Shellfish Aquaculture Interactions with the Environment - References

Anderson, J.L., R.J. Johnston, S.J. Jancart et al. A Strategic Plan for Rhode Island Aquaculture; RI Legislative Commission on Aquaculture. Dept. Env. & Nat. Res. Econ., URI. 1997. 169p.

Booth, J. and H. Rueggeberg. 1989. Marine birds and aquaculture in British Columbia: assessment of geographical overlap. Technical Report Series No. 73. Wildlife Service, Pacific and Yukon Region, British Columbia. 53 p. Notes that in 1989 high overlap in bird use and aquaculture sites for goldeneye sp., but medium for Bufflehead, scoters, cormorants, grebes, gulls, loons, Mallards, mergansers, and raptors. Little overlap existed between aquaculture and colonies of the birds studied and **none of the species studied appeared to be significantly impacted by aquaculture** in terms of number of colonies or the amount of important habitat area (colonies, breeding areas, moulting areas) that overlap with aquaculture operations.

Cheney, D., A. Suhrbier, A. Christy, J. Davis, M. Luckenbach, T. Getchis, C. Newell, D. Angel, and J. Richardson. Environmental and Technical Assessment of Alternative Shellfish Production Methods. NOAA/National Marine Aquaculture Program. In Prep.

Coen, L.D., M.W. Luckenbach, and D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. pp. 438-454 In: Fish Habitat: Essential Fish Habitat and Rehabilitation. Am. Fish. Soc. Symp. 22.

Connolly, L.M., M.A. Colwell. 2005. Comparative use of longline oysterbeds and adjacent tidal flats by waterbirds. Bird Conservation International 15: 237-255. Examined the comparative use of tidelands by birds with and without oyster long line sets. In that umboldt Bay study, the authors found significant differences between tidelands occupied with oyster longlines, and the paired control tidelands that were unoccupied. Seventeen species of birds were observed in the study plots. Seven of the 13 shorebirds, and three of four wading birds were nominally more abundant among the longline plots in the five paired treatments, and diversity, as measured by the Shannon diversity index, was also greater on the longline plots. Black-bellied plovers were more abundant on control plots, whereas the abundance of marbled godwit (Limosa fedoa), long-billed curlew (Numenius americanus) and Great Blue Heron (Ardea Herodias) showed no definite pattern. Where statistically significant differences were noted in use, five species (willet, whimbrel, dowitcher, peeps, and black turnstone) were always more abundant in the long-line plots, whereas **only one species, black-bellied plover were more abundant in control plots**.

Cranford, P., M. Dowd, J. Grant, B. Hargrave, and S. McGladdery. 2003 Ecosystem level effects of marine bivalve aquaculture. *In*, Fisheries and Oceans Canada. A Scientific Review of the Potential Environmental Effects of Aquaculture in Aquatic Ecosystems –Vol 1. Can. Tech. Rep. Fish. Aquat. Sci. 2450: ix + 131 p. A strong indication that bivalve filter-feeders are able to control suspended particulate matter in some coastal systems comes from documented ecosystem changes that occurred after large biomass variations in natural and cultured bivalve populations. Population explosions of introduced bivalve species in San Francisco Bay and dramatic reductions in oyster populations in Chesapeake Bay have been implicated as the cause of large changes in phytoplankton biomass and production experienced in these systems (Nichols 1985; Newell 1988; Nichols et al. 1990; Alpine and Cloern 1992; Ulanowicz and Tuttle 1992). Research on the whole-basin environmental effects of bivalve aquaculture in France and Japan indicate that intense bivalve culture in these regions led to changes in particulate food abundance and quality, resulting in large-scale growth reduction and high mortalities in the cultured bivalves (Héral et al. 1986; Aoyama 1989; Héral 1993). Speculation that intense bivalve culture can affect coastal ecosystems by reducing excess phytoplankton associated with eutrophication have been supported by some laboratory and field observations, but have not been rigorously proven.

Crawford, C.M., C.K.A. Macleod, and I.M. Mitchell. 2003). Effects of shellfish farming on the benthic environment. Aquaculture 224:117-140. Overall, the shellfish farms showed a minor effect on the benthic environment within the lease area, and the impact was much less than that from salmon farms. The risk of ecological impact from shellfish farming in Tasmania was also assessed qualitatively. The international scientific literature was examined for details of ecological effects of shellfish farming, and these results were related to the Tasmanian situation. **Beneficial effects of shellfish farming were identified as increased monitoring of the health of estuarine and coastal waters, the potential for scallop aquaculture to enhance wild stocks, and the likelihood of improved water clarity and reduced nutrients and phytoplankton concentrations in some areas.** Detrimental effects include the risk of spread of pests and pathogens as a result of shellfish farming activities, noting that this risk also exists through other anthropogenic activities. Changes to the habitat may occur on lease areas, whereas the risks of ecological impact due to organic enrichment and reduced food resources for filter feeders were rated as low.

Crawford, C. 2003b. Qualitative risk assessment of the effects of shellfish farming on the environment in Tasmania, Australia. Ocean and Coastal Management 46(1-2): 47-58. Community concerns about the detrimental effects of shellfish farming on the environment have been increasing over the last decade in many shellfish producing countries, including in Tasmania, Australia. Environmental effects of shellfish farming can be assessed and managed using risk management processes, The qualitative risk assessment of detrimental impacts of shellfish farming rated the risk of spread of introduced pests and/or pathogens as high. However, this high risk rating would also apply to many other activities in the marine environment, such as commercial and recreational fishing and sea transport. The level of risk due to habitat disturbance was rated as moderate within the lease area, but would not be expected to extend outside the farm. Risks of organic enrichment of the seabed and reduced food resources for other filter feeders were both rated as low.

Crawford, C. (2003) Environmental management of marine aquaculture in Tasmania, Australia. Aquaculture. 226(1-4)129-138. Marine farming is an important rural industry in coastal bays and estuaries of Tasmania. The two main species cultured are the introduced Pacific oyster, Crassostrea gigas, and Atlantic salmon, Salmo salar. Legislation has been introduced to assist the development of aquaculture, and this includes requirements for environmental management, such as baseline assessments and routine monitoring of leases. Local impacts on the seabed around salmon farm s are monitored using video footage, analysis of benthic invertebrate infauna, and chemical measures (redox and organic matter). **Monitoring of shellfish farms is minimal because our research has shown that shellfish culture is having little impact** on the environment.

Crawford, CM; Macleod, C.K; Mitchell, I.M. 2003. Effects of shellfish farming on the benthic environment Aquaculture 224(1-4)117-140. 30 Jun 2003. The benthic environment under and near three shellfish farms in Tasmania, Australia, which had had a relatively high level of production over many years was investigated. Benthic samples were collected along transects which ran across the farms, generally from 100 m upstream to 100 m downstream. Sediment deposition, redox values, sediment sulphide concentrations, organic carbon content and water turbidity levels near the bottom were significantly different between the farms but not between sites outside the farm, at the boundary and sites within the farm. Video recordings at one farm showed dense beds of seagrass both under trays of oysters and outside the farm. The benthic infauna did not show clear signs of organic enrichment, and neither univariate nor multivariate measures of benthic infauna were significantly different between sites inside and outside the farm, although they were different between farms. It was concluded from these results that **shellfish farming is having little impact**, and much less than salmon farming, on the benthic environment in Tasmania. Thus extensive monitoring of shellfish farms would appear to be not necessary.

Dealteris, J.T., B.D. Kilpatrick, R.B. Rheault. 2004. A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation, and a non-vegetated seabed. Journal of Shellfish Research, Vol. 23, no. 3, 867-874. Rhode Island; conclude that modified rack and bag gear for grow out of American oyster *Crassostrea virginica* has greater habitat value than shallow nonvegetated seabed in a tidal estuary, and has equal or better value to submerged aquatic vegetation (eelgrass *Zostera marina*). Habitat value as assessed from abundances of marine organisms and species diversity indices. **Species richness and abundance was significantly higher throughout the year in the seabed plots with SAG than in the seabed habitat with seagrass, or the bare seabed**. Found increased surface area (shell, wire, and plastic mesh) and **physical structure of rack and bag gear provided habitat for many organisms throughout the year, particularly early life history stages of native species of fish and invertebrates**. Many good references to ecological importance of oyster and artificial reefs.

Deslous-Paoli, J-M; Souchu, P; Mazouni, N; Juge, C; Dagault, F (1998) Relationship between environment and resources: impact of shellfish farming on a Mediterranean lagoon (Thau, France) Oceanol. Acta. 21(6)831-844 Shellfish farming leaves its mark on the environment in which it has developed, and the men who depend upon it. These changes have altogether balanced the lagoon cycle and have caused disastrous episodic events. **Shellfish farming nutrient transformations increase ecosystem productivity, even if the filtration pressure keeps phytoplankton biomass at a low level. Storage of phosphorus and nitrogen in animal tissue limits eutrophication in this ecosystem.** Transfer of oysters from growout facilities increases animal and vegetal specific diversity. The presence of large amounts of shellfish allows for the development of a massive benthos, while organic enrichment from biodeposition changes the specific composition of soft-bottom benthos.

Doering, P.H., Kelly, J.R., Oviatt, C.A., Sowers,T. 1987. Effect of the hard clam *Mercenaria mercenaria* on benthic fluxes of inorganic nutrients and gases. Mar. Biol. 94(3):377-383.

Environmental Defense. 1997. Murky Waters: Environmental Effects of Aquaculture in the US., NY, NY.

Environmental Protection Agency. September 2002. 57 Federal Register 57,872, 57,885.

Everett, R., G. Ruiz, and J. Carlton. 1995. Effect of oyster mariculture on aquatic vegetation: an experimental test in a Pacific Northwest estuary. Mar. Ecol. Prog. Ser. Vol 125. 205-217.

Ferraro, S.P. and F. A. Cole. 2006. Benthic macrofauna—habitat associations in Willapa Bay, Washington, USA. Estuarine Coastal and Shelf Science (in press).

Ferrero, S.P. and F.A. Cole. 2001. Oyster grounds, a superior habitat for small, sediment-dwelling invertebrates. U.S. Environmental Protection Agency. Presented at the 55th Annual Conference of the

Pacific Coast Shellfish Growers Association and the National Shellfisheries Association – Pacific Coast Section. Sept 20-21, 2001. Abstract Estuary-wide benthic macrofauna-habitat associations in Willapa Bay, Washington, United States, were determined for 4 habitats (eelgrass [*Zostera marina*], Atlantic cordgrass [*Spartina alterniflora*], mud shrimp [*Upogebia pugettensis*], ghost shrimp [*Neotrypaea californiensis*]) in 1996 and 7 habitats (eelgrass, Atlantic cordgrass, mud shrimp, ghost shrimp, oyster [*Crassostrea gigas*], bare mud/sand, subtidal) in 1998. There were significant differences among habitats within- and between-years on several of the following ecological indicators: mean number of species (S), abundance (A), biomass (B), abundance of deposit (AD), suspension (AS), and facultative (AF) feeders, Swartz's index (SI), Brillouin's index (H), and jackknife estimates of habitat species richness (HSR). In the 4 habitats sampled in both years, A was about 2.5x greater in 1996 (a La Nina year) than 1998 (a strong El Nino year) yet relative values of S, A, B, AD, AS, SI, and H among the habitats were not significantly different, indicating strong benthic macrofauna-habitat associations despite considerable climatic and environmental variability. In general, the rank order of habitats on indicators associated with high diversity and productivity (high S, A, B, SI, H, HSR) was eelgrass = oyster > Atlantic cordgrass > mud shrimp > bare mud/sand > ghost shrimp = subtidal. Vegetation, burrowing shrimp, and oyster density and sediment %silt + clay and %total organic carbon were generally poor, temporally inconsistent predictors of ecological indicator variability within habitats. The benthic macrofauna-habitat associations in this study can be used to help identify critical habitats, prioritize habitats for environmental protection, index habitat suitability, assess habitat equivalency, and as habitat value criteria in ecological risk assessments.

Gibbs, M.T. 2004. Interactions between bivalve shellfish farms and fishery resources. Aquaculture 240:267-296.

Glascoe, S. and A. Christy. 2004. Coastal urbanization and microbial contamination of shellfish growing areas. Puget Sound Action Team Olympia, WA. Publication # PSAT04-09, 27 pp.

Gottleib, S. J. and Schweighofer, M. E. 1996. Oysters and the Chesapeake Bay ecosystem: A case for exotic species introduction to improve environmental quality? Estuaries 19: 639-650.

Grant, J., A. Hatcher, D.B. Scott, P. Pockington, C.T. Schafer, G.V. Winters. 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries, Vol. 18, no. 1A, pp. 124-144. The impact of suspended mussel culture (Mytilus edulis, M. trossulus) on the benthos of a small Nova Scotia cove (7 m depth) was assessed using methods involving both benthic metabolism and community structure. Cluster analysis of macrofauna usually provided a clear separation between sites. Since the construction of a causeway (1968), foraminifera species composition showed a temporal response to temperature changes in the cove by shifting toward calcareous species, but assemblages downcore showed little or no relationship to aquaculture impacts. Although there is a shift toward anaerobic metabolism at the mussel lines, the impact of mussels falling to the sediments was more noticeable in benthic community structure than was any impact due to organic sedimentation or hypoxia. **In general the impact of aquaculture on the benthos appeared to be minor.** Further assessment of these consequences may mandate both taxonomic and energetic approaches to impact assessment.

Han Jie, Zhang Zhinan, Yu Zishan, and John Widdows, 2001. Differences in the benthic-pelagic particle flux (biodeposition and sediment erosion) at intertidal sites with and without clam (*Ruditapes philippinarum*) cultivation in eastern China. Journal of Experimental Marine Biology and Ecology 261 (2001) 245-261.

Hamouda, L., K.W. Hipel, and D.M. Kilgour**.** 2004. Shellfish conflict in Baynes Sound: a strategic perspective. Environmental Management 34(4):474-486. The shellfish aquaculture industry (SAI) has operated in Baynes Sound, British Columbia (BC) since the early 1900s. Recognizing the economic potential of the area, the industry has requested additional farming opportunities. However, Baynes Sound upland residents and many other stakeholders have expressed concerns that SAI activities are having a negative impact on the environment, quality of life, and other nonaquaculture resource uses in the area. To assist in assessing the strategic aspects of this conflict, the decision support system GMCR II is employed here to apply a new methodology, the graph model for conflict resolution, to systematically analyze the ongoing conflict over shellfish aquaculture development in Baynes Sound within a social, economic, and environmental framework. Valuable insights are procured to guide decision-makers toward sustainability of the shellfish industry.

Haven, D.S., and R. Morales-Alamo. 1966. Aspects of biodeposition by oysters and other invertebrate filter feeders. Limnol Oceanogr 11, 487-498. www.aslo.org/lo/toc/vol_11/issue_4/0487.pdf
Quantities of suspended matter removed by oysters (Crassostrea virginica) and deposited as feces or pseudofeces varied seasonally, reaching maxima in September. Laboratory studies indicated that the oysters on 0.405 hectare of an estuarine bottom may produce up to 981 kg of feces and pseudofeces weekly. The deposits contained 77-91% inorganic matter, mostly illite, chlorite, and mixed-layer clays, 4-12% organic carbon, and 1.0 g/kg phosphorus. Filter feeders may influence deposition, transport, and the composition of suspended sediments in estuaries.

Heral, M. 1993. Why carrying capacity models are useful tools for management of bivalve culture. In: Dame, R.F. (ed.) Bivalve Filter Feeders in Estuarine and Coastal Ecosystem Processes. Springer-Verlag, Heidelberg. p. 455-477.

Holsman, K.K., P.S. McDonald, and D.A. Armstrong. 2006. Autogenic ecosystem engineers and the influence of habitat complexity on intertidal migrations by a transient predator. Abstract. Journal of Shellfish Research 25: 740.

Hosack, G. R., B.R. Dumbauld, J.L. Ruesink, and D.A. Armstrong. In Press 2006. Habitat associations of estuarine species: Comparisons of intertidal mudflat, seagrass (*Zostera marina*) and oyster (*Crassostrea gigas*) habitats. Estuaries and Coasts 29(6):

Hosack, G., B. Dumbauld, I. Fleming, and D. Armstrong. 2006. Juvenile chinook salmon (*Oncorhynchus tswawytscha*) utilization of low-intertidal eelgrass and oyster aquaculture beds. Abstract. Journal of Shellfish Research 25: 740-741.

Jassby, A.D., Cloern, J.E, Cole, B.E. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanog. 47(3):698-712.

Jones, A.B., Dennison, W.C., and N.P. Preston. 2001. Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. Aquaculture 193_2001.155–178 significant reductions in nutrients and suspended particulates after sedimentation and biological treatment were observed. Overall, improvements in water quality final percentage of the initial concentration were as follows: TSS_12%; total N_28%.; total P _14%.; NH4_76%.; NO3_30%; PO4_35%; bacteria_30%.; and chlorophyll *a* _0.7%.. Despite the probability of considerable differences in sedimentation, filtration and nutrient uptake rates when scaled to farm size, these results demonstrate that integrated treatment has the potential to significantly improve water quality of shrimp farm effluent.

Kaiser, M.J., G. Burnell, and M. Costello. 1998. The environmental impact of bivalve mariculture: A review. Aquaculture 1998. As is the case with all anthropogenic activities that impinge upon the marine environment, the magnitude of the environmental changes that occur is linked to the scale of the cultivation processes. There are both positive aspects to coastal shellfish cultivation, such as the provision of hard substrate and shelter in otherwise barren sites with the possibility of using the cultured organisms as environmental sentinels, and negative effects such as habitat modification and multi-user conflict. Achieving a balance between nature conservation and shellfish farming requires both (I) more quantitative information on farmed shellfish interactions with the environment, and (2) a coastal zone management framework to educate, plan, control, and facilitate regular communication between the farmers and other interests. There is a growing body of literature that demonstrates the secondary effects of mechanical collecting devices on non-target fauna. These effects include direct mortality of nontarget species and destruction of suitable settlement substrata or habitats. In addition, other species, such as birds, may be deprived of valuable food resources. Many of the environmental changes that occur result from their filter feeding activities which produce faeces and pseudofaeces. These can accumulate beneath suspended cultures resulting in a locally anoxic environment and faunal impoverishment. In addition, the structures used during the cultivation process can themselves cause environmental change e.g. clam netting encourages local siltation. Intertidal mudflats are also essential feeding areas for internationally important populations of over-wintering birds in Britain and Ireland and although coastal shellfish farming may increase seabed productivity and provide more food for birds, the husbandry activity may disturb them and reduce their feeding time. The final stage of cultivation involves harvesting. In situations where the species are cultivated within sediment, or relayed on the seabed, the use of intrusive techniques is required. Both dredgers and suction devices cause disruption of the sediment and kill or directly remove non-target species. Here, we review the potential environmental effects that occur throughout the cultivation cycle, from collection of the seed to harvesting. We suggest that careful consideration of the techniques employed can effectively minimize environmental changes that might occur, and possibly ameliorate subsequent restoration of cultivated sites.

Kaspar, H.F., P.A. Gillespie, I.C. Boyer, and A.L. MacKenzie. 1985. Effects of mussel aquaculture on the nitrogen cycle and benthic communities in Kenepuru Sound, Marlborough Sounds, New Zealand. Marine Biology 85: 127-136. Increased biodeposition of organic matter in sediments leads to increased bacterial denitrification.

Koch, E. W. and Beer, S. 1996. Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. AQUAT.-BOT. 53(1-2): 97-107.

Langan, R. 1997. The effect of dredge harvesting on oysters and the associated benthic community. Effects of Fishing gear on the seafloor of New England. Conference A study was conducted in 1994 to determine the effects of dredge harvesting on oyster populations and as well as the benthic community associated with the oyster bed. The study area was located in the Piscataqua River which divides the states of Maine and New Hampshire. An oyster bed approximately 18 acres in size is located in the river channel and is divided nearly equally by state jurisdictional lines. The difference in the classification of the growing area and permissible uses of the resource between the two states provided a unique study opportunity. At that time, the State of Maine classified the area "restricted for depuration" and allowed commercial harvesting, whereas New Hampshire, where commercial harvest is not allowed, had placed a "prohibited" classification on the area many years prior to the study. The Maine side of the bed had been harvested using a small oyster dredge for five years prior to the study, while the New Hampshire side had not been harvested by any method for years. Six random samples of oysters were collected by SCUBA divers on each side of the river using a 0.25 m super(2) quadrat. All oysters were counted and measured. Five random grab samples were collected on each side of the river using a custom made 0.0625 m super(2) grab sampler. All epifaunal and infaunal species in the samples were identified and enumerated. Additionally, near bottom water samples collected in the tracks of the passing dredge were analyzed to assess the impact of the dredge on suspended sediment concentrations. On the Maine (dredge harvested) side of the river, oyster populations showed a normal size distribution and good recent recruitment while the size frequency of oysters on the New Hampshire unharvested side) was skewed toward older, larger individuals and recruitment was poor. **No significant differences between the two areas were found in the species richness, diversity and number of epifaunal and infaunal invertebrates**. **The suspended sediment plume created by the dredge was localized and concentrations returned to ambient conditions at a distance of approximately 110 meters behind the dredge.** (DBO)

Lindahl, O., R. Hart, B. Hernroth, S. Kollberg., L-O. Loo, L. Olrog, A-S. Rehnstam-Holm, J. Svensson, S. Svensson, and U. Syversen. 2005. Improving marine water quality by mussel farming: a profitable solution for swedish society. Ambio. 34(2)131-137. Eutrophication of coastal waters is a serious environmental problem with high costs for society globally. In eastern Skagerrak, reductions in eutrophication are planned through reduction of nitrogen inputs, but it is unclear how this can be achieved. One possible method is the cultivation of filter-feeding organisms, such as blue **mussels, which remove nitrogen while generating seafood**, fodder and agricultural fertilizer, thus recycling nutrients from sea to land. **The expected effect of mussel farming on nitrogen cycling was modeled for the Gullmar Fjord on the Swedish west coast and it is shown that the net transport of nitrogen (sum of dissolved and particulate) at the fjord mouth was reduced by 20%. Existing commercial mussel farms already perform this service for free, but the benefits to society could be far greater.** We suggest that rather than paying mussel farmers for their work that nutrient trading systems are introduced to improve coastal waters. In this context an alternative to nitrogen reduction in the sewage treatment plant in Lysekil community through mussel farming is presented. Accumulation of bio-toxins has been identified as the largest impediment to further expansion of commercial mussel farming in Sweden, but the problem seems to be manageable through new techniques and management strategies. On the basis of existing and potential regulations and payments, possible win-win solutions are suggested.

Mojica, R. Jr and W. G. Nelson. 1993. Environmental effects of a hard clam (*Mercenaria mercenaria*) aquaculture site in the Indian River Lagoon, Fl. Aquaculture. 113(4):313-329. The impact of the growout of cultured hard clams (Mercenaria mercenaria) was evaluated at a commercial mariculture site in the Indian River Lagoon, Florida. Selected biological, chemical and physical factors were compared between a hard clam growout facility and two nearby reference locations. Measurements of water column nutrients, chlorophyll and dissolved oxygen concentrations gave **no indication of differences which could be associated with the presence of the clam farm.** Alteration of sediments towards a decreased mean sediment grain size associated with an increase in silt/clay sized particles, as well as an increase in organic content, were observed within 1 m of clam growout bags. Sediment changes did not result in significant changes in benthic dwelling organisms. Differences in mobile macrofauna were minimal, and most differences appear to be associated with variation in seagrass coverage.

Mallet, A.L., C.L. Carver and T. Landry. In Press. Impact of suspended and off-bottom Eastern oyster culture on the benthic environment in eastern Canada. Aquaculture, In Press 02feb06. The impact of Eastern oyster culture (*Crassostrea virginica*) on the benthic environment at a shellfish farm in New Brunswick, Canada, was assessed using recommended methods for routine environmental monitoring, specifically measurements of sediment redox and sulfide levels. Maximum culture density was equivalent to 4000 oyster bags per hectare, or a final oyster biomass of 8 kg m-2. Two culture sites, one with floating bags and one with oyster tables, as well as two reference sites were monitored over 17 months (June 2002–October 2003). Seasonal variations in sediment redox and sulfide levels were observed, **but no significant differences were detected between the culture and the reference sites**. Biodeposition associated with the oyster biomass contributed to increased sedimentation rates of organic matter at the oyster table site, but there was **no indication of organic enrichment** in the sediment. Macrofauna biomass, abundance and number of species were higher at the oyster table site than at the other sites in September 2002, but values were similar for all sites in September 2003. In this region of eastern Canada, the bays are typically shallow and the upper layers of the sediment are frequently subjected to re-suspension by wave activity and physical erosion by winter ice. Given these highly dynamic conditions and the relatively low stocking densities per hectare, we would argue that the potential impact of oyster culture on the environment should be assessed on the basis of parameters other than sediment redox and sulfide levels.

Nelson, K.A., Leonard, L.A., Posey H., Alphin, T.D. and M.A. Mallin. 2004. Using transplanted oyster (Crassostrea virginica) beds to improve water quality in small tidal creeks: a pilot study. J.Exp.Mar.Biol.Ecol. 298(2):347-368. The Eastern oyster, Crassostrea virginica, may improve water quality by filtering large quantities of particulate matter (both organic and inorganic) and nutrients from the overlying water column. Additionally, oyster reefs alter hydrodynamic conditions, further increasing the removal of particulate matter from the water column. This study examined the effects of small-scale oyster additions on sediment loading, chlorophyll a, nutrient concentrations, and flow in small tidal creeks. Two reefs were established in Hewletts Creek, New Hanover County, North Carolina. Total suspended solids (TSS), chlorophyll a, and ammonium were measured upstream and downstream of each created reef and in an adjacent control channel that lacked a reef. Data were collected monthly during ebb tides over a 10-month period between September 2000 and June 2001. In the first month after initial reef placement, mean TSS concentrations downstream of reef placement were slightly lower than those upstream of the reef. Although not statistically significant, TSS concentrations downstream of the reefs were less than upstream concentrations for five out of nine and five out of seven post-reef sampling months for the upland and the lower creek sites, respectively. Chlorophyll a concentrations were not significantly affected by initial reef placement (2 x 3 m), but were reduced substantially after reef enlargement (3 x 4 m) in one of the experimental creeks. Reef placement resulted in significant increases in ammonium concentrations downstream of the transplanted-reefs. In addition, deposition of feces and pseudofeces by the oysters resulted in accumulation of finer-grained materials in the treated channel relative to the control channels. Oyster filtration was most effective three hours following high tide, when the ratio of flow discharge to reef surface area was the highest. This work demonstrates that small oyster reefs established and maintained in some small tributary channels can reduce TSS and chlorophyll a concentrations and that the magnitude of the effect may vary over the course of the tidal cycle.

Newell, C. R. 1998. Modeling the growth of bottom cultivated shellfish: A practical approach. Journal of Shellfish Research. 17(4).

Newell, R., Cornwell, J., and Owens, M. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: A laboratory study. Limnol. Oceanog. 47:1367-1379. http://aslo.org/lo/toc/vol_47/issue_5/1367.pdf Suspension-feeding eastern oysters, *Crassostrea virginica*, were once abundant in Chesapeake Bay and may then have exerted top-down control on phytoplankton and also reduced turbidities, thereby increasing light available to benthic plants. Alternatively, oysters may have simply recycled inorganic nutrients rapidly back to the water column, with no long-lasting reduction in phytoplankton biomass resulting from oyster feeding activity. To help distinguish between these scenarios, we explored changes in nitrogen fluxes and denitrification in laboratory incubations of sediment cores held under oxic and anoxic conditions in response to loading by pelletized phytoplankton cells, an experimental analog for oyster feces and pseudofeces. When organics were regenerated under aerobic conditions, typical of those associated with oyster habitat, coupled nitrification–denitrification was promoted, resulting in denitrification of ~20% of the total added nitrogen. In contrast, under anoxic conditions, typical of current summertime conditions in main-stem Chesapeake Bay where phytoplankton is microbially degraded beneath the pycnocline, nitrogen was released solely as ammonium from the added organics. We postulate that **denitrification of particulate nitrogen remaining in oyster feces and pseudofeces may enhance nitrogen removal from estuaries.**

Newell, R.I.E., 2004. Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: A review. J. Shellfish Res. 23(1) 51-61 http://www.hpl.umces.edu/faculty/newell/ecobivalve2.pdf **POSSIBLY THE BEST SINGLE RESOURCE** **Abstract.** Suspension-feeding bivalves serve to couple pelagic and benthic processes because they filter suspended particles from the water column and the undigested remains, ejected as mucus-bound feces and pseudofeces, sink to the sediment surface. This biodeposition can be extremely important in regulating water column processes where bivalves are abundant in coastal waters and in seasons when water temperatures are warm enough to promote active feeding. Bivalves under these conditions can exert "top-down" grazer control on phytoplankton and in the process reduce turbidity, thereby **increasing the amount of light reaching the sediment surface**. This has the effect of reducing the dominance of phytoplankton production and **extending the depth to which ecologically important benthic plants, such as seagrasses and benthic microalgae, can grow**. Nitrogen and phosphorus, excreted by the bivalves and regenerated from their biodeposits, are recycled back to the water column and support further phytoplankton production. In some situations, however, bivalves can also exert "bottom-up" nutrient control on phytoplankton production by changing nutrient regeneration processes within the sediment. Some of the N and P that was originally incorporated in phytoplankton, but was not digested by the bivalves, can become buried in the accumulating sediments. Where biodeposits are incorporated in aerobic surficial sediments that overlay deeper anaerobic sediments, microbially mediated, **coupled nitrification-denitrification can permanently remove N from the sediments as N2 gas. Consequently, natural and aquaculture-reared stocks of bivalves are potentially a useful supplement to watershed management activities intended to reduce phytoplankton production by curbing anthropogenic N and P inputs to eutrophied aquatic systems.** Environmental conditions at bivalve aquaculture sites should be carefully monitored, however, because biodeposition at very high bivalve densities may be so intense that the resulting microbial respiration reduces the oxygen content of the surrounding sediments, Reduction in sediment oxygen content can inhibit coupled nitrification-denitrification, cause P to become unbound and released to the water column, and the resulting buildup of H2S can be toxic to the benthos.

Newell, R.I.E., E.W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries. 27:793-806

Newell, R.I.E., T.R. Fisher, R.R. Holyoke, and J.C. Cornwell. 2005. Influence of eastern oysters on Nitrogen and Phosphorus regeneration in Chesapeake Bay, USA. Pages 93-120 In: *The comparative Roles of Suspension Feeders in Ecosystems*. R. Dame and S. Olenin (Eds.) Vol 47 NATO Science Series: IV - Earth & Env. Sci. Springer, Netherlands. UMCES contribution #3796. http://www.hpl.umces.edu/faculty/newell/Newell%20et%20al.%202005%20NATO%20paper.pdf

Newell, R. I. E., J. C. Cornwell, M. Owens and J. Tuttle. 1999. Role of oysters in maintaining estuarine water quality. J. Nat. Shellfish. Assoc. 18(1):300-301. Environmental changes in Chesapeake Bay, such as elevated phytoplankton biomass and loss of benthic plants, are often thought to be largely a function of nutrient-driven eutrophication. We propose, however, that populations of the eastern oyster, Crassostrea virginica, which have been reduced to <1% of their historic levels, may have exerted "top-down" control on phytoplankton stocks and also reduced turbidity, thereby increasing light available to benthic plants. In laboratory incubations under oxic and anoxic conditions we measured changes in sediment geochemistry, nutrient fluxes, and denitrification in response to loading by different amounts of algal paste, an experimental analog of oyster biodeposits. Increased organic loading to the sediment under oxidized conditions resulted both in higher rates of coupled nitrification/denitrification and denitrification in the presence of water column nitrate. In contrast, coupled nitrification/denitrification was suppressed under anoxic conditions. Similar incubations in the presence of benthic microalgae showed negligible ammonium fluxes from sediments, with the algal/microbial community efficiently retaining ammonium and fixing nitrogen. Because no DIN was recycled to the water column under oxic conditions we conclude that rehabilitation of natural oyster stocks will have the beneficial effect of removing phytoplankton from the water column without stimulating further phytoplankton production. Furthermore, nitrogen will be removed from the Bay via increased denitrification. **These data also suggest that private-sector oyster aquaculture should be encouraged not only for the obvious economic value but also for the broader ecological benefits to the Bay**.

Nugues, MM, M.J Kaiser, B.E. Spence, and D.B. Edwards, 1996. Benthic community changes associated with intertidal oyster cultivation. Aquacult. Res. 27(12) 913-924.

O'Beirn, F. X., P. G. Ross, and M. W. Luckenbach. 2004. Organisms associated with oysters cultured in floating systems in Virginia, USA. Journal of Shellfish Research 23:825-829.

Officer, C. B., Smayda, T. J., and Mann, R. 1982. Benthic Filter Feeding: A Natural Eutrophication Control. Mar. Ecol. Prog. Ser.. 9(2):203-210.

Orth, R. J., Luckenbach, M., and Moore, K. A. 1994. Seed dispersal in a marine macrophyte: Implications for colonization and restoration. Ecol. 75(7):1927-1939. Shellfish may also increase the survival of seedlings, by increasing light levels, nutrients, and protecting against erosion and herbivory

Peterson BJ, Heck Jr. KL (1999) The potential for suspension feeding bivalves to increase seagrass productivity. J Exp Mar Biol Ecol 240:37-52 http://www.pcsga.org/Research/

Peterson, B.J. and K.L. Heck. 2001. An experimental test of the mechanism by which suspension feeding bivalves elevate seagrass productivity. Marine Biology Progress Series – Mar. Ecol. Prog. Ser. Vol. 218:115-125, 2001 http://www.pcsga.org/Research/

Peterson B.J. and Heck Jr. K.L. (2001) Positive interactions between suspension-feeding bivalves and seagrass --a facultative mutualism. Mar Ecol Pro Ser 213:143-155 http://www.pcsga.org/Research/ The mussel density manipulations resulted in a doubling of the total nitrogen and total phosphorus levels of sediments, and a significant reduction in leaf tissue C:N, N:P and C:P ratios, demonstrating that the mussels increased the sediment nutrient content and that these increased nutrients were biologically available to the plant. T. testudinum responded to the presence of mussels by significantly increasing leaf widths and lengths. In addition, productivity significantly increased in the mussel-addition treatments.

Another response to the presence of mussels included a significantly reduced epiphytic load on the seagrass leaves. The mussel predation experiment evaluated the effects of seagrass on the survivorship of the associated mussel, M. americanus. Mean survival was significantly greater in vegetated habitats than in unvegetated sediments. Consequently, when mussels are present in seagrass meadows, they elevate seagrass productivity through either increased nutrient resource pools or reduced epiphytic loads on the leaves, while the seagrass increases mussel survivorship.

Pietros, J.M. and M.A. Rice. 2003. The impacts of aquacultured oysters, *Crassostrea virginica* (Gmelin, 1791) on water column nitrogen and sedimentation: results of a mesocosm study. Aquaculture 220: 407-422. http://www.pcsga.org/Research/documents/655.pdf Experimental mesocosm study showed tanks with oysters had increased rates of sedimentation but less than expected possibly due to maximal activity of decomposing bacteria in the benthos; a shift in large diatom population from domination by *Skeletonema* (selective feeding?) to *Nitzchia*; and lack of change in levels of ammonia and other forms of inorganic nitrogen implied rapid regeneration by phytoplankton in the test tanks. Good source of references on role of oysters in nutrient cycling and importance of oyster reefs.

Pinnix, W.D., T.A. Shaw, K.C. Acker, and N.J. Hetrick. 2005. Fish communities in eelgrass, oyster culture, and mudflat habitats of North Humboldt Bay, Calif. Arcata Fish. Tech. Rept #TR2005-02. 55pp.

Pregnall M.M. (1993) Regrowth and recruitment of eelgrass (*Zostera marina*) and recovery of benthic community structure in areas disturbed by commercial oyster culture in the South Slough National Estuarine Research Reserve, Oregon. MS thesis, Bard College, NY. Regrowth and recruitment of eelgrass (zostera marina) and recovery of benthic community structure in areas disturbed by commercial oyster culture in the south slough national estuarine research reserve, oregon. This study: (1) examines the impacts of commercial oyster culture on macrophytes and populations of estuarine fish and invertibrates, and (2) monitors the recovery of lost habitat values following the removal of oysters. In addition, the study also investigates acceleration of habitat recovery by experimental transplants of eelgrass (Zostera marina). Based on the findings of this study, we recommend that commercial oyster cultures be discontinued in areas previously occupied by eelgrass meadows. In addition, the Oregon Department of Agriculture should institute procedures to review and monitor existing oyster leases on a case-by-case basis in order to determine whether oyster cultivation should be continued. Tighter restrictions are needed to reduce further degradation to eelgrass habitats when granting new leases within Pacific Northwest estuaries.

Reusch TBH Chapman ARO, Gröger JP. 1994. Blue mussels (*Mytilus edulis*) do not interfere with eelgrass (Zostera marina) but fertilize shoot growth through biodeposition. Mar Ecol Pro Ser 108: 265–282

Reusch, T.B.H. and Williams, S.L. 1998. Variable responses of native eelgrass *Zostera marina* to a non-indigenous bivalve *Musculista senhousia*. Oecologia 113(3):428-441.

Rheault, R.B. (2006) Ecological Services Rendered by Cultured Eastern Oysters. Abstract, Nat. Shellfish Assoc. Monterey, Ca. March, 2006. (cultured Eastern oysters remove in excess of 357 MT N, 110 MT P, sequester 51,559 MT Carbon, release 1.7 x10E15 larvae annually and filter 94 million cubic meters of water daily)

Richardson, N.F., J.L. Ruesink, S. Naeem, S.D. Hacker, H.M. Tallis, B.R. Dumbauld, L.M. Wisehart.. Abundance and functional diversity of sediment microbes across natural and oyster aquaculture habitats in a northeastern Pacific estuary. Hydrobiologia, In press

Rice, MA (2001) Environmental Impacts of Shellfish Aquaculture: Filter Feeding to Control Eutrophication In: Marine Aquaculture and the Environment: A Meeting for Stakeholders in the Northeast. pp. 77-84. 11-13 Jan 2001 Tlusty, M; Bengtson, D; Halvorson, HO; Oktay, S; Pearce, J; Rheault, RB (eds) In many areas, coastal residents and others oppose establishment of bivalve molluscan aquaculture projects on the basis of perceived negative environmental impacts. Often overlooked are positive environmental impacts of shellfish aquaculture that can potentially mitigate the impacts of other anthropogenic activities. Filter feeding by populations of bivalve mollusks is reviewed with respect to their ability to act as an estuarine filter, increase clarity of coastal waters and facilitate the removal of nitrogen and other nutrients from eutrophic coastal waters. Most species of cultured bivalve mollusks clear particles from waters at rates of 1 to 4 L/h, and populations of shellfish in healthy assemblages can filter a substantial fraction of the water in coastal estuaries on a daily basis. **Actively growing shellfish incorporate nitrogen and other nutrients into their tissues as they grow. On average, 16.8 g of nitrogen is removed from estuaries for every kilogram of shellfish meats harvested**. In addition to removal of nutrients through shellfisheries and molluscan aquaculture, shellfish beds may act to promote removal of nitrogen from estuaries by increasing organic nitrogen deposition to the sediments that stimulate denitrification processes. It is suggested that shellfish restoration projects and establishment of **small-scale molluscan shellfish aquaculture operations may mitigate the effects of coastal housing development or other activities that promote excessive coastal eutrophication**.

Rodney, W.S. and Paynter, K.T. (2006) Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. J. Exp. Mar. Biol. Ecol. 335 (2006) 39–51. http://www.life.umd.edu/biology/paynterlab/labpub/R_P2006.pdf

Roycroft, D; Kelly, TC; Lewis, LJ (2004) Birds, seals and the suspension culture of mussels in Bantry Bay, a non-seaduck area in Southwest Ireland. Estuar. Coast. Shelf Sci. 61(4)703-712. The main aim of this study was to examine the interactions, and assess the impacts (if any) of mussel suspension culture on the seabird and seal community. There was no significant difference in species richness between mussel and control sites. Similarly, species diversity did not significantly differ between the mussel and control sites. Significantly higher numbers of Phalacrocoracidae, Laridae and Alcidae were recorded in mussel sites than in control sites. However, no significant difference was found between Gaviidae or common seal (Phoca vitulina) numbers in mussel and control sites. Mussel suspension culture does not appear to have an adverse effect on the abundance of seabirds or common seals in this area.

Ruesink, J.L., B.E. Feist, C.J. Harvey, J.S. Hong, A.C. Trimble, L.M. Wisehart. 2006. Changes in productivity associated with four introduced species: Ecosystem transformation of a "pristine" estuary. Marine Ecology Progress Series 311:203-215

Rumrill, S.S. and V.K. Poulton. 2004. The ecological role and potential impact of molluscan shellfish culture in the estuarine environment of Humboldt Bay, California. Final Report to the Western Regional Aquaculture Center. 79 pp.

Schaffner, R.A. (1999) The role of suspension feeding bivalves in the initiation and control of *Aureococcus anophagefferens* blooms. MS, SUNY, 86 pages.

Scott, T.M., D. Alves, R. B. Rheault, M. A. Rice. Aquaculture in Rhode Island, White Paper, Narragansett Bay Summit 2000, 12 April, 2000 http://www.nbep.org/summit/pdf/aquaculture.PDF

Short, F. T. 1987. Effects of sediment nutrients on seagrasses: Literature review and mesocosm experiment. Aquat.-Bot. 27(1), 41-57.

Simenstad CA, Fresh KL (1995) Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: scales of disturbance. Estuaries 18:43-70

Tallis, H., Dumbauld, B.R., Wisehart, L., Hacker, S., Ruesink, J. Eelgrass density and growth across natural and oyster aquaculture habitats in a northeastern Pacific estuary. In preparation for Aquaculture.

Tallman, J.C. and G.E. Forrester, (In Press) Oyster grow-out cages function as artificial reefs for temperate fishes. In Press, Trans. Am. Fish. Soc. Found that oyster grow-out cages were similar to natural and constructed rocky reefs, both provide good quality habitat for fishes typically associated with hard-bottom habitats. Habitat restoration programs for these fishes should thus consider grow-out cages alongside other types of artificial reef.

Thom R.M., Borde A.B., Rumrill S, Woodruff DL, Williams GD, Southard JA, Sargent SL. 2003. Factors influencing spatial and annual variability in eelgrass (*Zostera marina* L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon. Estuaries 26:1117-1129.

Trianni, M. S. 1996. The influence of commercial oyster aquaculture activities on the benthic infauna of Arcata Bay. Ms. Thesis, Humboldt State University, Arcata, California 91 p.

Waddell JE. 1964. The effect of oyster culture on eelgrass (*Zostera marina* L.) growth. MS thesis, Humboldt State College, Arcata, CA

Wechsler J.F. (2006) Assessing the Relationship between the Ichthyofauna and Oyster Mariculture in a Shallow Coastal Embayment, Drakes Estero, Point Reyes National Seashore MS Thesis, UC Davis 2006 This study was designed to assess whether oyster mariculture affected ichthyofaunal species abundance, species richness, species composition, and species diversity. **Found no statistically significant differences in fish abundance or species richness among the sampling locations, which indicated that the oyster farm had not exerted a noticeable effect on the ichthyofauna** of Drakes Estero. Species diversity and species richness were greatest at stations closest to the oyster racks, which indicated that the physical structure associated with the mariculture facility likely provided resources (e.g., feeding opportunities or refuge) to species of fish capable of taking advantage of artificial habitat. Additionally, four out of five Indices of Similarity showed that the fish assemblage adjacent to the racks was comprised of a group of species that diverged compositionally from the fish species captured in the reference site, which suggested that the racks favored structure-oriented and crevice dwelling fish capable of taking advantage of increased habitat complexity.

Wigand C and Churchill A C. 1988. Laboratory studies on eelgrass seed and seedling predation. Estuaries. 11(3), 180-183.

Wisehart, L. and S. Hacker. 2004. A description of eelgrass (Zostera marina L.) seed production and recruitment patterns inside and outside of oyster aquaculture areas in Willapa Bay, Washington. Presentation at the Pacific Estuarine Research Society 2004 Annual Meeting, May 17-18, 2004, Port Townsend, Washington. http://www.pers-erf.org/PERS04Program.pdf Seed production and seedling densities were observed in dredged and handpicked oyster ground–culture beds, long-line oyster culture areas and eelgrass control at three sites. Preliminary data suggest a positive relationship between oyster cover and eelgrass seed production and seedling density in ground cultured oyster beds.

Whiteley, J. ; Bendell-Young, L. (2007) Ecological implications of intertidal mariculture: observed differences in bivalve community structure between farm and reference sites. J. Appl. Ecol. In press. *Venerupis philippinarum* was the only species found in higher abundance on farm sites in low intertidal areas (227 ± 241·6 clams m 2 , *P* = 0·02; 872·9 ± 792·9 g m 2 , *P* = 0·037). Farmed sites showed no difference in mid-intertidal areas, nor in density of the other 25 bivalve species. Bivalve species composition was not significantly different between farm and reference sites.

Adverse impacts

See from above Kaiser, Carnford, Crawford

intense raft-based cultivation in Spain indicated the diversity of the benthic community beneath the most intensively cultivated systems was lowered because of organic enrichment from mussel feces and pseudofeces (Alvarez-Salgado 1996).

Eelgrass has also been shown to decline within a few weeks after placement of stake or rack oyster culture due to sediment deposition or erosion (Everett et al 1995).

For example, where space is limited and dredging of bottom culture oysters occurs, eelgrass can be uprooted. (Wadell 1964 and Trianni 1996).