deposition of feces and pseudo feces created several centimeters of sediment each year (Mattson & Linden, 1981). Within six months after the start of culture, brittle stars had disappeared and species originally dominant in the unimpacted community decreased in number and finally disappeared after 15 months. Opportunistic species became established in the culture area concurrently with the decline of the original fauna. Within six months, large populations of *Capitelia capitata* were established, and the species later reached densities as high as 20,000 individuals/m². Other opportunistic polychaetes (*Scoloplosia fuliginosa* and *Microphthalmus sczelklowii*) appeared after one year of culture.....Six months after removal the bottom was still covered by 20-40 cm of mussel shells and sulphide rich sediments. The benthos was numerically dominated by opportunistic species indicative of disturbance. Monitoring continued for a year and a half after mussel removal, during which only very limited macrobenthic recovery was observed."

8/...The importation of exotic species particularly shellfish, caused the introduction of new algae which can be considered as pests: so called "Japweed" has been introduced into British Columbia waters. Their growth tend to replace some native algae. Development of shellfish increases the release of nutrients and often provides additional substrate for attachment (e.g. cages, nets, racks, etc.) As a consequence, a large growth of green macro-algae can cause increased fouling on various substrates. The widespread dispersal of their spores can induce green tides near the culture installations, particularly in enclosed bays, marshes and ponds. These algae act in competition for nutrients with phytoplankton stocks, and this can have implications for the cultivation of molluscs. "Green tides" can also cause large decreases in dissolved oxygen.

8/...Arakawa (1973) was able to correlate the frequency of phytoplankton blooms in Hiroshima Bay with historical trends in oyster production in those waters."

8/...The numerous poles used to support the mussels reduced current velocity by up to 50%, thus accelerating the deposition of fine sediments. It is estimated that 30% of the oyster and mussel farms of France face problems of active sedimentation, forcing occasional relocation and abandonment of old beds (Sornin 1979)."

26. Simenstad, C, L. Weitkamp, and J. Cordell. 1993. Effects of substrate modification on littoral flat epibenthos: assemblage structure changes associated with predator exclusion nets. Technical Report FRI-UW-9310 to Washington Department of Fisheries, Brinnon, Washington.

12-13/...With nets, densities of selected, tropically important (fish prey) epibenthos taxa were generally depressed at the moderately exposed pebble/fine sand beach, but increase in coarse-grained sediment beach.

27. Sorokin, lu., et al. 1999. Need for restricting bivalve culture in the southern basin of the Lagoon of Venice. Hydrobiologia 400:141-148.

--impact of unregulated short-necked clam fishery has created an environmental emergency.

--suspended organic matter and acid volatile sulphides was higher in areas with bivalve farming

--biomass of micro-plankton in farming areas was quite high and mesozooplankton was extremely abundant.

28. Stenton-Dozey, Jeanie, Trevor Probyn, and Alistair Busby. 2001. Impact of mussel raft-culture on benthic macrofauna, in situ oxygen uptake, and nutrient fluxed in Saldanha Bay, South Africa.

"Raft biodeposition had a dramatic effect on benthic macro-fauna biomass, reducing it to between 5 and 15% of that of reference sites."

29. Straus, Kristina, L. Crosson, and B. Vadopalas. 2008. Effects of Geoduck aquaculture on the environment: a synthesis of current knowledge. Washington Sea Grant, Washington State Legislature (SSHB 2220).

http://www.wsg.washington.edu/research/geoduck/Geoduck_LiteratureReview.pdf

21/...“suspended or rack culture have a greater potential to effect the environment because more animals may be cultured in a given area...There are many ways that aquaculture can disturb the environment, and these disturbance events vary on spatial, temporal, and intensity scales (Simenstad and Fresh 1995)”

“...high densities of bivalves in suspended culture could rapidly recycle ingested organic matter back to the water...and thus stimulate phytoplankton growth (Sorokin et al 1999, Nizzoli et al. 2006...bivalves can locally decrease phytoplankton abundance...”

22/...Phytoplankton biomass was reduced by 37% after passing over an intertidal mussel bed...in Norway more than 50% of the phytoplankton depleted at the middle of the farm...”

“several dramatic ecosystem changes attributed to the robust filtering ability of bivalves. The loss of historical oyster reefs in Chesapeake Bay...has

been associated with phytoplankton blooms, increased turbidity, and the loss of SAV (submerged aquatic vegetation)... invasive clams introduced to the San Francisco Bay have altered food web dynamics via phytoplankton depletion to the detriment of native copepods

23/...“Oysters and mussels...increase their bio-deposition under high phytoplankton concentrations...bivalve bio-deposits are high in carbon and nitrogen, show high microbial activity, and may increase denitrification. Bio-deposition increases the flow of particulate nutrient to the sediment, increases sediment oxygen demand, and may increase dissolved nutrients in the water column

Bio-deposition rates of a 1-yr-old scallop...were 34-133 mg dry material per individual per d with mean rates of C, N, and P bio-deposition of 4.0, 0.51, and 0.11 mg per individual per d...ammonia concentrations are well documented to be higher under longline mussel farms.

“high bio-deposition rates may lead to anoxic conditions. The mechanism for anoxia was demonstrated at an oyster farm in France (Castel et al. 1989). Oyster bio. These changes led to anoxia which caused localized changes in benthic diversity.”

24/...“Many studies have shown that shellfish aquaculture can lead to increased sedimentation...nearly 2.5 times greater under scallop cultures... sedimentation four times higher on netted Manila clam plots

25/...Castel et al. (1989) “observed dramatic changes to the benthic community: meiofauna levels were 3-4 times higher at the oyster farm while macro-fauna levels were approximately 50% lower ...The benthic community under a New Zealand longline mussel farm experienced dramatic declines in species diversity from a healthy and diverse complex of species to a community consisting entirely of infaunal polychaetes (Kaspar et al. 1985) A...A decrease of suspension feeders and an increase of predators have also been noted beneath oyster farms (Dubois et al. 2007)

...more mobile invertebrates and fishes were found at the culture sites than the unstructured sand flat...Intertidal geoduck culture operations are sited in locations where birds forage at low tide.

26/...20%+ of intertidal in Baynes Sound is used for shellfish cultivation; Carswell et al. 2006 found no correlation between shellfish aquaculture variables and scoter density and conclude that mussel aquaculture may have beneficial effects for birds., but this interaction is not well studied

“In most cases...mechanical harvest reduced the number of species present and their abundance mix the sediment layers and reduce infaunal species

27-8/...“significant ecological changes in the surrounding community are likely before PCC (production carrying capacity) is reached, and this level of development may be unacceptable to many stakeholders. Ecological carrying capacity (ECC) is the highest level of culture that can be undertaken without leading to significant changes in ecological processes, individual species, or communities in the surrounding habitat.”

“Social carrying capacity (SCC) incorporates both PCC and ECC while taking into account demands of both the population (socioeconomic and cultural factors including employment, fisheries, and recreation).” No models yet developed that estimate SCC.

“at the theoretical PCC, the food web collapses into a nutrient-phytoplankton-bivalve culture”

30. Suchanek, T. et al. 1998. Zoogeographic distribution of the sibling species *Mytilus galloprovincialis* and *M. crossolus* and their hybrids in the North Pacific. *Biological Bulletin* 193:187-194.

31. Weston, Donald. 1985. The Environmental effects of floating mariculture in Puget Sound. Washington Department of Fisheries and Washington Dept. of Ecology.

49/...mussels produce 17 tons of feces per raft per year

50/... sediment deposition is 2-4 times normal under mussel longlines

56-8/... beneath mussel rafts fecal material prevents the establishment of aerobic sediment layers, creates negative Eh (redox potential, O₂ content) at the surface of benthic sediments.

Organic enrichment (TOC, TVS) occurs under mussel culture with high sulphide concentrations as the result of the reduced environment; this increases with the time that rafts are in place to 10 times normal after 6 years & causes mortality in aquaculture species [and probably many other species--BH] and increased diseases

60/...increases in P and N occur in solid wastes from mariculture with a high release rate to the water column creating anaerobic conditions

61/...O₂ consumption increases together with N compounds and phosphates. Ideally aquaculture should be sited to disperse wastes. In practice, most aquaculture is not and there is visible accumulation of wastes under facilities.

62/ ...Visible accumulations are generally less than 30 m from facilities, but it is not known if sediment chemistry is affected farther away [or overall in the water column—BH]

63/...This study recommends avoiding putting facilities in silted embayments or other locations that promote waste accumulation.

65-6/...Increased organic input from aquaculture creates an initial rise in biomass, abundance and diversity followed by the domination of a few species, then followed by total system collapse with anaerobic conditions.

67/...Changes under mussel longlines eliminate original species after 15 months with no recovery 1 1/2 years after removal of facilities.

69/...Phytoplankton blooms can create an initial enrichment.

ALL studies show an effect of floating mariculture on benthos; “Directly beneath the culture operation there was, at some sites, a complete absence of

macrofauna...the area of effect...on the macrobenthos generally corresponded to a 30 m radius of the culture facility.

“Only two investigators ...observed...a bio-stimulated zone around mariculture facilities, and in both cases data to support the claim were not presented...this potentially ‘beneficial’ effect should not be construed to mean that there is no net adverse effect of organic enrichment on the benthos (i.e., that the zone of bio-stimulation compensates for zones of mortality or zones of community degradation).”

71/...“as the level of organic enrichment increases, the extent of potentially adverse effects increase much more rapidly than the extent of potential bio-stimulation... recovery of the benthos following closure...require 3-8 years, often 10 years or more. ...as enrichment increases, sensitive species are replaced by a few opportunistic species tolerant of low dissolved oxygen, high sulfide concentrations...at high rates of organic input, complete community mortality occurs.”

72/...Major alterations of the benthos beneath and around mariculture operations is typically observed

74-76/...Low O₂ and high S are probably also harmful to the mega invertebrates (geoducks, large bivalves, &c.) leading to the exclusion or mortality of non-mobile fauna.

Almost all operations enhance fish and megafauna including mobile megafauna (crabs, starfish)

76/...“in cases where very limited flushing permits development of near-bottom anoxia or other pronounced deterioration of water quality, would an adverse effect on fish or epibenthic megafauna be expected. This deterioration has rarely been observed. More often there is an increase in abundance, species number, diversity, and/or biomass of fish and megafauna in the vicinity of culture operations.”

129/ ...“quantification of adequate flushing and determination of a maximum allowable culture intensity are very difficult...no such predictive capability currently exists...the objective of past studies has typically been the maintenance of the health of the cultured animals rather than environmental protection...Most work on the subject has been done by the Japanese where intensive culture in shallow, enclosed embayments has, in some cases exceeded the carrying capacity of the culture grounds. “

32. Wonham, Marjorie. 2004. Mini-review: Distribution of the Mediterranean mussel, *Mytilus galloprovincialis* and hybrids in the northeast Pacific. *Journal of Shellfish Research*.

“*M. galloprovincialis* alleles...are more widespread and abundant in Washington than previously known...indicate the presence of a major zone of sympatry and hybridization in Washington waters ...”

Research/Reports from 'Protect Our Shoreline' (USA)

- 1. Ruesink, Hacker, Dumbauld. n.s. Scale-dependent and indirect effects of filter feeders on eelgrass: Understanding complex ecological interactions to improve environmental impacts of aquaculture**
<http://www.fish.washington.edu/wrac/pdfs/Filter-Feeders-and-Eelgrass.pdf>

--"We have observed direct negative effects of disturbance and of geoducks on eelgrass density."

--"On the other hand, we have seen little evidence of indirect positive effects of geoducks"

- 2. Inglis, Graeme, et al. 2000. An Overview of Factors Affecting the Carrying Capacity of Coastal Embayments for Mussel Culture**
Ministry for the Environ

http://www.aquaculture.govt.nz/files/pdfs/Mussel_farms_-_carrying_capacity_of_coastal_embayments.pdf

--p. 9. *Mytilus galloprovincialis* is a fouling organism and that is especially noticeable in poorly flushed waters. "...organic enrichment of sediments by mussel feces and pseudofeces can cause increases in the rates of respiration and oxygen consumption by benthic micro-organisms." "Severely affected areas are characterized by films of chemoautotrophic sulphur bacteria (*Beggiatoa*) at the sediment-water interface..."

--P. 13 "Changes in the pattern of nutrient cycling have been linked to outbreaks of toxic red tide organisms (Cembella et al. 1997) and may indirectly affect recruitment of other important marine species. For example, it appears that blooms of the red tide dinoflagellate, *Gymnodinium mikimotoi*, in Japan are stimulated by increased release of ammonium and other micronutrients from the sea floor."

- 3. Pacific Oysters in the European Wadden Sea: an Irreversible Impact in a Highly Protected Ecosystem Stefam Nehring, Germany , 2003 P. 19-21**
http://www.stefannehring.de/downloads/142_Nehring-2003_Aliens-17_pacific-oyster.pdf

--P. 21. Article discusses the cultivation and escapement of the introduced *Crassostrea gigas*, the Pacific Oyster, as an example of what can happen to the natural ecology of a bay such as the Wadden Sea. The native oyster was originally harvested to extinction. Pacific oyster introduced from 1971. Since Pacific Oyster has a higher growth rate than some other species, there has been a decline in the original species. --P. 20. "...The threats of intensified aquaculture and increasing international transfer of exotic species for stocking and culture posed to natural communities needs to be pushed up to political

agenda." --P. 21 "...Alien invasions in aquatic systems are irreversible and should be avoided wherever possible."

4. Giles, Hilke, and Conrad Pilditch. 2006. Effects of mussel (*Perna canaliculus*) bio-deposit decomposition on benthic respiration and nutrient fluxes

Department of Biological Sciences, University of Waikato, Hamilton, New Zealand

<http://www.springerlink.com/content/n1534x64288t301t/>

--Suspension-feeding bivalves increase the quantity and quality of sedimenting organic matter through the production of feces and pseudo feces that are re-mineralized in coastal sediments and thus increase sediment oxygen demand and nutrient regeneration. Bivalves are intensively cultivated worldwide; however, no bivalve bio-deposit decay rates are available to parametrize models describing the environmental effects of bivalve culture.

-- observed in situ oxygen demand enhancements under mussel farms. Ammonium release increased rapidly after 5 days was 3.6 times higher compared to control cores.

5. Tang, Qishing, and Jianguang Fang. n.d. Impacts of Intensive Mariculture on Coastal Ecosystems and Environment in China and Suggested Sustainable Management Measures

--" the biomass of seaweed and bivalves in the seabed of intensive mariculture areas has declined dramatically since the 1970s. ... eelgrass *Zostera marina* were so rich that it could be found almost everywhere along the coastal zone from north to south of China before the 1970s, it is now very difficult to find. Although there are many factors causing the decline of eelgrass resources, the accumulation of bio-sediment from the intensive suspending culture may be one of the most important factors involved."

--"This bio-sediment matter can change not only the texture of the seabed, but can also be disturbed into the water column, especially during the storm season. This re-suspended particulate not only can cause heavy mortality by blocking the gills of bivalves, but may sometimes induce the occurrence of harmful micro-algae blooms because it can increase nutrient concentrations such as N, P, etc., in the intensive mariculture areas very rapidly ... heavy mortality of bivalves cultivated in coastal zone has increased year by year since early 1990s in China. ... it is recognized that the accumulation of bio-sediment on the intensive mariculture seabed is harmful to the ecosystem, the environment and to mariculture.

Recommendations:

1. To establish models to predict the potentiality of new sites for mariculture based on their mariculture carrying capacity and ecological carrying capacity.
2. To pay great attention to study the impact of mariculture on ecosystem and environment, the interaction between mariculture and environment, the relationship between intensive mariculture in the coastal zone and the variability of marine fisheries resources, etc.
3. To re-evaluate intensive mariculture sites in coastal zones not only based on their carrying capacity, but also according to standards of human health.
4. To establish a sustainable management system that can determine and control the mariculture species, areas and scale, density, culture models in different sites based on the specific ecological and environmental conditions of different regions.

6. Couturier, Christine. n.d. Effects of physical, chemical and rheological characteristics of mud on bioenergetics and habitat selection of the common sole *Solea solea*. Ph.D. Dissertation.

http://www.ifremer.fr/crema/thesards/CCouturier/couturier_anglais.htm

- " preliminary experiments showed the accumulation of organic matter on sea bed can influence the value of mudflats as nursery grounds for benthic fishes. ... water viscosity increase can impair the ventilatory activity of fish, reducing their physiological and adaptive performances ."
- "the accumulation of feces and pseudo feces on sea bed at the vicinity of bivalve farming facilities. During periods of intense filtration, shellfish culture in Marennes-Oleron Bay was calculated to generate up to 6 tons (dry weight) of bio-deposit per hectare and per day."

7. Heffernan, M.L. n.d. A Review of the ecological implications of mariculture and intertidal harvesting in Ireland. Irish Wildlife Manuals No. 7

<http://www.npws.ie/en/media/NPWS/Publications/IrishWildlifeManuals/Media,3762,en.pdf>

--documents effects of anti-predator netting, hydrology, harvesting, sediment enrichment, etc.

--P. 80 "We must resist introduction of such a method (as is used in Washington State for culture of Pacific oysters) to Ireland.

--P. 96."...most epibenthic crustaceans were depressed under the predator exclusion nets compared to the un-netted control."

--P. 96. "...the presence of the netting was shown to increase sedimentation which elevated the ground profile by about 10 cm and caused a small but significant increase in the percentage of fines and organic content of the sediment."

8. Willner, Georgina. 2006. The Potential Impacts of the Commercial Geoduck (*Panope generosa*) Hydraulic Harvest Method on Organisms in the Sediment and at the Water-Sediment Interface in Puget Sound. Master's Thesis, Evergreen State College.

--Hydraulic harvest methods of geoducks in subtidal areas of Puget Sound impact all organisms in the sediment.

--Sediment changes may cause irreversible changes in the ecosystem functions and nutrient cycling processes could be lost.

--Organisms removed or killed likely cause changes in cohesiveness and stability of the community structure and their loss may cause modification to microbial distribution, activity and processes that impact nutrient cycles.

--Pulses of nutrients, pollutants and release of dormant cysts and eggs could cause increase in phytoplankton blooms, paralytic shellfish poisoning and other health risks to Washington State citizens.

--Geoduck and other infaunal populations will become fragmented, affecting recovery rates.

9. McKindsey, C.W., M.R. Anderson, P. Barnes, S. Courtenay, T. Landry, and M. Skinner. 2006. Effects of shellfish aquaculture on fish habitat. Canadian Science Advisory , P. 25-26.

http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2006/RES2006_011_e.pdf

--" mussels consumed (based on stomach content analysis) copepods (<1.5 mm), crab zoeas (2mm), fish eggs (1-2mm), and even amphipods (5-6mm). Subsequent to this, Lehane and Davenport (Lehane and Davenport 2002) showed that mussels consumed organisms up to 3mm in length and that cockles (*Cerastoderma edule*) and scallops (*Aequipecten opercularis*) are also capable of consuming considerable quantities of zooplankton, both when suspended in the water column and when on the bottom. The size classes of organisms consumed in these studies suggest that the larvae of most commercial species may be at risk from this type of predation."

10. Newell, Roger. n.d. Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs

<http://www.hpl.umces.edu/faculty/newell/ecobivalve2.pdf>

--P.1~Environmental conditions at bivalve aquaculture sites should be carefully monitored, however, because bio-deposition at very high densities may be so intense that the resulting microbial respiration reduces the oxygen content of the surrounding sediments. Reduction in sediment oxygen...can be toxic to the benthos."

11. Simenstad, Charles. n.d. Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: scales of disturbance, P. 63.

<http://www.springerlink.com/content/763314272087w732/fulltext.pdf>

“ Management strategies that fail to consider the tolerance of estuaries to anthropogenic disturbance, such as that posed by intensive aquaculture, may well threaten the sustainability of estuarine resources and ecosystems processes upon which coastal economies depend. Estuaries have a critical role in the life histories of many economically and ecologically important animals. Salmon, herring, smelt, crab and flatfish feed in Pacific Northwest estuaries... and several species of migratory waterfowl and shorebirds feed on the large invertebrate production that occurs on the mudflats..."

Shellfish Industry Documents of Intensive Commercial Shellfish Aquaculture

1. Pacific Shellfish Institute, Baywater Inc., U. Washington. 2004. Comprehensive Literature Review and Synopsis of Issues Relating to Geoduck (*Panopea Abrupta*) Ecology and Aquaculture Production

This document, put forward by industry to support geoduck aquaculture, confirms that there are mostly unknowns in the area of intensive geoduck farming and that extensive research is needed before expanding geoduck farming activities.