ENVIRONMENTAL EFFECTS OF SHELLFISH AQUACULTURE: AN ANNOTATED BIBLIOGRAPHY

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OVERVIEW

The following annotated bibliography was compiled from a variety of literature sources and search engines, including Aquatic Sciences and Fisheries Abstracts, publicly available search engines, associations that conduct research on behalf of the shellfish aquaculture industry, as well as associations opposed to the culture of shellfish in the intertidal zone. We have endeavored to capture the range of recent papers that have been produced, canvassing both peer-reviewed literature and government and industry reports. Some of the abstracts from three very recent workshops are also included: the Washington SeaGrant sponsored symposium on 'Bivalve Aquaculture and the Environment' held in Seattle on September 13th and 14th, and the 2006 and 2007 proceedings from the NOAA-sponsored workshops on Native Oyster Restoration.

Several ongoing permitting efforts that engage the U.S. industry are ongoing, and this bibliography is intended as a tool to facilitate these exercises. To this end, the topics addressed in the bibliography largely reflect the themes of the new US Army Corps of Engineers Nationwide Permit (NWP) 48, which is intended to provide coverage for a range of existing shellfish aquaculture activities nationally. Because research is never static, this compilation should not be considered the 'de facto' summary of environmental effects, but rather a working document that will be updated regularly. Abstracts are generally reproduced as originally published by the author, unless not immediately available. They are separated by species within each environmental effect category considered. Some citations are not provided with an abstract simply because we were not able to retrieve them (or read the source fully) in time for this version, but the title was deemed appropriate within the categories of activities covered under NWP 48. As the document is updated, these 'holes' will be updated as possible.

1.0 EFFECTS OF SHELLFISH CULTURE ON WATER QUALITY, NUTRIENT CYCLING OR NUTRIENT DYNAMICS (e.g., NITROGEN, SULFUR, PHOSPHOROUS, PSEUDOFECES)

1.1 Clams

Bartoli, M., D. Nizzoli, P. Viaroli, E. Turolla, G. Castaldelli, E.A. Fano, and R. Rossi. 2001. **Impact of *Tapes philippinarum* farming on nutrient dynamics and benthic respiration in the Sacca di Goro.** Hydrobiologia 455: 203-212.

The introduction of the short-necked clam *Tapes philippinarum* into the Sacca di Goro has over a short period made this coastal environment one of the top European clam production sites. In recent years, this activity has been seriously impacted due to the appearance in the lagoon of large macroalgal beds and the occurrence of dystrophic events causing anoxia and massive deaths of molluscs in the cultivated areas. *Tapes* cultivation sites now cover more than one third of the lagoon surface at densities sometimes attaining 2000-2500 adult individuals m super(-2); such densities and the harvesting methods, based on sediment dredging, probably have a strong impact on the benthic system. Whilst a number of studies have reported water-sediment interface induced modifications due to oyster or mussel farming there have been few attempts to quantify how clam farming affects biogeochemical cycles of oxygen and nutrients, in particular in the Sacca di Goro. Two areas, a farmed and a control one, were compared for benthic fluxes and results were correlated with clam biomass. 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 O sub(2) demand and CO sub(2) production were stimulated by a factor of, respectively, 1.8 and 3.3, whilst nutrient release was 6.5 times higher for NH sub(4) super(+) and 4.6 times higher for PO sub(4) super(3-). Our results indicate that clam farmers should carefully consider sustainable densities of *Tapes* in order to prevent the risk of sediment and water anoxia. Rapid nutrient recycling (up to 4000 mu mol NH sub(4) super(+) m super(-2) h super(-1) and 150 mu mol PO sub(4) super(3-) m super(-2) h super(-1)) stimulated by the high biodegradability of clam faeces and pseudofaeces could in turn favor macroalgal growth.

Keywords: Benthos, Respiration, Nutrient dynamics, Lagoons, Dystrophic environments, Aquaculture, Biogeochemical cycle, Nutrient cycles, Anoxic conditions, Dissolved oxygen, Population density, Clam culture, Environmental impact, Italy, Emilia, Romagna, Ferrara, Po, Delta, Sacca di Goro, Biogeochemistry, Cycling, Nutrients, Clams, Sediment water, Interfaces, Dredging, Farming, Tapes philippinarum, Japanese-little neck, species culture.

Baudrimont, M., J. Schafer, and V. Marie, et al. 2005. **Geochemical survey and metal bioaccumulation of three bivalve species (*Crassostrea gigas*, *Cerastoderma edule* and *Ruditapes philippinarum*) in the Nord Medoc salt marshes (Gironde estuary, France).** Science of the Total Environment 337(1-3): 265-280.

A 15-month experiment combining a geochemical survey of Cd, Cu, Zn and Hg with a bioaccumulation study for three filter-feeding bivalve species (oysters, *Crassostrea gigas*; cockles, *Cerastoderma edule*; and clams, *Ruditapes philippinarum*) was conducted in a breeding basin of the Nord Medoc salt marshes connected to the Gironde estuary, which is affected by

historic polymetallic pollution. Regular manual surface measurements of temperature, salinity, pH and dissolved O sub(2) concentration and hourly multiprobe in situ measurements throughout several periods for 6-8 weeks were performed. The geochemical behavior of metals in water, suspended particulate matter and sediment and their ecotoxicological impact on the three bivalve species were evaluated by in situ exposure of juvenile oysters (water column) and adult cockles and clams (sediment surface). The physico-chemical parameters reflected seasonal variations and basin management. A distinct daily periodicity (except salinity) indicated intense photosynthesis and respiration. In summer, low dissolved O sub(2) saturations (similar to 40-50%) occurred in the early morning at 30 cm above the sediment, whereas in depressions, the water column near the sediment surface was suboxic. Cadmium, Zn and Cu concentrations in suspended particulate matter exceeded typical estuarine values and were much higher than the homogeneously distributed concentrations in different depth ranges of the basin sediment. Particles collected in sediment traps showed intermediate metal concentrations close to sediment values. These results suggest trace metal recycling due to reductive dissolution under suboxic conditions at the sediment surface resulting in trace metal release to the water column and adsorption onto suspended particles. Dissolved Cd, Zn and Hg concentrations (e.g. 13-136 ng l super(-1); 0.3-25.1 mu g l super(-1) and 0.5-2.0 ng l super(-1), respectively) in the basin corresponded to the concentration range typically observed in the Gironde estuary, except for some maximum values attributed to metal recycling. In contrast, dissolved Cu concentrations (1.08-6.08 mu g l super(-1)) were mostly higher than typical estuarine values, probably due to recycled Cu complexation by dissolved organic matter. Growth, bioaccumulation rates and kinetics in the whole soft body of the bivalves were analyzed every 40 days. Although Cd bioaccumulation of oysters was lower in the basin than in the estuary during the same period (27, 000 ng g super(-1), dry weight and 40, 000 ng g super(-1), respectively) these values are largely above the new human consumption safety level (5000 ng g super(-1), dw; European Community, 2002). For cockles and clams, Cd bioaccumulation was lower, reaching 1400 ng g super(-1) and 950 ng g super(-1), respectively. Similar results were obtained for Zn and Cu suggesting physiological differences between the species and/or differences in the exposure of the organisms due to physico-chemical conditions and metal distribution between dissolved and particulate phases. In contrast, Hg bioaccumulation was highest for cockles reaching bioconcentration factors of similar to 200,000, which even exceeded that of Cd in oysters (50, 000) for the same exposition period.

Keywords: Marine organisms, Salt marshes, Biogeochemistry, Bioaccumulation, Seasonal variations, Heavy metals, Zinc, Mercury, Cadmium, Copper, Marine molluscs, Brackishwater pollution, Resuspended sediments, Suspended particulate matter, Toxicity tests, Brackishwater environment, Geochemical surveys, Pollution indicators, Trace metals, Pollution effects, Estuarine sedimentation, Physicochemical properties, Dissolved organic matter, Suspended Sediments, Oysters, Mollusks, Estuarine EnvironmentClams, Water Pollution Effects, Particulate MatterExposure, Biological Magnification, Dissolved Solids, Crassostrea gigas, Cerastoderma edule, Ruditapes philippinarum, Bivalvia, France, Nord, MedocANE, France, Gironde EstuaryFrance, Gironde EstuaryPacific giant oyster, Bivalves, Marine, Brackish.

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

Little is known about the impacts of intensive shellfish farming on intertidal ecosystems. To assess such impacts, several indices of ecosystem structure and select geochemical characteristics were contrasted among three intertidal regions, which represented a gradient of shellfish farming activities, namely (1) no active aquaculture, (2) actively farmed for three years and (3) actively farmed for five years. All three intertidal regions were located in Baynes Sound (British Columbia, Canada) and were geographically similar. Among the three beaches, species richness, community composition, bivalve abundance, biomass, distribution, and composition and surficial sediment per cent organic matter (carbon) and silt were compared. The intertidal regions that had been used for farming for three and five years had lower species richness, different bivalve composition, abundance and distributions, and a foreshore community dominated by bivalves, as compared to the intertidal region where no active farming occurred. Beaches that were actively farmed also had greater accumulations of organic matter and silt. Simplification of the intertidal benthic community, coupled with accumulations of organic matter and increased siltation, may have altered the ecology of the foreshore region used for intense shellfish harvesting. To access the foreshore for shellfish farming in a sustainable manner, studies are needed to determine the scale to which intensive use of the foreshore for shellfish purposes alone is feasible without undue harm to the environment.

Keywords: aquaculture, biodiversity, ecological impacts, shellfish.

Berg, Jr., C.J., and P. Alatalo. 1984. **Potential of chemosynthesis in molluscan mariculture.** Aquaculture 39: 165-179.

The large edible clam *Codakia orbicularis* lives in sulfide-rich environments in subtropical regions. It possesses simplified gills, palps, and digestive systems. Gill tissues contain intracellular procaryotic cells and yield enzyme activities associated with sulfide oxidation, carbon fixation, and nitrogen reduction. Together with carbon-13 depletion values, these findings suggest chemoautotrophic capabilities similar to those of deep-sea hydrothermal vent animals. Reproduction, growth rates, and chemical composition of *C. orbicularis* are similar to other commercially exploited clams.

De Casabianca, L; T. Laugier, E. Marinho-Soriano, and D. Collart. 1998. **Environmental impact of shellfish farming in a Mediterranean lagoon (Thau, south France).** Aquaculture '98 Book of Abstracts. p. 99.

The French Mediterranean lagoon of Thau is characterized by an important shellfish farming dominated eutrophication (ca 15 times the terrestrial inputs). On the basis of increasing eutrophication, six areas were identified and monitored for one year (sediments features, overlying and sediment pore water nutrients, macrophytic biomass, species composition and diversity of macrophytes). With increasing eutrophication (total inorganic dissolved nitrogen: 0.140-0.295 mg l-1; dissolved reactive phosphorus: 0.045-0.110 mg l-1 and N/P atomic ratio: 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% d.wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in S-W sites and could be distinguished by their sediments features. In sites (N-E) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed

communities: an *Ulva rigida* community, outside the shellfishes tables, and a *Gracilaria bursa-pastoris* community among the shellfish tables (lower incident light).

Keywords: Brackishwater aquaculture, Shellfish culture, Culture effects, Aquaculture effluents, Eutrophication, Ecosystem disturbance, Sediment pollution, Pollution effects, Community composition, Sea grass, Seaweeds, Zostera marina, Ulva rigida, Gracilaria bursa-pastoris, MED, France, Languedoc-Roussillon, Thau Lagoon.

De Casabianca, M-L., T. Laugier, and D. Collart. 1997. **Impact of shellfish farming eutrophication on benthic macrophyte communities in the Thau lagoon, France.** Aquaculture International 5: 301-314.

In a large marine lagoon (Thau lagoon, southern France) with a shellfish farming dominant eutrophication, the macrophyte communities were sampled by six transects of three depths (1.5, 2.5 and 5 m) and their characteristics (species composition, diversity and biomass) were described in relation to environmental and sediment parameters. With increasing eutrophication (total inorganic nitrogen, 0.140-0.295 mg/l; dissolved reactive phosphorus, 0.045-0.110 mg/l; and N/P atomic ratio, 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% dry wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in SW sites and could be distinguished by their sedimentary features. In sites (NE) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfish tables, and a *Gracilaria bursa-pastoris* community in the shellfish tables (lower incident light).

Keywords: lagoons; marine environment; shellfish farming; eutrophication; macrophytes; benthic flora; algae; degradation; biological sampling; aquaculture effluents; shellfish culture; environmental impact; marine pollution; coastal lagoons; Zostera; Gracilaria; France, Thau lagoon; France; MED, France.

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

The effect of the hard clam *Mercenaria mercenaria* on the exchange of dissolved nutrients (silicate, phosphate, ammonium, nitrate+nitrite) and gases (oxygen, carbon dioxide) across the sediment-water interface was examined in 1983 and 1984 using experimental mesocosms (13 m super(3)), designed to simulate shallow coastal ecosystem, that allow for reciprocal biogeochemical interactions between water column (5 m) and bottom sediments (similar to 30 cm deep). Benthic, fluxes, measured during a spring-summer warming period, were compared for mesocosms maintained either with added *M. mercenaria*) (16 per m super(2) treatment) or without *M. mercenaria*) (control) as a component of the benthic community. Differences between regression slopes and intercepts for conditions with and without clams were assessed by analysis of covariance.

Keywords: filte, feederssediment, chemistry, dissolved, gases, dissolved, chemicals, Mercenaria, mercenaria.

Glasoe, S.D., and D. Fagergren. 2000. **Shellfish water quality trends and threats in Puget Sound.** Journal of Shellfish Research, Vol. 19, no. 1, p. 656. Jun 2000. Conference 92. Annual Meeting of the National Shellfisheries Association, Seattle, Washington (USA), March 19-23, 2000.

Puget Sound has some of the world's finest habitat for the cultivation of clams, mussels and oysters. Commercially, these products yield an annual farm-gate value of nearly $50 million. In broader terms, shellfish harvesting is a cherished part of Puget Sound's rich heritage and quality of life, and serves as a key measure of the estuary's environmental health. In the 1980s a number of the Sound's commercial shellfish areas were downgraded primarily because of nonpoint source pollution and additional monitoring information. This decline stabilized in the 1990s as a result of targeted efforts to restore water quality. A great success story, right? A broader review presents a mixed picture and forecasts an uncertain future for the Sound's shellfish tidelands, especially given the region's fast-growing population. Upgrades over the past decade have generally been offset by an equal number of downgrades. Some successful restorations have been reversed by recurring problems. Other sites have never recovered. And the harvesting classifications in most restored areas are tenuous, requiring constant monitoring and follow-up work. Given the persistent nature of these water quality threats, are we using our tools and resources to achieve temporary fixes or to make lasting changes? Do we have the vision and resolve to manage growth and control pollution in ways that will effectively preserve our environmentally sensitive tidelands, or are we carrying out a mission of haphazard restorations? Experiences in such areas as Drayton Harbor, Burley Lagoon and Lower Hood Canal provide some insight to these questions.

Keywords: Water quality; Pollution effects; Environmental impact; Shellfish culture; Shellfish fisheries; Filtration; Pollution control; Water Pollution Effects; Environmental Effects; Mussels; Clams; Oysters; Seafood; Shellfish; Aquaculture; Water quality (Natural waters); Pollution (Water); Pollution (Environmental); Bivalves (Mussels); Bivalves (Clams); Bivalves (Oysters); Food (see also Animal foodstuffs); INE, USA, Washington, Puget Sound; USA, Washington, Puget Sound.

Goldberg, R. 1978. **Some effects of gas-supersaturated seawater in *Spisula solidissima* and *Argopecten irradians*.** Aquaculture. 14(4):pp. 281-287.

Two size classes of the surf clam, *S.solidissima*, and the bay scallop, *A.irradians*, were exposed to different concentrations of gas-supersaturated seawater in a flowing seawater system. Both species tested experienced no mortality when held in the control treatment maintained at 96% oxygen and 109% nitrogen. Mortality, gill tissue damage, gas emboli, membranous tissue blisters, and abnormal secretion of shell material were induced experimentally at elevated levels of gas supersaturation. Results indicate significant mortalities of surf clams and scallops held at 114% O_2- and 195% N-SUB-2-, and at higher levels of gas concentration. These values suggest a point of reference for the bivalve culturist in identifying potential problems which can be caused by gas-supersaturated seawater.

Keywords: shellfish, culture, dissolved, gases, disease, control, pathology, Spisula, solidissima, Argopecten, irradians, mortality causes.

Hasbrouck, E.G. 1998. **The impact of a shellfish nursery on ambient chlorophyll-a concentrations.** Journal of Shellfish Research Vol. 17, no. 1, p. 355. June.

Filter feeders such as clams, oysters, mussels and scallops, obtain their food source by filtering surrounding waters. In an open environment there are many animals, but there is also generally a large enough food source to support these animals. In heavily populated areas, such as dense clam or mussel beds, growth, breeding and larval life can be severely affected by the availability of food. When large numbers of filter feeders are introduced into a limited source environment, the effect on the already existing population could be drastic. The Cornell Cooperative Extension Marine Program operates a shellfish hatchery and nursery in Southold, Long Island, NY, where they spawn, grow, and eventually release into the wild, a number of different types of shellfish. The nursery operation utilizes a flow-through system to draw in bay water with its associated microalgae as a food source for the shellfish. The nursery produced approximately 4 million hard clams, oysters and bay scallops during the 1997 growing season. This study was designed to determine the impact of the nursery's algal removal on the ambient algal concentrations of Cedar Beach Harbor. A chlorophyll-a sampling program was established. Sampling stations were setup at different locations in Cedar Beach Harbor, Peconic Bay and at both the intake and effluent of the nursery. The samples collected in Cedar Beach Harbor were compared with those collected in the Peconic Bay. The effluent of the nursery was compared to those samples taken in Cedar Beach Harbor. Samples in this study were analyzed for only chlorophyll-a concentrations as an approximation of microalgal density. Algae were not identified as to species or diversity. The seven sampling stations were sampled a total of nine times during the time period between 6-7-97 and 10-16-97.

Keywords: Shellfish culture; Hatcheries; Environmental effects; Aquaculture effluents; Phytoplankton; Chlorophylls.

Kaiser, M.J., G. Burnell, and M. Costello. 1998. **The environmental impact of bivalve mariculture: A review.** Aquaculture '98 Book of Abstracts. pp. 81-82.

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 multiuser 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. Bivalve cultivation can be broadly split into three main processes: (1) seed collection, (2) seed nursery and on-growing, and (3) harvesting. In many instances, commercial species are reared as seed in hatcheries prior to seeding, with few effects on the environment. However, some species are collected from the wild using spat collectors or dredgers. 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. The nursery and ongrowing of bivalves either takes place intertidally (clams and oysters) or subtidally (mussels and scallops). 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 t he 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.

Keywords: Marine aquaculture; Mollusc culture; Clam culture; Mussel culture; Oyster culture; Scallop culture; Culture effects; Off-bottom culture; Seed collection; Harvesting; Anthropogenic factors; Filter feeders; Suspended particulate matter; Excretory products; Anoxic conditions; Degradation; Nursery grounds; Habitat; Environmental impact; Intertidal environment; Ecosystem disturbance; Trophodynamic cycle; Biological stress; Mortality causes; Biota; Marine birds; Bivalvia; British Isles; ANE, British Isles; Eire; ANE, Eire.

Mark, W.L., and V.W. Harry. 2004. **Linking watershed loading and basin-level carrying capacity models to evaluate the effects of land use on primary production and shellfish aquaculture.** Bulletin of Fisheries Research Agency (Japan) no. Sup. 1, pp. 123-132. IS: ISSN 1346-9894.

Aquaculture production of hard clams, *Mercenaria mercenaria*, in the lower Chesapeake Bay, Virginia, U.S.A., has increased dramatically within the last decade. In recent years concern has been raised that some growing areas may be approaching the exploitation carrying capacity for clam production. Preliminary calculations indicate that large-scale intensive clam aquaculture may be controlling nutrient and phytoplankton dynamics in this system. To date, carrying capacity models for that purpose. Moreover changing land use in the watersheds surrounding the clam-producing areas raises the need for an improved understanding of how these changes will affect water quality, primary production and shellfish production. We describe an ongoing project linking a watershed-based loading model with a physical transport-based water quality model to simulate primary production and predict carrying capacity for clam aquaculture. Extensive calibration and verification of the water quality model has demonstrated its utility for simulating primary production and water quality parameters in the Chesapeake Bay. In our present efforts, watershed loading models have been developed and tested for predicting both surface and groundwater inputs into the coastal waters. We are currently coupling the water quality and watershed loading models, and developing clam physiology and population-level sub-models. Also, under development is a sediment deposition/resuspension sub-model. Each of these components will be linked to estimate exploitation carrying capacity for clam production in

this system. Our goal is to use the coupled models to predict how varying land use scenarios impact water quality, primary production and shellfish carrying capacity of coastal waters.

Mojica, R. Jr., and W.G. Nelson. 1993. **Environmental effects of a hard clam (*Mercenaria mercenaria*) aquaculture site in the Indian River Lagoon, Florida.** 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.

Keywords: environmental, impactclam, culture, Effluents, water, qualitymarine, aquaculturesea, grass, Mercenaria, mercenaria, Indian River, Lagoon, USA, Florida seagrasses, hard clam..

Nizzoli, D., M. Bartoli, and P. Viaroli. 2007. **Oxygen and ammonium dynamics during a farming cycle of the bivalve *Tapes philippinarum*.** Hydrobiologia 587:25–36.

Fluxes of dissolved oxygen and ammonium across the water sediment interface were measured in a control and in an experimental area farmed with the clam *Tapes philippinarum*. Young clams were seeded in March 2003 at mean (~500 ind m–2) and high (~1500 ind m–2) densities in a sandy area (2100 m2) of the Sacca di Goro Lagoon, Italy. Approximately every two months, until October 2003, intact sediment cores were collected and incubated in the light and in the dark and surface sediments (0–2 cm) were analysed for organic matter and nitrogen content. Clams farming induced pronounced changes in sediment characteristics and metabolism. Oxygen consumption and ammonium production at the high density area were, on average, 3 to 4 and 1.9 to 4.9 folds higher than those measured in the control field respectively; rates were positively correlated with clams biomass. Experimental fields resulted ‘‘Net and Total Heterotrophyc’’ in 3 out of 4 sampling dates and clams were the major factor shifting the benthic system towards this status. In only one occasion the appearance of the macroalgae *Ulva spp*. pushed the system rapidly towards hyperautotrophic conditions. Our results indicated that clams have the potential to drive benthic metabolism in farmed areas and to sustain macroalgal growth through regeneration of a limiting nutrient for seawater as inorganic N.

Keywords: Clam farming, Tapes philippinarum, Surficial sediment metabolism, Oxygen and ammonium benthic fluxes.

Rice, M.A. 2001. **Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication.** pp. 76-86 In: Marine Aquaculture and the Marine Environment. January 2001, Cape Cod Press, Falmouth, Massachusetts.

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 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 of other activities that promote excessive coastal eutrophication.

Keywords: environment, aquaculture, shellfish, eutrophication.

Sauve, S., P. Brousseau, and J. Pellerin, et al. 2002. **Phagocytic activity of marine and freshwater bivalves: in vitro exposure of hemocytes to metals (Ag, Cd, Hg and Zn).** Aquatic Toxicology. Vol. 58(no. 3-4):pp. 189-200.

We measured non-specific immune function of various bivalves from marine (*Cyrtodaria siliqua, Mactromeris polynyma, Mesodesma arctatum, Mya arenaria, Mya truncata, Mytilus edulis, Serripes groenlandicus, Siliqua costata*) and freshwater environments (*Dreissena polymorpha and Elliptio complanata*). We used flow cytometry to quantify the phagocytosis of fluorescent microspheres by hemocytes exposed in vitro to increasing levels of various metal compounds ($AgNO_3$, $CdCl_2$, CH_3HgCl, $HgCl_2$ and $ZnCl_2$. In some species, low doses of mercury (organic and inorganic) and Zn suggest a hormesis-like stimulation of phagocytic activity. At higher levels of exposure, all metals tested induced a significant dose-related inhibition of hemocyte phagocytosis. The species-specific sensitivity of the assay was determined by comparing the *in vitro* exposure using the metal concentration inducing 50% suppression (EC_{50}) of the phagocytic activity. Different species expressed different levels of sensitivity. Our results show the variability of the toxic response of different species within a group of similar organisms. It also highlights the need to consider species-species differences in ecotoxicological risk assessment.

Keywords: Aquatic organisms, Heavy metals, Silver, Cadmium, Mercury, Zinc, Immunology, Toxicity testing, Cytotoxicity, Flow cytometry, Phagocytosis, Pollution effects, Defence mechanisms, Water, Pollution, Effects, Variability, Mollusks, Experimental, Data, Animal Physiology, Inhibition, Metals, Pollution, WaterToxicity, see also Lethal limits, Molluscs, see also, Bivalves, Gastropods, Chemical inhibitors, Mercury, 197, Cyrtodaria siliqua, Mactromeris polynyma, Mesosdesma arctatum, Mya arenaria, Mya truncate, Mytilus edulis, Serripes groenlandicus, Siliqua costata, Dreissena polymorpha, Elliptio complanata, Bivalvia, Mesodesma arctatum, Northern propeller clam, Arctic, surfclam, Softshell clam, Truncate softshell clam, Blue-mussel, Greenland cockle, Atlantic razor, Zebra mussel, Eastern elliptio, Bivalves,Clams, Arctic, wedge, clam, immune system.

Sorokin, I.I., O. Giovanardi, F. Pranovi, and P. I. Sorokin. 1999. **Need for restricting bivalve culture in the southern basin of the Lagoon of Venice.** Hydrobiologia 400: 141–148.

At present, one of the environmental emergencies in the Lagoon of Venice is the impact of shortnecked clam (*Tapes philippinarum*) fishery, which is practically an unregulated fishery. Although one of the proposed solutions would be the restriction of *Tapes* fishery to licensed areas, high seeding density can cause undesired effects on the environment. In this study several hydrobiological variables are compared between small areas of the Lagoon of Venice traditionally used for bivalve culture (clam, *T. philippinarum* and mussel, *Mytilus galloprovincialis*), and areas in the southern basin with seagrass meadows. Labile and suspended organic matter in the water was higher in areas with bivalve farming than in *Zostera* areas (undisturbed control). The same pattern was recorded for contents of total organic matter and acid volatile sulphides. The biomass of microplankton in farming areas was quite high (0.82.7 g m super(3)). Mesozooplankton was extremely abundant, particularly at night, when its biomass was 12 orders of magnitude higher than during the day. Its composition was different in the culture areas and in *Zostera* areas. The biomass of *Tape*s in culture beds and their filtering capacity were also estimated.

Keywords: ECOP, mussels, seagrass.

1.2 Geoducks

Pearce, C.M., Y.X. An, J.M. Blackburn, L.J. Keddy, D.L. Paltzat, and S.W. Williams. 2007. **Intertidal culture of juvenile geoduck clams (*Panopea abrupta*): an examination of predator protection technology and potential environmental interactions.** Pacific Biological Station, Department of Fisheries and Oceans, Canada. (Presentation)

No abstract identifying these species for this category.

1.3 Mussels

Brylinsky, M. 1989. **Development of a simulation model of a cultured mussel (*Mytilus edulis*) population: Potential and limitations.** Journal of Shellfish Research. 8(2):470.

In an attempt to elucidate the complex relationships existing between the physical and biological processes that control the growth, spawning and mortality of cultured mussels, a computer simulation model was developed. The model is driven by temperature and particulate inorganic and organic matter concentration, and outputs shell and meat growth rates and spawning times. The model has been validated against several independent data sets and appears to have considerable predictive ability. The potentials and limitations of the model will be discussed in terms of its usefulness for addressing problems such as site selection, carrying capacity, summer mortality and the environmental impact of mussel culture.

Keywords: growth, simulation, Mytilus, edulismortality, mussel, culture

Cheney, D.P., A.D. Suhrbier, and A.E. Christy, et al. 2003. **Mussel growth and food utilization in relation to water column conditions on raft systems in Puget Sound, Washington.** Journal of Shellfish Research, 22(1):324.

Suspended mussel and oyster culture on the U.S. west coast is predicted to increase significantly in coming years. Description of the changes associated with the culture of these crops is essential for the siting and evaluation of new culture facilities and in improving yield and production of existing facilities. This research had three general objectives: 1) to assess at large-scale farm sites, mussel growth and yield against a suite of measured physical, chemical and biological variables; 2) to compare the same suite of variables with measurements of mussel feeding and biodeposit production; and 3) to utilize available nutrient and yield models to estimate potential mussel carrying capacity in the farming area. During a two year period (2001-03), multiple observations were made of water currents, water chemistry, phytoplankton, mussel growth, seston removal and absorption, fouling, and fish utilization at commercial mussel raft culture sites in Totten Inlet and Penn Cove, Washington. Although parameters, such as water currents and phytoplankton abundance varied markedly inside and outside the raft units and under different tidal regimes, these effects were localized and did not correlate with mussel growth. This research is supported by a Sea Grant National Marine Aquaculture Initiative grant.

Keywords: Marine aquaculture, Mussel culture, Raft culture, Growth rate, Yield, Food availability, Phytoplankton, Physicochemical properties, Current velocity, Nursery grounds, Mytilus, INE, USA, Washington, Puget Sound.

Dame, R., N. Dankers, T. Prins, H. Jongsma, and A. Smaal. 1991. **The influence of mussel beds on nutrients in the western Wadden Sea and eastern Scheldt estuaries.** Estuaries 14: 130-138.

The uptake and release of materials by intertidal mussel beds were directly measured in two cultivated Dutch estuaries. Generally, chlorophyll a, seston, and particulate organic carbon were taken up, while ammonium, orthophosphate, and silicate were released. The observed rates were higher than values computed from organismic observations and similar to those observed for intertidal oyster reefs in South Carolina. Specific estuarine material turnover rates varied from 1week to 38 weeks when calculated with mussel bed fluxes. The fastest turnover rates were for chlorophyll a and ammonium. These results support the idea that dense assemblages of bivalves are major components in the recycling of nutrients in estuaries.

Dankers, N., and D.R. Zuidema. 1995. **The role of the mussel (*Mytilus edulis L.*) and mussel culture in the Dutch Wadden Sea.** Estuaries. 18(1):71-80.

Mussel populations (*Mytilus edulis*) in the Dutch Wadden Sea (intertidal mussel beds, subtidal beds and culture plots), the culture methods, the extent of mussel culture, and the ecology of the mussel are described. Mussels filter suspended matter from the water column and deposit it as feces and pseudofeces. Mussel beds consume large amounts of phytoplankton and speed up the cycle of production and breakdown of organic matter. There are indications that the consumption of phytoplankton can lead to food shortage for several animal groups. Mussels serve as an important food source for a wide range of organisms (e. g., starfish, eider ducks, and oystercatchers). Because mussel culture increased the mussel biomass in the Dutch Wadden Sea, the impact also increased. The most obvious impact of the culture is the dredging of seed mussels. Overexploitation of intertidal mussel and cockle beds and bad spatfall of both mussels and cockles since 1988 had a negative impact on bird populations. The extent of positive and negative aspects of mussel culture depends on natural and human influences. The negative

aspects may (partly) be overcome by appropriate measures.

Keywords: mussel, culture, Mytilus, edulis species, culture, Wadden Sea..

Dolmer, P. and R.P. Frandsen. 2002. **Evaluation of the Danish mussel fishery: suggestions for an ecosystem management approach.** Helgoland Marine Research. Vol. 56, no. 1, pp. 13-20. IS: ISSN 1438-387X.

In Limfjorden, Denmark, an extensive mussel fishery exploits the wild stocks of *Mytilus edulis* with annual landings of 80,000-100,000 t of mussels. During the last 10 years the impact of mussel dredging on the ecosystem has been studied, including the effect of resuspension of sediment and nutrients and the impoverishment of in- and epi-fauna assemblages. Furthermore, dredging changes the physical structure and complexity of the seabed which affects mussel growth and interactions among zoo benthic species. The blue mussel constitutes the dominant fraction of the zoobenthic suspension feeders, and is important for the transport of material and energy from the pelagic to benthic systems and the control of phytoplankton biomass. In order to evaluate the impact on clearance capacity of a reduction in mussel densities due to mussel dredging, mussel filtration activity measured in situ has been related to the mixing of the water column and the amount of near-bed phytoplankton. Fishery practice for mussel dredging in Limfjorden is discussed in relation to its known impact on the ecosystem and the ecological role of the mussels, and modifications towards an ecosystem management approach and a more sustainable fishery are suggested. The suggested modifications include: a fishery practice where the mussel beds are thinned out when the mussels have attained good quality, and a transplantation practice of mussels from areas with a high mortality to areas with a high growth rate. Both practices intensify the production in a certain area, leaving other areas open for alternative production or for permanent closure for the benefit of the benthic flora and fauna. In addition, other shellfish species represent interesting new resources for fishing or aquaculture. Habitat restoration, such as the relaying of mussel shells from the mussel industry, is another important management tool that should be included in an ecosystem management approach of the mussel fishery.

Grant, J.; A. Hatcher, D.B. Scott, P. Pocklington, C.T. Schafer, and G.V. Winters. 1995. **A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities.** Department of Oceanography, Dalhousie University, Halifax, NS B3H 4J1, Canada, Estuaries. Vol. 18, no. 1A, pp. 124-144. IS: ISSN 0160-8347.

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.

Keywords: mussel culture; zoobenthos; environmental impact; ecosystem disturbance; community composition; aquaculture; environmental effects; benthos; effluents; Mytilus; mussels; Mytilus; ANW, Canada, Nova Scotia; Canada, Nova Scotia.

Holmer, M., N. Ahrensberg, and N. P. Jorgensen. 2003. **Impacts of mussel dredging on sediment phosphorus dynamics in a eutrophic Danish fjord**. Chemistry and Ecology. 19: 343–361.

Effects of mussel dredging on sediment metabolism (oxygen uptake and sulfate reduction rates) and phosphorus dynamics (flux across sediment-water interface and sequential extraction) were examined in Limfjorden (Denmark) during spring (May) and summer (August). Sediment samples were taken during mussel dredging and in addition an experimental simulation of the dredging was performed to investigate short-term changes in phosphorus (P) dynamics. Iron-bound P was reduced by up to 2=3 in the surface layer in the dredging track (from 31 to 8 mmol Pm_2), whereas the dissolved P-pools and less reactive particulate pools were not affected by dredging. Sediment oxygen consumption was enhanced immediately after dredging, but returned to the initial level after 4 days (20–40 mmolm_2 d_1). The enhanced consumption was attributed to reoxidation of reduced compounds released during dredging. Sulfate reduction rates were high in the area (13–15 mmolm_2 d_1) and sulfides competed with P for oxidized iron resulting in low iron-bound pools in the area (<4% of total P pools). Sulfate reduction rates were stimulated by the resuspension of sediments, especially in August, where a subsurface maximum was found, possibly due to a mixing of labile organic matter into these layers. In contrast sulfate reduction rates were reduced in the dredging track due to removal of labile organic matter from the surface layers. The loss of P during dredging was to some extent counteracted by regeneration of iron-bound P pools in the surface layers. The release of P due to mussel dredging was estimated to be in the same order of magnitude as the annual loading from the catchments and point sources to Limfjorden.

Keywords: Phosphorus; Mussel dredging; Sediment; Sulfate reduction; Oxygen consumption.

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.

La Rosa, T., S. Mirto, E, Favaloro, B. Savona, G. Sara, R. Danovaro, and A. Mazzola. 2002. **Impact on the water column biogeochemistry of a Mediterranean mussel and fish farm.** Water Research. Vol. 36, no. 3, pp. 713-721. Feb 2002. IS: ISSN 0043-1354.

We investigated and compared the impact of organic loads due to the biodeposition of mussel and fish farms on the water column of a coastal area of the Tyrrhenian Sea (Western Mediterranean). Physico-chemical data (including oxygen, nutrients, DOC and particulate organic matter), microbial variables (picoplankton and picophytoplankton density and biomass) and phytoplankton biomass (as chlorophyll-a) were determined on a monthly basis from March 1997 to February 1998. The results of this study indicate that both fish farm and mussel culture did not alter significantly dissolved inorganic phosphorus and chlorophyll-a values, while inorganic nitrogen concentrations were higher in mussel farm area. However, waters overlying

the fish farm presented significantly higher DOC concentrations. In contrast, no significant differences were observed comparing particulate matter concentrations. The increased DOC concentrations determined a response of the heterotrophic fraction of < BR>picoplankton, while picophytoplankton, likewise phytoplankton, did not display differences among fish or mussel farms and control site. From the analysis of the different microbial components, it is possible to conclude that the impact of fish farms is evident only for the heterotrophic components. The comparative analysis of the mussel biodeposition and fish-farm impact revealed that mussel farms induced a considerably lower disturbance, apparently limited to an increased density and biomass of microbial assemblages beneath the mussel cultures.

Lindahl, O., R. Hart, and B. Hernroth, et al. 2005. **Improving Marine Water Quality by Mussel Farming: A Profitable Solution for Swedish Society**. Ambio. 34(2):131-138.

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.

Mwangi, S.N. 1994. **The influence of bivalve filter feeders on bacteria populations and seston in Gazi Bay and Wadden Sea. 92.**

This study investigated the effect that bivalve filter feeders had on the bacteria and seston concentration of the water that flowed through their beds, the tidal influence on food availability for the bivalves and seasonal changes of bacteria and seston concentrations. The study was carried out in an oyster culture plot in Gazi Bay, Kenya and in the Dutch Wadden Sea where intensive mussel culture is carried out. On a few occasions, the oysters in Gazi were observed to reduce the bacteria biovolume and thus the biomass, reduce chlorophyll-a concentration in the water and take up the easily degradable organic material. Bacteria and the total seston concentration in the water varied with the tide thus influencing food availability for the oysters. Resuspension during both flood and ebb tides resulted in a general increase in bacteria abundance and biomass, dissolved oxygen, suspended matter, easily degradable organic material, POC and chlorophyll-a. In the Wadden Sea, the water overlying mussel beds was observed to have a high bacteria abundance but of low biovolume thus low total biomass in autumn. There were more indications of enhanced bacteria abundance than bacteriovory. Phytoplankton uptake was not clearly observed probably due to the prevailing hydrodynamic conditions. The total microbial biomass was not strongly influenced by the tide and bacteria contributed the highest

proportion of the biomass. Respiratory activity was not high and was also not strongly influenced by the tide. In spring, increase in bacteria biomass through increased biovolumes was observed with indications of bacteriovory. A reduction of POC and chlorophyll-a in the water overlying the mussel beds was observed suggesting the uptake of organic matter and phytoplankton. There were high tidal fluctuations of POC, chlorophyll-a and bacteria abundance and biomass. Bacteria contributed less to the total microbial biomass in spring.

Keywords: Seston, Intensive, culture, Oyster, culture, Mussel, culture, Tidal constituents, Phytoplankton, Resuspension, Dissolved, oxygen, hlorophylls, Particulate ,organic, carbon, Filter, feeders, Ostreidae ,Mytilidae ,ISW, Kenya, Coast, Gazi Bay, Netherlands, Wadden Sea, Bacteria, Bivalves, Clams, Mussels, Bivalvia.

Nizzoli, D., D. T. Welsh, M. Bartoli, and P. Viaroli. 2005. Impacts of mussel (*Mytilus galloprovincialis*) farming on oxygen consumption and nutrient recycling in a eutrophic coastal lagoon. Hydrobiologia. 550(1):183-198.

Fluxes of oxygen, nitrogen and phosphorus were determined in two areas of the Sacca di Goro lagoon, at a site influenced by the farming of the mussel *Mytilus galloprovincialis* and a control site. Mussel farming induced intense biodeposition of organic matter to the underlying sediments, which stimulated sediment oxygen demand, and inorganic nitrogen and phosphorus regeneration rates compared to the nearby control station. Overall benthic fluxes (-11.4 ± 6.5 mmol $O_2\, m^{-2}\, h^{-1}$; 1.59 ± 0.47 mmol $NH_4^+\, m^{-2}\, h^{-1}$ and 94 ± 42 μmol $PO_4^{3-}\, m^{-2}\, h^{-1}$) at the mussel farm are amongst the highest ever recorded for an aquaculture impacted area and question the belief that farming of filter-feeding bivalves has inherently lower impacts than finfish farming. *In situ* incubations of intact mussel ropes demonstrated that the mussel rope community was an enormous sink for oxygen and particulate organic matter, and an equally large source of dissolved inorganic nitrogen and phosphate to the water column. Overall, a one meter square area of mussel farm (mussel ropes and underlying sediment) was estimated to have an oxygen demand of 46.8 mmol $m^2\, h^{-1}$ and to regenerate inorganic nitrogen and phosphorus at rates of 8.5 and 0.3 mmol $m^2\, h^{-1}$, with the mussel ropes accounting for between 70 and more than 90% of the overall oxygen and nutrient fluxes. Even taking into account that within the farmed area of the Sacca di Goro lagoon, there are 15–20 m^{-2} of open water for each one covered with mussel ropes, the mussel ropes would account for a large and often dominant part of overall oxygen and nutrient fluxes. These results demonstrate that it is essential to take into account the activity of the cultivated organisms and their epiphytic community when assessing the impacts of shellfish farming. Overall, whilst grazing by the mussel rope community could act as a top-down control on the phytoplankton, most of the ingested organic matter is rapidly recycled to the water column as inorganic nutrients, which would be expected to stimulate phytoplankton growth. Consequently, the net effect of the mussel farming on phytoplankton dynamics may be to increase phytoplankton turnover and overall production, rather than to limit phytoplankton biomass.

Keywords: aquaculture, impacts, biodeposition, benthic, metabolism, ropes, metabolism, nutrient, cycles, species, culture.

Richard, L. 2004. **Balancing marine aquaculture inputs and extraction: Combined culture of finfish and bivalve molluscs in the open ocean.** Bulletin of Fisheries Research Agency (Japan). no. Sup. 1, pp. 51-58. IS: ISSN 1346-9894.

Enrichment of the water column with dissolved nutrients and of bottom sediments with organic matter as a result of culturing finfish in sea cages have been identified as real and potential environmental impacts of fish culture. While severe impacts have been documented in shallow, poorly flushed waters, proper siting of sea cage operations generally results in only minor localized impacts to the benthic community on the sea floor directly beneath the cages. None the less, the perception of environmental groups and regulatory agencies in the U.S.A. that fish waste and uneaten feed will impact the marine environment regardless of siting has affected the expansion of existing sites and the establishment of new sites. In order for the industry to expand to meet the growing demand for seafood, measures to mitigate these impacts must be taken. One possible solution is to balance inputs of feed with extraction of biomass of organisms such as marine plants and bivalve molluscs that do not require external feed application. In 1999, the University of New Hampshire established the Open Ocean Aquaculture Demonstration Project. Funded by the National Oceanic and Atmospheric Administration, the project was designed to provide a commercial scale demonstration and research site for open ocean aquaculture in the northeast U.S.A. The project is an integrated, multi-disciplinary, regional effort that includes biology, oceanography, engineering, sociology, economics, technology transfer, and education. While the development of technologies for finfish and shellfish production in offshore environments is central to the mission of the project, demonstration of the environmental sustainability of open sea culture is critical to the social acceptance of industry development. Since 1999, the project has produced harvests of several species of finfish using submersible sea cages and six crops of molluscan shellfish (primarily blue mussels) using submerged longlines in close proximity to the sea cages. While not considered true polyculture, the harvest of the filter feeding bivalve molluscs represents a net removal of nitrogen, carbon and phosphorus that can be used in mass balance to offset the addition of these nutrients from finfish feeding. In this paper, data the potential for balancing inputs associated with feed application and fish wastes with extraction of fish and bivalve biomass will be examined.

Smaal, A., M. van Stralen and E. Schuiling. 2001. **The interaction between shellfish culture and ecosystem processes**. Canadian Journal of Fisheries and Aquatic Sciences. 58(5):991-1002.

The carrying capacity of the Oosterschelde ecosystem for the production of mussels (*Mytilus edulis*) was evaluated before and after completion of a large-scale coastal engineering project in 1987. This project caused hydrodynamic and water-quality changes; hence, phytoplankton-species composition change and phytoplankton turnover increased but primary production remained the same. In the prebarrier period (1980-1986), condition of mussels showed a significant negative correlation with the annual shellfish standing stock and a significant positive correlation with the annual primary production. The system was exploited at maximum capacity. In the postbarrier period (1987-1997), the significant correlation between mussel condition and primary production remained, but there was no longer a negative correlation between standing stock and condition. This indicates overstocking, but yields were maintained. This was explained by 1) feedbacks of the mussels in the Oosterschelde ecosystem - through their large filtration and nitrogen-regeneration capacity, increased phytoplankton turnover was induced; and 2) adaptation to new conditions by the shellfish farmers in their management of mussel stocks. It was concluded that feedbacks by filter feeders and farmers have

to be addressed in estimating the exploitation capacity of ecosystems.

Keywords: Mussel, culture, Carrying, capacity, Primary, production, Dams, Storm, surge, barriers, Environmental impact, Ecological balance, Mytilus, edulis, ANE, Netherlands, Zeeland, Oosterschelde.

van der Veer, H.W. 1989. **Eutrophication and Mussel Culture in the Western Dutch Wadden Sea: Impact on the Benthic Ecosystem; A Hypothesis.** Helgolaender Meeresuntersuchungen HEMEDC. Vol. 43, No. 3/4, p 517-527, 6 fig, 1 tab, 25 ref.

Since 1950, two large-scale changes have taken place in the western Dutch Wadden Sea, namely the eutrophication of the area and the introduction of an extensive mussel culture. Although eutrophication in the fresh waters started already around 1950, nutrient concentrations in the western Wadden Sea remained fairly constant until about 1970, due to the retention of nutrients in Lake Ijssel, the main source. From 1970-1980 concentrations increased strongly, and during the last years the situation has stabilized. Mussel culture was introduced in 1950 and expanded during the next decade to an area of 70 sq km, all situated in the sublittoral area. From 1960 the area of mussel culture remained about constant with fluctuating yields of between 35 and 120 million kilograms of fresh weight. Due to a lack of data for the period until 1970 the impact of eutrophication and mussel culture cannot be assessed. From 1970 onwards an increased biomass and production of the macrofauna in the intertidal zone has been observed, which is attributed to eutrophication. The hypothesis is postulated that the introduction of mussel culture between 1950 and 1960 has resulted in an increased competition for food in the area, leading to a decreased stock of the macrofauna in the intertidal. Eutrophication from about 1970 onwards has improved the food conditions and as a result both the macrofauna in the intertidal and the mussel in the sublittoral area would have increased in biomass, allowing higher maximum yields of the mussel culture. Monitoring programs will be used to follow these trends in the near future and to check the above hypothesis in areas where it is decided to introduce or to intensify mussel culture. (Author 's abstract).

Keywords: Aquaculture; Benthic environment; Eutrophication; Mussels; Shellfish farming; The Netherlands; Wadden Sea; Water pollution effects; Water quality trends; Aquatic animals; Biomass; Competition; Ecosystems; History; Intertidal areas; Lake IJssel; Monitoring; Nutrient Concentrations.

1.4 Oysters

Bacher, C., P. Duarte, J.G. Ferreira, M. Héral, and O. Raillard. 1997. **Assessment and comparison of the Marennes-Oléron Bay (France) and Carlingford Lough (Ireland) carrying capacity with ecosystem models.** Aquat. Ecol. 31(4):379-394.

Based on the individual growth, food limitation, population renewal through seeding, and individual marketable size, a theoretical model of the cultured species population dynamics was used to assess the carrying capacity of an ecosystem. It gave a dome-shape curve relating the annual production and the standing stock under the assumption of individual growth limited by the available food in an ecosystem. It also showed the influence of mortality rate and marketable size on this curve and was introduced as a means to explore the global properties resulting from the interactions between the ecophysiology of the reared species and the environment at the

ecosystem level. In a second step, an ecosystem model was built to assess the carrying capacity of Marennes-Oléron bay, the most important shellfish culture site in France, with a standing stock of *Crassostrea gigas* around 100000 tonnes fresh weight (FW) and an annual production of 30000 tonnes FW. The ecosystem model focused on the oyster growth rate and considered the interaction between food availability, residence time of the water, oyster ecophysiology and number of individuals. It included a spatial discretization of the bay (box design) based on a hydrodynamic model, and the nitrogen or carbon cycling between phytoplankton, cultured oysters, and detritus. From simulations of the oyster growth with different seeding values, a curve relating the total annual production and the standing stock was obtained. This curve exhibited a dome shape with a maximum production corresponding to an optimum standing stock. The model predicted a maximum annual production of 45000 tonnes FW for a standing stock around 115000 tonnes FW. The prediction confirmed some results obtained empirically in the case of Marennes-Oléron bay and the results of the theoretical model. Results were compared with those obtained in Carlingford Lough (Ireland) using a similar ecosystem model. Carlingford Lough is a small intertidal bay where the same species is cultured at a reduced scale, with current biomass less than 500 tonnes FW. The model showed that the standing stock can be increased from 200 tonnes FW to approximately 1500 tonnes FW before any decrease of the production.

Ball, B., R. Raine, and D. Douglas. 1997. **Phytoplankton and particulate matter in Carlingford Lough, Ireland: An assessment of food availability and the impact of bivalve culture.** Estuaries. 20(2):430-440.

In an attempt to assess the impact of bivalve culture in Carlingford Lough, Ireland, the seasonal cycles of nutrients, particulate matter, chlorophyll a, and phytoplankton in the lough was investigated in 1992. Chlorophyll levels showed an increase in April, corresponding to the annual spring bloom, and levels remained relatively high (212 mg/m super(3)) throughout the summer before dropping to a winter minimum by December. Throughout the summer the phytoplankton community was dominated by diatoms, with microflagellates becoming an increasingly larger fraction of the biomass in autumn and winter. Dinoflagellates were only present on occasion in low numbers during the summer months. Seasonal variations in nitrate, phosphate, and silicate concentrations at all stations showed characteristic winter maxima and summer minima. Nitrate concentrations had reached a minimum undetectable level by June, at a time when the main freshwater input from the Clanrye River had dropped to <0.3 m super(3)/s. Particulate organic carbon (POC) composed approximately 5% of the suspended matter, with highest values in winter due to resuspension. Levels of biologically available POC, as determined by a modified BOD technique, were greatest in summer, and an inverse relationship was observed between total POC and its fraction that was biologically available. Most of the labile fraction was considered to be phytoplankton, and remineralization during the summer is suggested as a mechanism for maintaining high productivity during the summer months. Although the phytoplankton biology was uncoupled with that outside the lough, it is concluded that there is scope for expansion of the local bivalve mariculture industry without altering the ecosystem of the lough. The upper limit on such expansion would be set by practical considerations such as availability of space and site suitability due to water quality.

Keywords: ECOP, phytoplankton, particulate, bivalve, oyster.

Banas, N.S., B.M. Hickey, J.A. Newton, J.L. Ruesink. 2007. **Tidal exchange, bivalve grazing, and patterns of primary production in Willapa Bay, Washington.** Marine Ecology Progress Series 341:123-139.

Modeling study to explore causes of declining phytoplankton abundance into Willapa Bay. The model shows that, during the summer, phytoplankton declines from bay Center to Sunshine Pt (junction of Naselle R and Lon Island Slough) more than would be expected from simple mixing of rich ocean and poor river water. The extra loss is consistent with the capacity of cultured oysters to filter it out. The model indicates that adding more oysters to the bay would reduce individual growth rates – essentially the bay is near carrying capacity. Interestingly, this result is achieved even though a large fraction of the bay's water (>80%) never moves over a shallow tideflat and is not susceptible to filtration. [Funding: NOAA Sea Grant. NSB at UW Oceanography].

Barille, L., J. Prou, M. Heral, and D. Razer. 1997. **Effects of high natural seston concentrations on the feeding, selection, and absorption of the oyster *Crassostrea gigas* (Thunberg).** Journal of Experimental Marine Biology and Ecology. 212: 149-172.

Feeding, selection and absorption were determined for the Pacific oyster *Crassostrea gigas* cultivated in the Bay of Marennes-Oléron, over a spring/neap tidal cycle. Physiological determinations were related to the highly variable food environment with continuous recordings of turbidity and fluorescence. In this bay, resuspension processes have a major influence on food availability and quality. Seston characteristics experienced by oysters can be summarized by high turbidity levels from 20 to 350 $mg \cdot l^{-1}$ and a predominance of the detritic fraction among the organic fraction (mean C/N ratio=16.57). Food is diluted by the fine resuspended sediment, and organic content of particulate matter in the water column decreases from 30% to 10% with increasing seston loads.

Significant differences (Ancova, $P<0.01$), due to low retention efficiencies of the smaller particle size range, were recorded between the food quality (estimated by the organic content and the total pigment content) measured in the water column and the fraction retained by the oyster's gill. Below seston concentrations of 90 $mg \cdot l^{-1}$ ingestion rate was regulated by pseudofaecal production. Above 90 $mg \cdot l^{-1}$, a sharp reduction of filtration and rejection rates suggests physical constraints limiting food acquisition. The oyster selectively rejects inorganic from organic particles, enriching the ingested fraction. Amongst the potentially nutritive particles, significantly fewer particles containing phytopigments were rejected relative to organic particles (non-linear regressions, $P<0.001$). The negative influence, through food dilution, of high seston loads on net absorption efficiency was determined. This efficiency decreases with decreasing organic ingested fraction. Scope for growth calculations confirm the negative influence of seston loads, but show, supported by field growth measurements, that resuspended organic particles play an important role in the oyster's nutrition.

Keywords: Crassostrea gigas; Ecophysiology; Tidal cycle; Turbidity.

Baudrimont, M., J. Schafer, and V. Marie, et al. 2005. **Geochemical survey and metal bioaccumulation of three bivalve species (*Crassostrea gigas, Cerastoderma edule* and *Ruditapes philippinarum*) in the Nord Medoc salt marshes (Gironde estuary, France).** Science of the Total Environment 337(1-3): 265-280.

A 15-month experiment combining a geochemical survey of Cd, Cu, Zn and Hg with a bioaccumulation study for three filter-feeding bivalve species (oysters, *Crassostrea gigas*; cockles, *Cerastoderma edule*; and clams, *Ruditapes philippinarum*) was conducted in a breeding basin of the Nord Medoc salt marshes connected to the Gironde estuary, which is affected by historic polymetallic pollution. Regular manual surface measurements of temperature, salinity, pH and dissolved O sub(2) concentration and hourly multiprobe in situ measurements throughout several periods for 6-8 weeks were performed. The geochemical behavior of metals in water, suspended particulate matter and sediment and their ecotoxicological impact on the three bivalve species were evaluated by in situ exposure of juvenile oysters (water column) and adult cockles and clams (sediment surface). The physico-chemical parameters reflected seasonal variations and basin management. A distinct daily periodicity (except salinity) indicated intense photosynthesis and respiration. In summer, low dissolved O sub(2) saturations (similar to 40-50%) occurred in the early morning at 30 cm above the sediment, whereas in depressions, the water column near the sediment surface was suboxic. Cadmium, Zn and Cu concentrations in suspended particulate matter exceeded typical estuarine values and were much higher than the homogeneously distributed concentrations in different depth ranges of the basin sediment. Particles collected in sediment traps showed intermediate metal concentrations close to sediment values. These results suggest trace metal recycling due to reductive dissolution under suboxic conditions at the sediment surface resulting in trace metal release to the water column and adsorption onto suspended particles. Dissolved Cd, Zn and Hg concentrations (e.g. 13-136 ng l super(-1); 0.3-25.1 mu g l super(-1) and 0.5-2.0 ng l super(-1), respectively) in the basin corresponded to the concentration range typically observed in the Gironde estuary, except for some maximum values attributed to metal recycling. In contrast, dissolved Cu concentrations (1.08-6.08 mu g l super(-1)) were mostly higher than typical estuarine values, probably due to recycled Cu complexation by dissolved organic matter. Growth, bioaccumulation rates and kinetics in the whole soft body of the bivalves were analyzed every 40 days. Although Cd bioaccumulation of oysters was lower in the basin than in the estuary during the same period (27, 000 ng g super(-1), dry weight and 40, 000 ng g super(-1), respectively) these values are largely above the new human consumption safety level (5000 ng g super(-1), dw; European Community, 2002). For cockles and clams, Cd bioaccumulation was lower, reaching 1400 ng g super(-1) and 950 ng g super(-1), respectively. Similar results were obtained for Zn and Cu suggesting physiological differences between the species and/or differences in the exposure of the organisms due to physico-chemical conditions and metal distribution between dissolved and particulate phases. In contrast, Hg bioaccumulation was highest for cockles reaching bioconcentration factors of similar to 200,000, which even exceeded that of Cd in oysters (50, 000) for the same exposition period.

Keywords: Marine organisms, Salt marshes, Biogeochemistry, Bioaccumulation, Seasonal variations, Heavy metals, Zinc, Mercury, Cadmium, Copper, Marine molluscs, Brackishwater pollution, Resuspended sediments, Suspended particulate matter, Toxicity tests, Brackishwater environment, Geochemical surveys, Pollution indicators, Trace metals, Pollution effects, Estuarine sedimentation, Physicochemical properties, Dissolved organic matter, Suspended Sediments, Oysters, Mollusks, Estuarine, Environment, Clams, Water Pollution, Effects, Particulate Matter, Exposure, Biological , Magnification, Dissolved, Solids, Crassostrea gigas, Cerastoderma edule, Ruditapes philippinarum, Bivalvia, France, Nord Medoc, ANE, France, Gironde Estuary, France, Gironde Estuary, Pacific giant oyster, Bivalves, Marine, Brackish

Boghen, A.D., J. Allard, P. Beninger, and E. Battaler. 1990. **A monitoring program for the oyster industry of New Brunswick: Current status.** Aquaculture Association of Canada Conference. 90(4):75-78.

A pilot-scale monitoring program was established for the oyster industry in 1987. The project is managed by the Environmental Sciences Research Centre (ESRC) of the Universite de Moncton, in close collaboration with a team of oyster growers located on the Acadian Peninsula and in southeastern New Brunswick. In order to acquire a thorough understanding of the environmental impact on growth and development of the native oyster *Crassostrea virginica* at specific sites, various water chemistry tests are conducted at sea, accompanied by biological studies in the laboratory.

Keywords: aquaculture, pollution, effects, industrial production, Crassostrea virginica, environmental monitoring, ANW, Canada, New Brunswick oyster, culture, general aquaculture.

Cardwell, R.D., C.E. Woelke, M.I. Carr, and E.W. Sanborn. 1977. **Evaluation of water quality of Puget Sound and Hood Canal in 1976.** NOAA Tech.Memo.41.

Marine water quality of Puget Sound basin south of Whidbey island and of Hood Canal was assessed on 20 July and 15 September 1976, respectively. Water quality was described toxicologically using Pacific oyster (*Crassostrea gigas*) larvae as an indicator and chemically using the following synoptic parameters: dissolved oxygen, pH, salinity, temperature, ammonia, Pearl-Benson Index-sensitive substances, and total organic carbon. The principal water quality problem of this area caused oyster larvae to die, usually within approximately 20 hours. Restricted mainly to waters from the heads of bays and inlets in the basin, larval mortality possibly may be linked etiologically to toxic metabolites of phytoplankton or bacteria or both. Densities of the armored dinoflagellate Ceratium fusus explained 72% of the variation in larval mortality for waters from three inlets where the relationship was examined. Total organic carbon explained only 22% of such variation. Commencement Bay was the principal area where larval development was affected. Larvae also developed abnormally in waters possessing salinities below those considered acceptable for their normal development. Locales possessing diminished water quality are usually embayments and similar areas possessing restricted flushing.

Keywords: water quality, pollution effects, red tides, Crassostrea gigas, Ceratium fusus, INE, Puget Sound, estuarine, circulation.

Chapelle, A., A. Menesguen, J.M. Deslous-Paoli, P. Souchu, N. Mazouni, A. Vaquer, and B. Millet. 2000. **Modelling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters farming and inputs from the watershed.** Ecological Modelling 127: 161-181.

An ecosystem model based on nitrogen cycling and oxygen has been developed for the Thau lagoon. It takes into account the specific features of this Mediterranean lagoon, a semi-confined system with watershed inputs and oyster farming. The ecosystem model uses currents calculated by a two-dimensional hydrodynamic model and integrated into a box model. This model is compared with a year survey data and used to estimate nitrogen and oxygen fluxes between the different ecosystem compartments. The yearly simulation shows that the ecosystem behavior is driven by meteorological forcing, especially rain which causes watershed inputs. These inputs trigger microphytoplankton growth, which is responsible for new primary production. During dry periods, nitrogen is recycled into the lagoon thanks to oyster's excretion, sediment release, microzooplankton excretion and mineralization. Ammonium produced in this way is consumed by a population of pico- and nanophytoplankton causing regenerated primary production. Consequently, the ecosystem remains highly productive in summer even without external inputs. Shellfish farming also plays an important role in the whole lagoon through biodeposition. Driven by biodeposition, sediment release is the major source of nitrogen in the water column and causes oxygen reduction. The oysters contribute to the recycling activity by excretion, which supports the regenerated primary production. They are also involved in oxygen consumption by respiration which can cause local hypoxia. Further improvements are proposed before this model may become a functional environmental model for a lagoon ecosystem.

Keywords: Models; Productivity; Aquaculture; Nutrient concentrations; Lagoons; Oyster culture; Aquaculture effluents; Environmental impact; Primary production; Nitrogen cycle; Coastal lagoons; Anoxic conditions; Mathematical Models; Cycling Nutrients; Oysters; Primary Productivity; Environmental Effects; MED.

Cheney, D.P., A.D. Suhrbier, and A.E. Christy, et al. 2003. **Mussel growth and food utilization in relation to water column conditions on raft systems in Puget Sound, Washington.** Journal of Shellfish Research, 22(1):324.

Suspended mussel and oyster culture on the U.S. west coast is predicted to increase significantly in coming years. Description of the changes associated with the culture of these crops is essential for the siting and evaluation of new culture facilities and in improving yield and production of existing facilities. This research had three general objectives: 1) to assess at large-scale farm sites, mussel growth and yield against a suite of measured physical, chemical and biological variables; 2) to compare the same suite of variables with measurements of mussel feeding and biodeposit production; and 3) to utilize available nutrient and yield models to estimate potential mussel carrying capacity in the farming area. During a two year period (2001-03), multiple observations were made of water currents, water chemistry, phytoplankton, mussel growth, seston removal and absorption, fouling, and fish utilization at commercial mussel raft culture sites in Totten Inlet and Penn Cove, Washington. Although parameters, such as water currents and phytoplankton abundance varied markedly inside and outside the raft units and under different tidal regimes, these effects were localized and did not correlate with mussel growth. This research is supported by a Sea Grant National Marine Aquaculture Initiative grant.

Keywords: Marine aquaculture, Mussel culture, Raft culture, Growth rate, YieldFood availability, Phytoplankton, Physicochemical properties, Current velocity, Nursery grounds, Mytilus, INE, USA, Washington, Puget Sound.

Clark, H., and G.H. Wikfors. 1998. **Oysters as processors of particulate organic nitrogen: Quantitative and qualitative assessment of inputs and outputs.** Journal of Shellfish Research. 17(1):351.

Cycling of nutrients in estuaries may be controlled in large part by filter feeding bivalves. Nutrient cycling patterns may depend, however, upon which algal species are available to bivalves at any given time. Bivalves may feed selectively, so that certain particles are ingested and digested while others are rejected as pseudofeces. Such selective feeding could affect the processing of nitrogen and cycling of that nitrogen in estuaries inhabited by oysters. This study was done to enhance knowledge of how the oyster, *Crassostrea virginica*, processes microalgal particulate organic nitrogen (PON), and whether the oyster processes PON differently when fed a variety of different algal types. Results suggest that oysters process PON differently depending upon the algal species available in the diet, and that a large amount (78%) of ingested nitrogen is excreted in fecal material. Biodeposition by feeding oysters translocates nitrogen from the water column to the benthic region, thereby modifying the dynamics of nitrogen in coastal waters inhabited by oysters. Both this effect upon pelagicbenthic coupling, and the differential processing of PON with different algal diets, may have important implications for natural waters and for aquaculture settings.

Keywords: Food webs, Energy flow, Nitrogen cycle, Oyster culture, Food preferences, Eastern oyster.

Crawford, C. 2003. **Environmental management of marine aquaculture in Tasmania, Australia.** Aquaculture. Vol. 226, no. 1-4, pp. 129-138. 31 Oct. IS: ISSN 0044-8486.

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 farms 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. Research related to management of aquaculture wastes is ongoing. Studies include investigating appropriate inexpensive measures for an industry-wide long-term monitoring program. Mitigation measures against excessive loadings of organic matter from fish farms, mainly by fallowing, i.e. rotating the position of fish pens around a lease, are currently being researched. Rates of recovery of a heavily impacted salmon lease area after the removal of fish have also been studied. A new project is investigating system-wide effects of salmon farming on the environment, in particular, increased release of nutrients into waterways. This includes monitoring dissolved oxygen, nutrients and phytoplankton, modelling the system, and investigating ecological indicators of eutrophication.

Crawford, C;I. Mitchell, and C. Macleod. 2001. **Effects of shellfish farming on the environment.** Tasmanian Aquaculture and Fisheries Institute, University of Tasmania,

Aquaculture 2001: Book of Abstracts. 143 p. Conference Aquaculture 2001, Lake Buena Vista, FL (USA), 21-25 Jan 2001.

The production of shellfish, mainly *Crassostrea gigas*, in Tasmania, Australia is approximately 2,500 metric tons per annum, which is small by world standards. Nevertheless, there is considerable community opposition to the expansion of the industry, partly because of concerns about possible detrimental effects on the environment. As a consequence, several projects were instigated to investigate the interactions between shellfish farming and the environment. The effects of shellfish farming on the benthic environment were investigated in detail at three deep water shellfish farms in Tasmania which have had a relatively high level of production. Benthic samples collected from within and outside the farm area were analyzed for physical/chemical variables, and composition and abundance of the invertebrate faunal community. Rates of sediment deposition were measured, and sections of the seabed were recorded using a video camera. 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.

Keywords: Marine aquaculture; Shellfish culture; Oyster culture; Environmental effects; Benthic environment; Ecosystem disturbance; Disease transmission; Eutrophication; Sedimentation; Suspended particulate matter; Particulate organic matter; Particulate flux; Man-induced effects; Aquaculture; Human impact; Population-environment relations; Sediments; Risk assessment; Pests; Pathogens; Coastal zone; Estuaries; Filter feeders; Nutrients; Environmental impact; Crassostrea gigas; Australia, Tasmania; PSE, Australia, Tasmania.

Crosby, M.P. 1988. **Using bioenergetics of intertidal oyster populations as a measurement of anthropogenic perturbations to shellfish growing waters.** Journal of Shellfish Research. 7(1):199-200.

Shellfish growing waters, such as salt marshes and estuaries, adjacent to urban sprawl receive a myriad of wastes and other inputs previously foreign to these sensitive coastal ecosystems. Because oysters are sessile, benthic, and feed by filtering large volumes of water, they serve as "sentinels" of, and are directly affected by, the quality of water passing over them. For this reason, sub-lethal changes in oyster scope for growth can infer that alterations in their surrounding environment have occurred. Methods are described of a study, to examine sub-lethal effects of coastal development on the ecophysiology of intertidal oyster populations in the North Inlet Estuary, SC. Methods discussed will include in situ measurements of oyster scope for growth, O:N ratios, biochemical composition, seston food quantity and quality, recruitment, juvenile survival, and susceptibility to parasitic diseases such as "Dermo" and "MSX". Anticipated accomplishments and benefits of studies of this design are to elucidate the effects of

coastal development on shellfish growing waters in terms of 1) nutrient storage; 2) fecundity, recruitment, and juvenile survival; 3) susceptibility to disease; 4) scope for growth; and 5) overall energetics of oysters.

Keywords: shellfish, culture, oyster, culture, water, quality, pollution, effects, pollution, monitoring, indicator, species, man induced effects, Crassostrea virginica, ANW, USA, South Carolina, North Inlet Estuary, pollution indicators, bioenergetics.

Deslous-Paoli, J.M., N. Mazouni, P. Souchu, S. Landrein, P. Pichot, and C. Juge. **Oyster farming impact on the environment of a mediterranean lagoon (Thau) (Preliminary results of the OXYTHAU program).** NATO ASI Series. G 33

The lagoon on Thau is a shallow microtidal system exposed to terrestrial and marine influences. The residence time and the vertical mixing of water-mass are controlled by winds. Periodical absence of wind in summer can lead to strong anoxia in sediments and bottom waters. Moreover, low incorgainc ntirogen and chlorophyll - levels confer seasonal oligotrophic features to the ecosystem. Nevertheless, a large productive stock of oysters (*Crassostrea giga*) cultivated on suspended lines and colonized by epibiota covers 20% of the total area. The aim of the present programme (OXYTHAU 1991-1995) is to study effects of oyster farming on the environment of the lagoon of Thau. Preliminary results obtained are presented here.

Keywords: Oysters, farming, impact, ECOP.

Dewey, W.F. 2000. **The various relationships between shellfish and water quality.** Taylor Shellfish Company, Inc. USA Journal of Shellfish Research, Vol. 19, no. 1, p. 656. Jun. Conference Annual Meeting of the National Shellfisheries Association, Seattle, Washington (USA), March 19-23, 2000.

Shellfish Growers dedicate considerable resources to protect and restore clean water to produce wholesome shellfish which are safe to consume raw. This is the foundation of the National Shellfish Sanitation Program. Recognized as equally important is the role that filter feeding molluscan shellfish play in cleansing water. Touted as keystone species, significant efforts have been made to reintroduce oysters to New York Harbor and the Chesapeake Bay to improve water quality in these systems. Aside from the valuable function the oysters physically serve as habitat and refuge is their ability to filter huge volumes of phytoplankton which, in heavy blooms, can cause low dissolved oxygen problems when the blooms die off as well as blocking critical sunlight for seagrasses and macroalgae. In the Pacific Northwest a citizens group, organized in opposition to mussel farm expansion on the basis of the aesthetic impact, is attempting to change the water-cleansing image of shellfish into a water-polluting image. The group recently filed suit in federal court claiming the feces, pseudofeces, mussel shell debris and escaped mussel spat from propagating mussels are a point source of pollution and require a National Pollution Discharge Elimination System (NPDES) permit under the Clean Water Act. This paper discusses the dichotomy between the views of shellfish as polluters versus the view of shellfish as capable of improving water quality and habitat.

Keywords: Water quality; Aquaculture effluents; Environmental impact; Shellfish culture; Filter feeders; Filtration; Pollution control; Oyster fisheries; Mussels; Water Pollution Effects;

Effluents; Aquaculture; Oysters; Shellfish; Seafood; Water quality (Natural waters); Bivalves (Mussels); Pollution (Water); Effluent; Bivalves (Oysters); Food (see also Animal foodstuffs).

Gifford, S., R.H. Dunstan, W. O'Connor, T. Roberts, and R. Toia. 2004. **Pearl aquaculture--profitable environmental remediation?** Science of the Total Environment. Vol. 319, no. 1-3, pp. 27-37. Feb. IS: ISSN 0048-9697.

Bivalve molluscs are filter feeders, with pearl oysters able to filter water at rates up to 25 l h super(-1) g super(-1) of dry wt. tissue. Since this process leads to rapid bioaccumulation of recalcitrant pollutants such as heavy metals, organochlorine pesticides and hydrocarbons from impacted sites, it has prompted the widespread use of molluscs as biomonitors to quantify levels of marine pollution. This paper proposes pearl oyster deployment as a novel bioremediation technology for impacted sites to remove toxic contaminants, reduce nutrient loads and lower concentrations of microbial pathogens. Estimates extrapolated from the literature suggest that a modest pearl oyster farm of 100 t oyster material per year could remove 300 kg heavy metals plus 24 kg of organic contaminants via deposition into the tissue and shell. Furthermore, it was estimated that up to 19 kg of nitrogen may be removed from the coastal ecosystem per tonne of pearl oyster harvested. Pearl oysters are also likely to filter substantial amounts of sewage associated microbial pathogens from the water column. Method of cultivation and site selection are the key to minimizing negative environmental impacts of bivalve cultivation. Deployment of oysters at sites with high nutrient and contaminant loadings would be advantageous, as these compounds would be removed from the ecosystem whilst generating a value- added product. Future potential may exist for harvesting bio-concentrated elements for commercial production.

Mazouni, N., J.C. Gaertner, J.M. Deslous-Paoli, S. Landrein, and M. Geringer d'Oedenberg. 1996. **Nutrient and oxygen exchanges at the water-sediment interface in a shellfish farming lagoon (Thau, France).** Journal of Experimental Marine Biology and Ecology. Vol. 205, no. 1-2, pp. 91-113. 1 Nov.

The Etang de Thau (France) is a shallow lagoon characterized by the semi-intensive farming of oysters (*Crassostrea gigas*, Thunberg) cultured in suspension on frames. Analysis of the benthic fluxes of inorganic nutrients and oxygen over a period of a year has provided a basis for describing the dynamics of the water-sediment interface in the lagoon. Monthly measurements of fluxes at the water-sediment interface at two stations have been compared. One station (UC) is located under a culture table, and is subject to intensive accumulation of organic matter (biodeposition); the other (OC) is located outside the area directly under the impact of the culture activities. Oxygen consumption ranged from 288.24 to 1026.85 mu mol times m super (-2) times h super(-1) according to the season and the station. Ammonium production was maximal at station UC in Summer (600 mu mol times m super(-2) times h super(-1)) and minimal at station OC in the Autumn (30 mu mol times m super(-2) times h super(-1)). In general, the fluxes recorded at station UC were 1.8-3 times higher than those recorded at station OC for oxygen and 1-5 times higher for ammonium. Nevertheless, the variability between stations was lower than the seasonal variability. Using a Multiple Correspondence Analysis (MCA), it was possible to point out the occurrence of an atypical event that was responsible for the disruption of the seasonal cycle. This event was a state of hypoxia known locally under the generic name of malaiegue. The dystrophic crisis consists of a major perturbation of the ecosystem, responsible for a massive mortality affecting both the benthos and the reared stocks.

Keywords: Oyster culture; Aquaculture effluents; Sediment-water exchanges; Biogeochemistry; Eutrophication; Nitrogen cycle; Zoobenthos; Pollution effects; Hypoxia; Crassostrea gigas; MED, France, Languedoc-Roussillon, Thau lagoon.

Mazouni, N., J.M. Deslous-Paoli, and S. Landrein. 1998. **Impact of oyster culture on nutrients and oxygen fluxes in a coastal lagoon.** Symposium-on-the-National-Coastal-Oceanography-Program-PNOC-Programme.

The impact of suspended oyster culture (*Crassostrea gigas*, Thunberg) on oxygen and nutrient fluxes has been studied in situ, in a coastal lagoon (Thau, France), during a seasonal cycle. On the first plan of the multiple factorial correspondences analysis (MCA), seasons were well discriminated. The fluxes were maximum in summer and minimum in winter. However, this seasonal pattern was not only linked to the water temperature, as autumn and spring (similar temperatures of about 12 degree C) were distinct in the second factorial plan (2.3). Oxygen uptake by the oyster cultures varied between 0 mu mol m super(2) h super(1) (January) and 11 823 plus or minus 377 mu mol m super(2) h super(1) (July). Ammonia and nitrate nitrites were released into the water column respectively at a rate of 2905 plus or minus 327 mu mol m super(2) h super(1) and 891 plus or minus 88 mu mol m super(2) h super(1) in the summer and 0 mu mol m super(2) h super(1) and 177 plus or minus 97 mu mol m super(2) h super(1) in the cold season. During the summer, the nitratenitrites flux was about 20 % of the total dissolved inorganic nitrogen production. Phosphate release was low except for two periods during which an important release was measured; in May (1686 plus or minus 44 mu mol m super(2) h super(1) and in November (2691 plus or minus 800 kmol m super(2) h super(1). No linear relation between water temperature and phosphate flux was found. In Than Lagoon, oyster cultures (oysters and epibiota) by producing 2 x 10 super(7) molN y super(1) play a central role in nitrogen renewal in the water column

Keywords: Oyster culture, Nutrient cycles, Oxygen, Coastal, lagoons, Nitrogen, Water, ammonia, oyster.

Mazouni, N., J.C. Gaertner, and J.M. Deslous–Paoli. 1998. **Influence of oyster culture on water column characteristics in a coastal lagoon (Thau, France).** Hydrobiologia. Vol. 373-374, no. 1-3, pp. 149-156.

The development of shellfish farming activities causes great changes in ecosystems functioning. In the Thau lagoon, oysters are reared on long constantly submerged lines, and these become fouled by several epifaunal species. The assemblage (oysters and epifauna) is defined as Oyster Culture Unit (OCU). The aim of our study was to estimate (i) how much the composition and the abundance of the epifaunal species can influence the nutrient and oxygen fluxes recorded at the shellfish-water interface and (ii) how these fluxes modify water column characteristics. We used Principal Component Analysis with Instrumental Variables (PCAIV). Two analyses were carried out, using sets of data on fluxes, the specific composition of the cultivated communities, and on oxygen, nutrient and chlorophyll a concentrations in the water column. The highest fluxes at the OCU-water interface were measured when epifaunal species richness was maximum. However, at our measurement scale (i.e. the oyster frame) no influence of this filter-feeders assemblage was observed on the chlorophyll a level. Conversely, we found a significant influence of oyster culture on the oxygen and dissolved nitrogen concentrations in the water column. The use of this recent factorial analysis was helpful to estimate the influence of the

biofouling species composition on the fluxes at the OCU-water interface, and to estimate the potential impact of oyster cultures on the conditions prevailing in the water column.

Keywords: Oyster culture; Nutrient cycles; Aquaculture effluents; Environmental impact; Dissolved oxygen; Fouling organisms; Coastal Waters; Lagoons; Oysters; Cultures; Species Composition; Principal Component Analysis; Biofouling; Estimating; Chlorophyll A; Oxygen; Nitrogen; Shellfish; Aquaculture; Fisheries; Nutrients; Chlorophyll; Fouling; Water quality; MED, France, Languedoc-Roussillon, MED, France, Thau lagoon.

Moran, A. L. and D. T. Manahan. 2004. **Physiological recovery from prolonged 'starvation' in larvae of the Pacific oyster *Crassostrea gigas*.** Journal of Experimental Marine Biology and Ecology. 306(1):17-36.

Previous studies of energy metabolism in larvae have described a developmental "point of no return" (PNR), a time by which larvae of planktotrophic marine species must feed in order to survive and grow. This study investigated the effects of long-term food deprivation on developing larvae of the oyster *Crassostrea gigas* with the goal of providing a biochemical and metabolic description of larvae at the PNR in this species. Mortality of unfed larvae was low for the first 14 days without the addition of phytoplankton foods. Even after 33 days without food, larvae were still swimming. Unfed larvae did not lose their ability to capture and digest algal cells when provided with food after 33 days. Growth, metabolic rate and biochemical constituents all increased at the same or greater rates in larvae whose feeding was delayed for 5, 8, 11, 14 or 17 days compared to larvae fed at 2 days old, when feeding was possible. These results show that larvae of C. gigas can survive long feeding delays while maintaining a constant rate of metabolism. These results suggest that oyster larvae have the capacity to survive 'starvation' using alternative sources of energy. If there is a "point of no return" beyond which larvae of C. gigas must feed on microalgae to survive, our findings suggest this point may be set by the availability of detrital material or dissolved organic carbon that can fuel maintenance metabolism for extended periods equivalent to over four times the predicted lifespan.

Mori, K. 1982. **Physiological effects of 17 beta-estradiol on the Japanese oyster *Crassostrea gigas*.** J. 305-317.

Unusual mass mortalities of oysters have occurred frequently in many parts of the world from the end of the 19th century to the present. Physiological analyses of mass mortalities of oysters, C. gigas, in hanging cultures in Matsushima Bay, Japan were carried out and consequently the results revealed that the artificial eutrophication in this bay induces excessive soft-body growth in the oysters and over-maturation of the gonad, possibly resulting in some physiological disorder and mass mortality. This paper deals with the various physiological effects of 17-Beta-estradiol on the Japanese oyster in relation to reproduction and energy metabolism. The ensembles of the results of this study are discussed with special reference to the oyster mass mortality caused by eutrophication.

Keywords: sexual reproduction, animal metabolism, pollution effects, eutrophication, hormones, oyster culture, metabolism, Crassostrea gigas, Japanmass mortality.

Mori, K. 1979. **Effects of artificial eutrophication on the metabolism of the Japanese oyster *Crassostrea gigas*.** Marine Biology. 53(4):361-369.

Matsushima Bay, one of the richest oyster-culture areas in Japan, is subject to heavy artificial eutrophication, mainly from the inflow of city and factory sewages. The physiological activity in C. gigas- in hanging cultures in this embayment declines markedly with progressive development of the gonads; this decline in activity coincides with eutrophication-induced accumulation of fatty material in the epithelia of the digestive organs; the oyster is thereby forced to depend on these accumulated fats for respiratory substrates in order to maintain its increased physiological needs. However, the fats are inefficient energy sources for the oyster and hence, during each spawning season, 50% mortality occurs. Such phenomena as overmaturation of the gonad and disturbance of the lipid and steroid metabolism seem to accelerate this mass mortality. On the basis of the results, the author has compiled a schematic diagram which illustrates the possible causes of mass mortality among C. gigas- in an eutrophic environment such as Matsushima Bay.

Keywords: eutrophication, oyster culture, Crassostrea gigas, Japan Matsushima Bay, sewage, effluents, bioaccumulation, spawning seasons, Bivalvia, oyster, mass mortality.

Mugg, J., M.A. Rice, and M. Perron. 2001. **Effects of filter-feeding oysters on sedimentation rates and phytoplankton species composition: preliminary results of mesocosm experiments.** Journal-of-Shellfish-Research. vol. 20(no. 1):525.

Eutrophication is occurring in many coastal estuaries. A possible solution to this problem is to raise aquaculture oysters to improve water clarity and to help remove excess nitrogen. In order to determine what effects aquaculture oysters have on the environment, a mesocosm study was performed at the Marine Ecosystem Research Laboratory (MERL) from June to October 2000. The MERL facility is located adjacent to Narragansett Bay with thirteen 13,000 L mesocosm tanks that simulate the environmental conditions of the Bay. Two hundred oysters (approximately 35 mm in valve length; nominally filtering about 48 L da super(-1) ind super(-1)) were placed into three mesocosms, and three mesocosms were maintained without oysters as controls. Experiments were run with varying rates of water exchange in the tanks ranging from 0% to 100% per day (0-13,000 L da super(-1)). Several parameters were measured and compared between the two treatments, which included chlorophyll-a, particulate organic and inorganic matter, sedimentation rates, nitrate, ammonia, phytoplankton analysis and growth rates. Preliminary results show that oysters have an effect on species composition of phytoplankton in the water column and induce increased rates of sedimentation to the benthos. Diatoms of the genus Nitzschia were predominant in mesocosms with oysters, and in the control tanks Skeletonema were dominant. Tanks with oysters consistently showed rates of sedimentation greater than twice the control tanks. We speculate that this increased organic sedimentation by actively filter feeding oysters may contribute to increased rates of sediment deposition leading to increased denitrification in natural systems. This is work from RI-AES Project H-886, and is publication number 3857 of the College of the Environment and Life Sciences, University of Rhode Island.

Keywords: Filter feeders, Phytoplankton, Oyster culture, Water quality control, Biological control, Habitat improvement, Marine molluscs, Sedimentation, Energy flow, Detritus, Denitrification, Eutrophication, Nitzschia, Crassostrea virginica, Skeletonema, Eastern oyster.

Nelson, K.A., L.A. Leonard, M.H. Posey, T.D. Alphin, and M.A. Mallin**.** 2004. **Using transplanted oyster (*Crassostrea virginica*) beds to improve water quality in small tidal creeks: a pilot study.** Journal of Experimental Marine Biology and Ecology. 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, R.I.E., J.C. Cornwell, M. Owens, and J. Tuttle. 1999. **Role of oysters in maintaining estuarine water quality.** J. National Shellfisheries Association. 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.

Keywords: Nitrogen, Denitrification, Biogeochemical cycle, Water quality control, Estuaries, Filter feeders, Phytoplankton, Sediment chemistry, Ecosystem management, Herbivores, Crassostrea virginica, ANW, USA, Chesapeake Bay, general aquaculture.

Newell, R.I.E. 2004. **Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: A review.** Journal of Shellfish Research. 23(1):51-61.

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 N sub(2) 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 H sub(2)S can be toxic to the benthos.

Keywords: Freshwater molluscs, Natural populations, Cultured organisms, Filter feeders, Biotic factors, Water filtration, Suspended particulate matter, Excretory products, Grazing, Phytoplankton, Biomass, Nutrient cycles, Nitrogen cycle, Phosphorus cycle, Water column, Turbidity, Anoxic sediments, Bioremediation, Environment management, Watersheds, Bivalvia.

Newell, R.I.E., T.R. Fisher, R.R., Holyoke, and J.C. Cornwell. 2004. **Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA.** P. In: Dame, R., Olenin, S. (Eds.), The Comparative Roles of Suspension Feeders in Ecosystems. NATO Science Series IV — Earth and Environmental Sciences. Kluwer Academic Publishers, Dordrecht, The Netherlands.

No abstract.

North, E.W., S. Chen, and R. R. Hood, et al. 2005. **Understanding the effects of oyster reefs and breakwaters on seagrass habitat: an open-source modeling approach.** Abstract presented at Estuarine Interactions; the 2005 Conference of the Estuarine Research Foundation, held Oct 16-21, Norfolk, Virginia.

Oyster filtration and an optimum level of wave attenuation associated with oyster reefs and breakwaters could improve seagrass habitat by reducing sediment resuspension and enhancing light penetration. We conducted a coupled field and modeling program to address this hypothesis. The modeling program incorporated results from field research and linked and enhanced several existing open-source models to create a Seagrass-Waves-Oyster-Seston-Light (SWOLS) model. We used the open source circulation model SHORECIRC to simulate tide- and wave-induced currents, the wave model REF/DIF (REFraction/DIFfraction) to simulate wave damping effects of reefs, and added a suspended sediment transport module. We included light, seagrass and oyster filtration modules to predict light-controlled growth of seagrass and the effects of seston- and temperature-dependent oyster filtration. We applied this model to quantify the impact of oyster reefs, breakwaters, and sediment grain size on wave attenuation and water clarity. Model predictions were compared with field results which indicated that high wave attenuation may inhibit seagrass growth by promoting fine organic particle deposition. Our model has value for guiding oyster and seagrass restoration efforts. By understanding and modeling how well man-made breakwaters/reefs fulfill the ecosystem service of wave attenuation/filtration, it will be possible to design future structures that enhance seagrass habitat.

Keywords: oyster reefs, seagrass habitat, general aquaculture, modeling.

O'Beirn, F. X., P. G. Ross, and M. W. Luckenbach. 2001. **A review of organisms associated with oysters cultured in floating systems.** Aquaculture 2001: book of abstracts, World Aquaculture Society. 484 pp.

No abstract.

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.

No abstract.

Paterson, K.J., M.J. Schreider, and K.D. Zimmerman. 2003. **Anthropogenic effects on seston quality and quantity and the growth and survival of Sydney rock oyster (*Saccostrea glomerata*) in two estuaries in NSW, Australia.** Aquaculture. 221(1-4):407-426.

The influence that catch ment development has on the growth and survival of the Sydney rock oyster, through its effect on the quality and quantity of seston was investigated in Brisbane Water and Lake Macquarie. Developed locations recorded elevated levels of dissolved nitrogen (NH3 and NOx) and chlorophyll a compared to undeveloped locations. Total particulate matter (TPM), particulate inorganic matter (PIM), particulate organic matter (POM), particulate carbon (PC) and particulate nitrogen (PN) were all significantly higher at developed locations in both estuaries. The PC/Chl a ratios were high, indicating that the seston was comprised of detrital matter as opposed to living phytoplankton, yet the C/N ratios were low compared to those expected of estuarine conditions. Sydney rock oysters cultured at the developed locations attained a greater mean shell length and live weight than those cultured at undeveloped locations

however higher mortality rates were observed at developed locations. In Brisbane Water, seston quantity measures (TPM, PIM, POM, PC, PN) were positively related to live weight growth rate (GR) while shell length GR was negatively related to salinity. In Lake Macquarie, POM had a positive relationship with oyster live weight GR while shell length GR also had an inverse relationship with salinity. Thus, elevated seston loads associated with low salinities contributed to increased oyster growth at the developed locations where run-off is high. The concentration of the seston was therefore the controlling factor in the growth of oysters cultured in Brisbane Water and Lake Macquarie. The seston quality ratios indicated that the detrital, particulate component of the seston was high-quality food for bivalves, possibly due to associated microbial biomass. In New South Wales (NSW), a high proportion of oyster leases are located in estuaries sourced by developed catchments and the results of this study will be of interest to resource managers and oyster farmers.

Phinney, D.E., and E. Hurlburt. 1990. **Supplemental Environmental Impact Statement: Use of the Insecticide Carbaryl to Control Ghost and Mud Shrimp in Oyster Beds of Willipa Bay and Grays Harbor Final.**

A Final Supplemental Environmental Impact Statement for use of the insecticide carbaryl to control burrowing shrimp on oyster beds by the Willapa Bay and Grays Harbor oyster growers.

Keywords: Mud shrimp, Sand, Shrimp, Shrimp, CarbarylSevin, oyster, insecticide, willapagrays harbor.

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(1-4):407-422.

To determine effects of aquacultured oysters *Crassostrea virginica* (Gmelin, 1791) on the overlying water column, a mesocosm study was performed at the Marine Ecosystem Research Laboratory (MERL) from June to October, 2000. The MERL facility is located adjacent to Narragansett Bay and consists of fourteen 13,000-l mesocosm tanks designed to simulate the Bay environmental conditions. Two hundred oysters ([ap]35 mm valve height; nominally filtering about 55 l/day/individual) were placed into three mesocosms, and three mesocosms were maintained without oysters as controls. Experiments were run with varying rates of water exchange in the tanks ranging from 0% to 100% per day (13,000 l/day). Parameters that were measured and compared between the two treatments included chlorophyll-a, particulate organic and inorganic matter, sedimentation, nitrate, ammonia, selected phytoplankton species and oyster growth rates. Oysters affected phytoplankton species composition and increased rates of sedimentation. Large diatoms were net sampled, and Nitzchia striata was predominant in mesocosms with oysters, while Skeletonema costatum dominated the control tanks. Ammonia excretion rates were determined for *C. virginica* using the salicylate-hypochlorite method. Ammonia excretion can be described by the allometric equation E=50.65w0.699 when E is the ammonia excretion rate in [mu]g/h, and w is the soft tissue dry weight in grams. Based on rates of ammonia excretion by oysters and observed steady states of ammonia and other forms of inorganic nitrogen in mesocosm tanks, it can be hypothesized that ammonia generated by oysters is taken up by rapidly regenerating phytoplankton in the water column.

Keywords: Crassostrea virginica, oysters, environmental impacts, mesocosm, sedimentation rates, nitrogen cycling.

Rice, M.A. In: Tlusty, M.F., D.A. Bengston, H.O. Halvorson, S.D. Oktay, J.B. Pearce, and R.B. Rheault, JR. (Eds) 2001. **Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication**. pp. 76-86 In: Marine Aquaculture and the Marine Environment. January 2001, Cape Cod Press, Falmouth, Massachusetts.

No abstract.

Ruesink, J.L., G.C. Roegner, B.R. Dumbauld, J.A. Newton and D. Armstrong. 2003. **Contributions of oceanic and watershed energy sources to secondary production in a northeastern Pacific estuary.** Estuaries 26:1079-1093.

Along the estuarine gradient of Willapa Bay, oysters generally grow slower into the estuary, where carbon stable isotope ratios indicate that they receive proportionally lower amounts of marine-derived resources. [NOAA – PNCERS]. Since the publication of this paper, additional work has been done suggesting that a large fraction of oyster diet may actually come from macrophyte detritus, for instance eelgrass decomposed by bacteria.

Ruesink, J.L., M.N. Dethier, H. Berry, A.G. Sprenger, A.C. Trimble, in preparation. **Large productivity fluctuations on beaches along a subtle estuarine gradient.**

Along the estuarine gradient of central to south Puget Sound, oysters generally grow faster into the estuary, but carbon stable isotope ratios indicate no variation in marine- vs. terrestrially-derived resources among regions. $\delta^{15}N$ suggests contributions from human-derived nutrients are relatively high in Budd Inlet, but not around Tacoma or Seattle. Along the estuarine gradient of Totten Inlet, oysters also grow faster into the estuary, where carbon stable isotope ratios indicate that they receive proportionally higher amounts of terrestrially-derived resources.

Sajus, M.C., C. Audemard, B. Sautour, F. Berthes, and P. G. Sauriau. 2001. **Zooplankton populations diversity of an oysters claire in Marennes-Oleron Bay (France).** Littoral zones and anthropization: management and nuisance, La Rochelle, 4-5-6 July 2000, Zones littorals et anthropisation: Gestion et nuisances, La Rochelle, 4-5-6 juillet 2000 Miramand, P. (ed.); Guyot, T. (ed.); Alligner, N.(ed.). vol. 26(no. 3):p. 162. (English Translation Ongoing).

Original Abstract: Les claires ostreicoles sont des bassins semi-fermes traditionnellement utilises a des fins aquacoles pour le stockage et l'affinage des huitres. Les variations importantes des parametres environnementaux, temperature et salinite mais aussi le volume reduit des bassins ainsi que le renouvellement d'eau de mer limite aux periodes de grandes marees, limitent le nombre d'especes pouvant survivre et se reproduire dans un tel ecosysteme. Ce fait, deja demontre pour la macrofaune benthique a ete verifie pour les peuplements zooplanctoniques d'une claire ostreicole au cours d'une etude realisee en 1998 sur l'ile d'Oleron. Des prelevements bimensuels realises de mars a novembre indiquent que les copepodes constituent la majeure partie des populations zooplanctoniques de la claire. Des especes pelagiques presentes egalement dans le bassin de Marennes-Oleron comme Acartia bifilosa, Acartia clausi, Acartia discaudata, Temora longicornis et Euterpina acutifrons sont observees mais leurs abondances restent faibles par rapport au copepode Calanoide Acartia grani qui peut representer jusqu'a 100% des abondances estivales. Cette espece est donc particulierement adaptee a ce type d'ecosysteme confine. D'autres especes de copepodes Harpacticoides comme Canuella perplexa ont aussi ete

echantillonnees. La dynamique temporelle de l'abondance des especes planctoniques apparait fortement influencee par la gestion de l'eau des claires. L'exemple des 4 especes du genre Acartia illustre alors les processus se realisant lors des phase de renouvellement d'eau et les phases de confinement avec respectivement 1) une colonisation par les especes caracteristiques de masses d'eau neritiques (Acartia clausi), des masses d'eau de la baie (Acartia discaudata) ou des eaux plus estuariennes (Acartia bifilosa) 2) un effondrement des effectifs de ces populations en parallele au developpement des especes de masses d'eaux confinees (Acartia grani). Une modulation de ce schema temporel estival se produit au printemps et en automne.

Keywords: Littoral zone, Zooplankton, Aquaculture, Oyster culture, ANE, France, Poitou-Charentes, Marennes, Oleron Bay.

Scott, G.I., M.H. Fulton, and E. D. Strozier, et al. 1996. T**he effects of urbanization on the American oyster, *Crassostrea virginica* (Gmelin).** Journal of Shellfish Research. 15(2):523-524.

Rapid development of coastal areas of the southeastern US has resulted in significant alterations of upland terrestrial habitats adjacent to sensitive estuarine salt marsh ecosystems in the southeastern US. Most remaining coastal development in the southeastern US will be residential and tourism/service related industries rather than industrial development and will occur around the >300 small high salinity tidal creeks and estuaries found in the region. These alterations may result in potential impacts to living resources within estuaries, including molluscan shellfish such as the American oyster, *Crassostrea virginica*. The Urbanization in Southeastern Estuarine Systems (USES) study has addressed impacts of coastal development on adjacent small, high salinity estuaries of the southeastern US by comparing Murrells Inlet (MI), a highly urbanized estuary with pristine North Inlet (NI). A total of 60 monitoring stations were sampled in both estuaries. Surface waters, sediments and oysters (*Crassostrea virginica*) were monitored for fecal coliform bacteria densities; serotyped to individual bacterial species; analyzed for trace metals, polycyclic aromatic hydrocarbons (PAHs), pesticides and polychlorinated biphenyls (PCBs) to characterize chemical contaminant inputs; and adult oysters were monitored for survival, condition index, gonadal index and juvenile spat settlement. Geographical Information Processing (GIP) was conducted on multiple data layers to indicate geographic regions where multiple contaminant interactions had occurred. One of the more significant effects from urbanization study was the increased closure of shellfish harvesting waters due to increased inputs of fecal coliform bacteria. More than 67% of the sampling sites in MI exceeded the SA water classification fecal coliform standard versus 35% in NI. Fecal coliform monitoring of shellfish meats indicated that >50% of stations in each estuary exceeded the Interstate Shellfish Sanitation Conference Depuration Meat Standard. Mortality rates among adult and juvenile oysters was much higher in MI than NI, and the pattern of spat settlement was different. GIP analysis indicated areas where multiple contaminant interaction occurred and where coastal ecosystem health was adversely affected.

Keywords: oyster, fisheries, environmental impact, urbanization, sewage, disposal, microbial contamination, larval settlement, survival recruitment, pathogenic bacteria, Crassostrea virginica, USA.

Songsangjinda, P., O. Matsuda, T. Yamamoto, N. Rajendran, and Hajime Maeda. 2000. **The role of suspended oyster culture on nitrogen cycle in Hiroshima Bay**. Journal of Oceanography. 56(2):223-231.

The predominance of bivalves affects the cycle of materials in the coastal ecosystem. In the present study, the role of suspended oyster culture on the nitrogen cycle was demonstrated for the northern Hiroshima Bay. The nitrogen cycle was considered as two systems, (1) the primary production (PP) system and (2) the oyster culture (OC) system. The results show that about 26% of N productivity was supplied to process by cultured oysters in the OC system. This process varies seasonally due to the seasonal variations of PON, physiological activities and biomass of oysters. The N processing rates were found to be high in summer and low in winter. The biodeposition and excretion of N in the OC system are 3.0 and 2.1 ton N/d while the natural sedimentation rate and N regeneration in the PP system are 8.3 and 18.0 ton N/d which indicates that the PP system is a major system regenerating N in the water column. The release of total dissolved N from the bottom to the water column is about 8.3 ton N/d. The amount of N harvested as oyster product was about 1.3 ton N/d which is about 10% of daily N loading in north Hiroshima Bay. According to the N cycle developed in the present study, the results suggest the significant role of suspended oyster culture on the nitrogen cycle in Hiroshima Bay. In addition, our results indicate that oyster production was efficiently harvested, suggesting that oyster culture could probably be used as a tool to remove N from Hiroshima Bay.

Keywords: Oyster, culture, Off-bottom, culture, Culture effects, Nitrogen cycle, Particulate, organic, nitrogen, Primary production, Marine molluscs, Biomass, Excretory products, Biogenic deposits, Faecal pellets, Biogeochemica cycle, Mollusc culture, Excretion,Harvesting, Phytoplankton, Crassostrea gigas, INW, Japan, Honshu, Hiroshima Prefect, Hiroshima, Bay, Seasonal, variations suspended.

Toro, J.E., M.A. Sanhueza, J.E. Winter, C.M. Senn, P. Aguila, and A. M. Vergara. 1995. **Environmental effects on the growth of the Chilean oyster *Ostrea chilensis* in five mariculture locations in the Chiloe Island, southern Chile.** Aquaculture. 136(12):153-164.

A cohort of juvenile oysters (*Ostrea chilensis*), produced in the laboratory using mass spawning, were grown in pearl nets, at three different depths and stocking densities, at five mariculture farms in southern Chile. Live weight, shell height and mortality were monitored monthly over 24 months. Chlorophyll a, seston, seawater temperature, salinity, and dissolved oxygen were recorded monthly during the study period. Oysters grew at different rates among locations (P0.05). The overall survival was 71.8% with lower values in the estuarine location, caused probably by the low salinity and high concentrations of particulate inorganic matter in sexually mature oysters.

Keywords: growth, oyster, culture, Ostrea chilensis, Chile laboratory, culture, mortality, ECOP.

Wheat, E. **Filtration capacity of oysters**. This project involves direct measurement of water properties as water moves across the tideflat. Water is tracked with small "drifter" with GPS and datasondes attached to record positions and chlorophyll concentrations. These drifts have occurred over different habitat types and at different water depths. Reduction of chlorophyll has been observed for relatively long (>15 minute) drifts in shallow (1<1 m) water over adult oysters at aquaculture densities.

Wheat, E. (in preparation). Along the **estuarine gradient of Hood Canal**, oysters generally grow faster into the estuary and show stable isotope signals of proportionally more terrestrially-derived resources and anthropogenic nitrogen. [Funding: Washington DNR]

Zimmerman, R., T. Minello, T. Baumer, and M. Castiglione, 1989. **Oyster reef as habitat for estuarine macrofauna. NOAA Technical Memorandum NMFS-SEFC-249.** NOAA/NMFS Southeast Fisheries Science Center, Galveston Texas.

Ecosystem modeling and mesocosm studies have indicated that restoring shellfish populations to even a modest fraction of their historic abundance could improve water quality and aid in the recovery of seagrasses (Newell and Koch 2004; Ulanowicz and Tuttle 1992).

1.5 Scallops

Goldberg, R. NMFS Northeast Fish. Cent. Milford Lab. Milford CT 06460 USA. 1978. **Some effects of gas-supersaturated seawater in *Spisula solidissima* and *Argopecten irradians*.** Aquaculture. 14(4):pp. 281-287.

Two size classes of the surf clam, *S. solidissima*, and the bay scallop, *A.irradians*, were exposed to different concentrations of gas-supersaturated seawater in a flowing seawater system. Both species tested experienced no mortality when held in the control treatment maintained at 96% oxygen and 109% nitrogen. Mortality, gill tissue damage, gas emboli, membranous tissue blisters, and abnormal secretion of shell material were induced experimentally at elevated levels of gas supersaturation. Results indicate significant mortalities of surf clams and scallops held at 114% O-SUB-2- and 195% N-SUB-2-, and at higher levels of gas concentration. These values suggest a point of reference for the bivalve culturist in identifying potential problems which can be caused by gas-supersaturated seawater.

Keywords: shellfish, culture, dissolved, gases, disease control, pathology, Spisula, solidissima, Argopecten irradians, mortality causes.

Nunes, J.P., J.G. Ferreira, and F. Gazeau, et al. 2003. **A model for sustainable management of shellfish polyculture in coastal bays.** Aquaculture. 219(1):257–277.

A multi-species model for shellfish polyculture in coastal embayments is presented, and an application of the model to a test site (Sanggou Bay, Northern China) used for large-scale long line cultivation of the Chinese scallop *Chlamys farreri*, the Pacific oyster *Crassostrea gigas* and the kelp *Laminaria japonica* is described. The model integrates a bay-scale ecological simulation with individual-based modelling of scallops and oysters, and upscales the individual processes for the target species (scallops and oysters) by means of a multi-cohort population dynamics model. Human interaction with the target cohorts over a number of years is explicitly simulated. The model has been used to estimate the exploitation carrying capacity for scallops and oysters in the system, the harvest potential for different seeding and harvesting scenarios, and the impacts on the ecosystem of different polyculture management strategies. Although an increase in seeding to 2$ and 15$ standard seeding for scallops and oysters respectively optimizes the yield of both, thus corresponding to the exploitation carrying capacity, the ratio of harvest/seed is lowered, which may make the fishery less attractive from an economic point of

view. Progressive increases in seeding lead to a collapse of the fishery: this occurs at >15$ standard seeding for scallops, and at >30$ for oysters. In parallel, there are profound modifications at the ecosystem level, which were studied by means of a mass balance carried out on the model. Under standard conditions, there is a net export of primary production from the bay to the Yellow Sea, butat 15–20$ increase in seeding, the bay becomes a net phytoplankton importer, due to phytoplankton clearance by cultivated shellfish. The model simulates a period of 6 years in about 2 min, and was shown to be a useful tool for polyculture management over multi annual periods; a development of the socioeconomic component will allow feedbacks between economic consequences of different cultivation scenarios and ecosystem responses to be explicitly considered. The application of this type of model may be of use in promoting a more holistic approach to shellfish aquaculture management. D 2003 Elsevier Science B.V. All rights reserved.

Keywords: Polyculture, Scallop, Oyster, Model, Aquaculture management, China general, aquaculture.

Reitan, K.I., G. Oeie, Y. Olsen, and H. Reinerstsen. 1999. **Effect of increased primary production in a fjord on growth of bluemussels and scallops.** Journal of Shellfish Research. 18(2):726.

The growth of scallops (Pecten maximus) and blue mussels (*Mytilus edulis* is dependent on both the availability and the quality of the food, and physical factors as temperature and water current in the fjord. The primary production in a fjord normally fluctuates during the season. A controlled addition of nitrogen, phosphorous and silicon (N:Si:P = 16:8:1, where P = 0.4 mg m super(-3) day super(-1)) to a closed small fjord (Hopavaaegen in Norway) increased the primary production with 50% compared to control locations. However, this addition of nutrients gave no increase in biomass of phytoplankton in the fjord. The increased primary production in Hopavaegen resulted in higher growth of scallops compared to the control. This increased growth of scallops was probably due to a higher growth rate of phytoplankton in the fjord when extra nutrients were added. The growth pattern of blue mussels differed from that of scallops. No significant difference in shell height was obtained for blue mussels with and without extra addition of nutrients to the water.

Keywords: Fjords, Phytoplankton, Primary production, Secondary production, Scallop fisheries, Mussel fisheries, Pecten maximus, Mytilus-edulis, ANE, Norway, Hopavaegen, Edible blue mussel.

Wilbur, K.M. 1986. **Effects of phosphates on shellfish and on calcium carbonate crystallization in vitro. Final report.** NTIS Order No.: DE86014992/GAR.

It has been known that inorganic phosphate inhibits the precipitation of calcium carbonate in artificial sea water. This work addresses the question of whether phosphate also affects the deposition of CaCO sub 3 in the exoskeletons of invertebrates. Tetrasodiumpyrophosphate and pentasodiumtripolyphosphate in concentrations of 15 ppM caused abnormality, mortality, and inhibition of shell deposition in trochophore larvae of the oyster *Crassostrea*. Inhibition of shell growth resulting from pollution at 15 ppM could be expected in Rangian with orthophosphate, terasodium pyrophosphate, and sodiumtripolyphosphate.

1.6 Other Shellfish Aquaculture Impact References

Andrew, M.L., and L. Frank. 2004. **Integrated aquaculture system for nutrient reduction in agricultural wastewater: potential and challenges.** Bulletin of Fisheries Research Agency (Japan). no. Sup. 1, pp. 143-152. IS: ISSN 1346-9894.

The integration of aquaculture with agriculture, such and fish production with poultry, has been practiced for hundreds of years and takes advantage of the nutrient output of one crop to increase pond primary productivity, subsequently, enhancing herbivorous fish production. Applying this integration concept for the purpose of reducing the environmental impact of agriculture via the nutrient extraction ability of various shellfish, plant and fish species, is however, a relatively new concept and is increasingly justified by nutrient discharge regulations and associated increasing effluent treatment costs. Agricultural operations, such as animal feedlots, are specific nutrient point sources in which integration with extraction aquaculture could reduce environmental impact. In addition to playing a key role in nutrient reduction, extraction aquaculture species can be an important source of income, critical to offsetting increasing nutrient treatment costs and increasing farm profitability. This paper will review current strategies to apply this concept in the field, present an overview of specific efforts in Florida and summarize the challenges of implementation of integrating production of various aquaculture species to reduce nutrients in agricultural wastewater.

Asami, H., M. Aida and K. Watanabe. 2005. **Accelerated sulfur cycle in coastal marine sediment beneath areas of intensive shellfish aquaculture.** Applied and Environmental Microbiology. 71(6):2925-2933.

Prokaryotes in marine sediments taken from two neighboring semi enclosed bays (the Yamada and Kamaishi bays) at the Sanriku Coast in Japan were investigated by the culture-independent molecular phylogenetic approach coupled with chemical and activity analyses. These two bays were chosen in terms of their similar hydrogeological and chemical characteristics but different usage modes; the Yamada bay has been used for intensive shellfish aquaculture, while the Kamaishi bay has a commercial port and is not used for aquaculture. Substantial differences were found in the phylogenetic composition of 16S rRNA gene clone libraries constructed for the Yamada and Kamaishi sediments. In the Yamada library, phylotypes affiliated with delta -Proteobacteria were the most abundant, and those affiliated with gamma -Proteobacteria were the second-most abundant. In contrast, the Kamaishi library was occupied by phylotypes affiliated with Planctomycetes, gamma -Proteobacteria, delta -Proteobacteria, and Crenarchaeota: In the gamma -Proteobacteria, many Yamada phylotypes were related to free-living and symbiotic sulfur oxidizers, whereas the Kamaishi phylotype was related to the genus Pseudomonas: These results allowed us to hypothesize that sulfate-reducing and sulfur-oxidizing bacteria have become abundant in the Yamada sediment. This hypothesis was supported by quantitative competitive PCR (qcPCR) with group-specific primers. The qcPCR also suggested that organisms closely related to Desulfotalea in the Desulfobulbaceae were the major sulfate-reducing bacteria in these sediments. In addition, potential sulfate reduction and sulfur oxidation rates in the sediment samples were determined, indicating that the sulfur cycle has become active in the Yamada sediment beneath the areas of intensive shellfish aquaculture.

Keywords: Sediments, Aquaculture, Sulfur, Phylogeny, Primers, Coastsr, RNA, 16S, Sulfate reducing bacteria, sulfur oxidation, Sulfate reduction, Polymerase chain reaction, Shellfish, Bays, Marine, Sediments, Sulfur, Bacteria, Sulfur, Cycle, Pseudomonas, Sulfates, Oxidation, Marine aquaculture, Intensive culture, Shellfish culture, Culture effects, Aquaculture effluents, Nutrient cycles, Sulphur, Sulphate reduction, Phylogenetics, Microorganisms, Nucleotide sequence, Microbiological analysis, Sediment chemistry, Coastal zone, DNA, Clones, Crenarchaeota, Planctomycetes, Japan INW, Japan, Honshu, Iwate Prefect, Kamaishi Bay INW, Japan, Honshu, Iwate Prefect, Yamata BayINW, Japan, Honshu, Sanriku CoastMarine.

Berry, A.W. 1996. **Aquaculture and sea loch nutrient ratios: a hypothesis.** Aquaculture and Sea Lochs. pp. 7-15.

Sea lochs and coastal waters are utilized by aquaculture as open state bioreactors, transporting and biotransforming production wastes away from source. Assessments of the possible ecological effects of inputs from marine aquaculture generally assume that dissolved wastes discharged into the water column are primarily taken up by phytoplankton rather than pelagic bacteria which dominate the biomass of coastal waters. None of the assessments or related studies demonstrate this to be the case. The danger that nutrient enrichment and regional eutrophication could lead to an increase in the frequency of toxic algal blooms is however recognized by every assessment. Significantly, although unknown in Scottish sea lochs until 1998, Paralytic Shellfish Poisoning (PSP) toxins are now regular seasonal contaminants of wild and cultivated shellfish. This hypothesis suggests that discharges from cage fish farming enhance bacterial biomass production and perturb ambient nutrient ratios, promoting seasonal physiological nutrient stress in, and the production of biotoxins by, organisms in the receiving waters. Systematic nutrient limitation may also develop on a wider scale.

Keywords: Aquaculture effluents; Eutrophication; Environmental impact; Nutrients (mineral); Pollution effects; Fish diseases; Fish culture; Water quality control; ANE, British Isles, Scotland, West.

Burford, M.A., S.D. Costanzo, W.C. Dennison, C.J. Jackson, A.B. Jones, A.D. McKinnon, N.P. Preston, and L.A. Trott. 2003. **A synthesis of dominant ecological processes in intensive shrimp ponds and adjacent coastal environments in NE Australia.** Marine Pollution Bulletin. Vol. 46, no. 11, pp. 1456-1469. Nov. IS: ISSN 0025-326X.

One of the key environmental concerns about shrimp farming is the discharge of waters with high levels of nutrients and suspended solids into adjacent waterways. In this paper we synthesize the results of our multidisciplinary research linking ecological processes in intensive shrimp ponds with their downstream impacts in tidal, mangrove-lined creeks. The incorporation of process measurements and bioindicators, in addition to water quality measurements, improved our understanding of the effect of shrimp farm discharges on the ecological health of the receiving water bodies. Changes in water quality parameters were an oversimplification of the ecological effects of water discharges, and use of key measures including primary production rates, phytoplankton responses to nutrients, community shifts in zooplankton and delta super(15)N ratios in marine plants have the potential to provide more integrated and robust measures. Ultimately, reduction in nutrient discharges is most likely to ensure the future sustainability of the industry.

Carver, C.E. A. Chisholm, and A.L. Mallet. 2003. **Strategies to mitigate the impact of *Ciona intestinalis (L.)* biofouling on shellfish production.** Journal of Shellfish Research. Vol. 22, no. 3, pp. 621-631. Dec. IS: ISSN 0730-8000.

A sudden increase in the population of the solitary ascidian *Ciona intestinalis (L.)* is causing serious biofouling problems for shellfish growers on the Atlantic coast of Nova Scotia, Canada. The objective of the present study was to document the growth, spawning, and recruitment patterns of this species, and to develop strategies to minimize its impact on the culture of European oysters at two locations in Lunenburg Bay, Nova Scotia. Profiles of condition index, which may be indicative of spawning activity, suggested that the *C. intestinalis* population at the Bayport site spawned from mid-May through June, whereas the population at Mason's Beach spawned from mid-July to mid-August. Histological assessment of reproductive status indicated a period of gametogenesis in March-April (>3 degree C) followed by spawning from mid-May to mid-August (>8 degree C). Although mature eggs were observed in the ovary in July-August, spawning trials suggested a decline in the fecundity of the Bayport population during this period. Two main recruitment events were observed at Mason's Beach (June and August), but only one at Bayport (June). From the data on fecundity and settlement rates, it was estimated that a 100-mm long *C. intestinalis* (0.6 g dry w eight) may produce 12,000 eggs in a season and that recruitment intensity may reach 3,000 individuals m super(-2). Laboratory predation trials indicated that rock crabs (*Cancer irroratus*) consumed significantly more *C. intestinalis* than did green crabs (*Carcinus maenas*). A maximum predation rate of 11 individuals per day per rock crab (80 mm carapace width) was recorded at peak water temperatures of 18 degree C. In a series of chemical width eradication trials, exposure to 5% acetic acid was found to be a more effective strategy for eliminating *C. intestinalis* than hydrated lime, saturated brine, or hypochlorite solution. Total mortality was observed following exposure to 5% acetic acid for 15 to 30 s, with no corresponding mortality in the control mussels or oysters. Initial field trials indicated that spraying with acetic acid might prove to be an effective means of eliminating *C. intestinalis* under commercial conditions.

Chopin, T.; C. Yarish, C. Neefus, G. Kraemer, J. Zertuche-Gonzalez, E. Belyea, and R. Carmona. 2001. **Aquaculture from a different angle: the seaweed perspective, and the rationale for promoting integrated aquaculture.** Marine Aquaculture and the Environment: A Meeting for Stakeholders in the northeast. pp. 69-72.

Aquaculture, especially in the Western World, is very often conducted in a monotypic manner without employing a balanced approach for long-term sustainability, which would take into consideration the assimilative capacity of the ecosystem. To develop innovative, effective and responsible practices - maintaining the health of coastal waters, and, consequently, of the cultured organisms - fed aquaculture types (e.g. finfish, shrimp) and organic or inorganic extractive aquaculture types (e.g. shellfish or seaweed) need to be integrated to avoid pronounced shifts in coastal processes. Most impact studies on aquaculture operations typically have focused on organic matter/sludge deposition. However, the inorganic output of aquaculture is presently emerging as a pressing issue as nutrification of coastal waters is a worldwide phenomenon, which has not spared the Bay of Fundy (Chopin et al. in press). Conversion, not dilution, is the solution so that the "wastes" of one resource user become a resource (fertilizers) for the others.

Keywords: Polyculture; Marine aquaculture; Environment management; Pollution control.

Crawford, C.M., C.K. Macleod, and I.M. Mitchell. 2003. **Effects of shellfish farming on the benthic environment.** Aquaculture. Vol. 224, no. 1-4, pp. 117-140. 30 Jun. IS: ISSN 0044-8486.

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 coverage of fine filamentous algae and patchy bacterial mats directly under some longlines and this algae is thought to have fallen off the mussel longlines. At another farm dense beds of seagrass were observed in the videos 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.

De Casabianca, M. L., T. Laugier, and D. Collart. 1997. **Impact of shellfish farming eutrophication on benthic macrophyte communities in the Thau lagoon, France.** Aquaculture International. 5(4):301-314.

In a large marine lagoon (Thau lagoon, southern France) with a shellfish farming dominant eutrophication, the macrophyte communities were sampled by six transects of three depths (1.5, 2.5 and 5 m) and their characteristics (species composition, diversity and biomass) were described in relation to environmental and sediment parameters. With increasing eutrophication (total inorganic nitrogen, 0.140-0.295 mg/l; dissolved reactive phosphorus, 0.045-0.110 mg/l; and N/P atomic ratio, 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% dry wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in SW sites and could be distinguished by their sedimentary features. In sites (NE) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfish tables, and a *Gracilaria bursa-pastoris* community in the shellfish tables (lower incident light).

Keywords: France, Thau lagoon, lagoons, marine, environment, shellfish farming, eutrophication, macrophytes, benthic, floraalgae, degradation, biological, sampling, effluents, shellfish, culture, environmental, impact, marine, pollution, coastal lagoons, Zostera, Gracilaria, France, MED, France.

De Casabianca, L., T. Laugier, E. Marinho-Soriano, and D. Collart. 1998. **Environmental impact of shellfish farming in a Mediterranean lagoon (Thau, south France).** World Aquaculture Society. Aquaculture '98 Book of Abstracts99.

The French Mediterranean lagoon of Thau is characterized by an important shellfish farming dominated eutrophication (ca 15 times the terrestrial inputs). On the basis of increasing eutrophication, six areas were identified and monitored for one year (sediments features, overlying and sediment pore water nutrients, macrophytic biomass, species composition and diversity of macrophytes). With increasing eutrophication (total inorganic dissolved nitrogen: 0.140-0.295 mg l-1; dissolved reactive phosphorus: 0.045-0.110 mg l-1 and N/P atomic ratio: 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% d.wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in S-W sites and could be distinguished by their sediments features. In sites (N-E) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfishes tables, and a *Gracilaria bursa-pastoris* community among the shellfish tables (lower incident light).

Keywords: Brackishwater, aquaculture, Shellfish culture, Culture effects, Aquaculture effluents, Eutrophication, Ecosystem disturbance, Sediment pollution, Pollution effects, Community composition, Sea grass, Seaweeds, Zostera marina, Ulva rigida, Gracilaria bursa-pastoris, MED, France, Languedoc-Roussillon, Thau Lagoon.

Dowd, M. 2003. **Seston dynamics in a tidal inlet with shellfish aquaculture: a model study using tracer equations.** Estuarine, Coastal and Shelf Science. 57(3):523-537.

A process-oriented modelling study is used to examine biophysical control of the distribution of particulate organic matter, or seston, in a tidal embayment with shellfish aquaculture. The focus is on the spatio-temporal dynamics of seston as influenced by the processes of water motion and mixing, internal primary production of seston, and the clearance of the water volume by the grazing activity of a large bivalve population. A fluid dynamical framework is used wherein seston is treated as a non-conservative tracer in an advection–diffusion equation with additional source and sink terms. An idealized one-dimensional (1D) tidal inlet is first used to examine the sensitivity of tidally averaged seston concentration and flux to variations in tidal transport, internal production, and shellfish grazing. This model is then applied to Tracadie Bay, a tidal inlet off Canada's east coast, to illustrate temporal variability in seston level and flux for a more complex tidal regime. The results of this study suggest that seston flux is mainly under physical control, with its spatial distribution set by tidal transport processes. Seston level, on the other hand, is affected by both grazing and production, with the magnitude of these effects being spatially dependent as dictated by the tidal currents. Grazing and production effects on seston are most pronounced near the head of the inlet, which depends on internal, or local, processes. More seaward areas are buffered against these changes due the advection of seston from the adjacent open ocean. Variation in the spatial distribution of grazing activity demonstrates how local processes have inlet-wide effects. The temporal response of the inlet to tidal changes in the incoming far-field seston flux resembles a low-pass filter with a phase lag; temporal changes in seston at the head of the inlet are highly dampened and occur later than the forcing flux at the mouth. The implications of these results for marine bivalve aquaculture in terms of growth potential (seston level) and carrying capacity (seston flux) are discussed.

Keywords: aquaculture, sestontidal currents, shellfish, inlets, coastal lagoons, productivity, particle transport, carrying capacity.

Gilbert, F., P. Souchu, M. Bianchi, and P. Bonin. 1997. **Influence of shellfish farming activities on nitrification, nitrate reduction to ammonium and denitrification at the water-sediment interface of the Thau lagoon, France.** Marine Ecology Progress Series. 151143-153.

The seasonal patterns of nitrification and dissimilatory ammonium production (DAP) rates were studied in the sediment of 2 stations in the Thau lagoon (south of France). The station ZA was located within the shellfish farming zone and station B was the reference site. A marked effect of shellfish farming on bacterial activities was observed. Spatial differences were associated with discrepancies in the organic content and the reduction state of sediments, i.e. highest reductive processes (denitrification and DAP) were noted in shellfish farming area, where as the oxidative process (nitrification) was predominate outside the farming zone. At both stations, the DAP activity increased in September (autumn) concomitant with an increase of the C/N ratio in the sediment due to the sedimentation of the summer phytoplanktonic production. Nitrification and denitrification rates exhibited maximum in November (winter) corresponding to dissolved inorganic nitrogen inputs from the surrounding land. In the shellfish farming site, 98% of nitrate was reduced to NH4 and 2% to N2O, showing that the most of the NO3 was reduced to ammonium and remained for the ecosystem.

Keywords: shellfish farming, nitrogen, nitrification, denitrification, Thau lagoon, oysters, shellfish, ECOP.

MacDonald, B.A., G.S. Bacon, and J.E. Ward. 1998. **Physiological responses of infaunal (*Mya arenaria*) and epifaunal *Placopecten magellanicus*) bivalves to variations in the concentration and quality of suspended particles. 2. Absorption efficiency and scope for growth.** Journal of Experimental Marine Biology and Ecology. 219(1-2):127-141.

Placopecten magellanicus, an epibenthic scallop, and *Mya arenaria*, an infaunal clam were studied to compare their physiological responses to variations in the quantity and quality of suspended food. The two bivalve species were exposed, simultaneously, to four concentrations of seston (1, 3, 7 and 14 mg l super(1)) at each of three levels of organic quality (25, 50 and 80%) for several days. Experimental diets consisted of mixtures of microalgae and silica at concentrations typical of those observed in their natural habitats. Absorption efficiency (AE) was not significantly different between scallops and clams. In both species, AE was independent of concentration, and increased as the organic fraction of the seston increased. Oxygen consumption and ammonia excretion were also similar for both scallops and clams, and there was no consistent effect of concentration or food quality on these metabolic processes for either species. Scope for growth (SFG) in both species increased at a decreasing rate with elevated particle concentrations and organic content of the seston until an asymptote was reached. SFG in scallops was equal or exceeded SFG in clams at low concentration, but the opposite was true at high concentrations. *Mya arenaria* appeared to be better suited than *Placopecten magellanicus* to cope with higher concentrations of seston, especially if it consisted of relatively poor quality particles.

Keywords: Marine molluscs, Animal physiology, Filter feeders, Growth, Food, Softshell clam, Sea scallop.

MacFarlane, S., and G. Flimlin. 2005. **Shellfish aquaculture on the East Coast: A snapshot.** Journal of Shellfish Research. Vol. 24, no. 1, p. 327. Jan. IS: ISSN 0730-8000.

The authors conducted a survey of all East Coast states through their extension agents to determine the extent and diversity of the East Coast shellfish aquaculture industry. The survey was conducted for the East Coast Shellfish Growers Association as a prelude to developing best management practices or an environmental management system for the shellfish aquaculture industry. Respondents answered questions relative to the number of leases, sizes, species cultivated, methods and gear used, number of people employed, and other pertinent questions concerning growout. The survey also requested information on leasing and regulatory frameworks, constraints to expanding aquaculture, problems perceived by either growers or licensing agencies, and comments. Survey revealed that the shellfish industry on the East Coast is diverse in size and scope of operations, but there are common threads as well that overlap state jurisdictions.

Monteiro, P.M.S., B. Spolander, G.B. Brundrit, and G. Nelson. 1998. **Shellfish mariculture in the Benguela system: Estimates of nitrogen-driven new production in Saldanha Bay using two physical models**. Journal of Shellfish Research. 17(1):3-13.

This study uses two independent physical models, based on entrainment and turbulent diffusion, to estimate nitrate-driven new production rates in Saldanha Bay, South Africa. The two modeling approaches use yearlong wind and thermistor chain data sets that spanned a complete upwelling season in the southern Benguela System. The nitrate flux estimates from the two approaches were found to be in good agreement where the entrainment-based value was 9.40 mmol of N m super(-2)d super(-1) and the turbulent diffusion-based value was 6.47 mmol of N m super(-2)d super(-1). This provided a mean value of 7.94 mmol of N m super(-2)d super(-1) which converts to a carbon-based new production estimate of 0.63 g of C m super(-2)d super(-1). The resulting F ratio of 0.19 is in close agreement with average 0.2 for the southern Benguela System. The estimates of new production driven by the natural NO sub(3) super(-) flux were also compared with potential contributions from anthropogenic sources. Only one anthropogenic input, from a pelagic fish factory, was found to be numerically equivalent to the natural flux (8.24 mmol m super(-2)d super(-1)). However, the biogeochemical pathway for the regeneration of this fish waste flux precluded it from having more than a 20% effect in the overall estimate of new production in the bay. It was concluded that the nitrate flux that drives new production in Saldanha Bay is limited principally by physical factors, namely thermocline dynamics. The estimate of new production provides an upper limit to the carrying capacity, the real value of which is subject to better understanding of shelf-bay coupling dynamics.

Keywords: Marine aquaculture, Shellfish culture, Nitrogen cycle, Environmental effects, Energy flow, PSW, South Africa, Saldanha Bay.

Orth, Luckenbach, and Moore 1994, and Ruckelshaus. 1996. **Shellfish may also increase the survival of seedlings, by increasing light levels, nutrients, and protecting against erosion and herbivory.**

No abstract.

Rice, M.A. 2001. **Environmental Impacts of Shellfish Aquaculture: Filter Feeding to Control Eutrophication.** Marine Aquaculture and the Environment: A Meeting for Stakeholders in the northeast. pp. 77-84.

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.

Keywords: Habitat improvement; Filter feeders; Eutrophication; Water filtration; Water quality; Shellfish culture.

2.0 POTENTIAL EFFECTS OF SHELLFISH CULTURE ON CARBON SEQUESTRATION

2.1 Clams

Philippart, C.J.M., H.M. van Aken, J.J. Beukema, O.G. Bos, G.C. Cadee, and R. Dekker. 2003. **Climate-related changes in recruitment of the bivalve *Macoma balthica*.** Limnology and Oceanography. Vol. 48, no. 6, pp. 2171-2185. Nov. IS: ISSN 0024-3590.

Population dynamics of common intertidal bivalves (*Cerastoderma edule, Macoma balthica, Mya arenaria, Mytilus edulis*) are strongly related to seawater temperatures. In northwestern European estuaries, series of mild winters followed by low bivalve recruit densities lead to small adult stocks. In this study, we examine temperature-induced effects on reproductive output (eggs m super(-2)), onset of spawning (day of the year), and the juvenile instantaneous mortality rate (per day) of M. balthica. Data analysis was based on an extensive long-term data set (1973-2001) originating from the western Wadden Sea. Our results strongly suggest that rising seawater temperatures affect recruitment by a decrease in reproductive output and by spring advancement of bivalve spawning. Apparently, global warming upsets the evolved reproductive strategy of this marine bivalve to tune its reproduction to the most optimal environmental conditions for the first vulnerable life stages, most importantly the match/mismatch of time of spawning with that of the phytoplankton bloom and the settlement of juvenile shrimps on the tidal flats. It is hypothesized that the observed density-dependent mortality of juvenile bivalves may act via competition for food, a behavioral response of shrimp to low spat densities, or be the result of the response of age and size at metamorphosis of marine bivalves to resource variability. It is to be expected that prolonged periods of lowered bivalve recruitment and stocks will lead to a reformulation of estuarine food webs and possibly a reduction of the resilience of the system to additional disturbances, such as the depletion and disturbance by shellfish fisheries.

2.2 Geoduck

No papers identified for this species under this topic.

2.3 Mussels

No papers identified for this species under this topic.

2.4 Oysters

Davis, R.P. 2000. **James river market sized oysters have their late summer survival rates doubled by marl treatment of their water.** Journal of Shellfish Research. Vol. 19, no. 1, pp. 569-570. Jun. IS: ISSN 0730-8000.

James River oysters, market sized at about 250 per bushel, are not normally expected to survive another summer. The cause of death is usually attributed to either MSX or Dermo. This experiment appears to reproduce conditions under which oysters thrived abnormally well. Prior to this experiment it appears that no one successfully intervened late in the disease process. The

closest research is particularly relevant in that iron is proven to be a factor in the Dermo disease process. A lot of those older oysters were given water that was run through a mesh bag of fossil shell hash. Twice the proportion of oysters survived in the treated water as did in the untreated water. Approximately, 20.8% of the no-marl oysters survived and 41.7% of the marled oysters survived. Given the sample size and the binomial nature of the survival statistic there is a 1:16 chance that the marl treatment made no difference. The shell hash was dissolved by the passing water indicating calcium carbonate under-saturation. The existence of instances of calcium carbonate under-saturation appears controversial. The accumulation of iron sulfide in the troughs was surprising and inspired additional inquiry into the geochemistry of iron sulfide. Apparently, extremes in sediment carbonate/sulfide ratios do occur. When iron sulfide is resuspended and oxidized, the resulting burst of sulfuric acid can produce calcium carbonate undersaturation particularly at the sediment/water boundary layer. This process could explain some disappearance of shell hash and cultch. Additional sediment chemistry experiments shed light upon the geochemical mechanisms behind the abrupt discontinuity in Virginia between prehistoric sediments that are dominantly oxic/carbonate and historic sediments that are dominantly anoxic/sulfide. These sediment chemistry experiments explored extremes in carbonate/sulfide ratios and suggest that a restoration to prehistoric levels of estuarine productivity is too conservative a goal - Sunlight-limited high goals for shellfish productivity may be easier to achieve than more modest goals provided that "whole-river husbandry" is allowed.

Elfwing, T., and M. Tedengren. 2002. **Effects of copper on the metabolism of three species of tropical oysters, *Saccostrea cucullata*, *Crassostrea lugubris* and *C. belcheri*.** Aquaculture. vol. 204 (no. 1-2):pp. 157-166.

The rapid industrial development in Southeast Asia, in combination with increased population pressure, has in many places caused degradation of natural resources that many people in the region highly depend on. Attempts to evaluate environmental impacts and changes in the ecosystem due to pollution suffer from lack of data, since most knowledge about marine pollution is based on experiences from temperate areas. In the present work, physiological effects of enhanced copper concentrations on three oyster species of commercial interest were studied in laboratory experiments. Two of the species are intertidal, *Saccostrea cucullata* and *Crassostrea lugubris*, and one species is subtidal, *C. belcheri*. After a short-term (12 h) exposure to 20 mu g copper/l, the oxygen consumption, ammonia excretion, clearance rate and absorption efficiency were measured and scope for growth calculated. The results from this study indicate that the two intertidal species are far more tolerant than the subtidal species. This is probably because they inhabit a more variable environment and have to be able to handle constantly changing environmental conditions. The subtidal habitat is normally less variable, why the copper exposure was a more severe stress, seen mainly as decreased filtration activity. The final result, i.e. changes in scope for growth, indicates that for the specific stress factor studied here, habitat selection seemed to be more important than genus.

Keywords: Copper, Marine molluscs, Animal metabolism, Pollution effects, Oxygen consumption, Ammonia, Tropical environment, Bioaccumulation, Metabolism, Environmental impact, Tropical environments, Crassostrea lugubris, Crassostrea belcheri, Saccostrea cucullata, ISEW, Southeast Asia.

Sara, G., and A. Mazzola. 1997. **Effects of trophic and environmental conditions on the growth of *Crassostrea gigas* in culture**. Aquaculture. 153(1-2):81-91.

In order to study the possibility of exploiting protected marine areas, comparative data on the cultivation of the oyster Cassostrea gigas in the South Tyrrenian Sea are reported. The oysters were cultured at -7 and -13 m on long lines linked to artificial reefs. The observations, made during a 12-month period, were of the chemical-physical and trophic properties of the water column and growth rates of the oysters. Temperature ranged between 19.81 plus or minus 4.67 degree C at -7 m and 18.03 plus or minus 3.03 degree C at -13 m. Salinity showed typical Mediterranean values. The area presented oligotrophic features: the chlorophyll-a (CHLa) concentration ranged between 0.05 plus or minus 0.01 and 0.04 plus or minus 0.02 mu g l-1 at -7 and -13 m, respectively. The labile particulate organic matter (LPOM) ranged between 344 plus or minus 201 and 334 plus or minus 228 mu g l-1 at -7 and -13 m, respectively, and the CHLa carbon/POM carbon ratio (index of the autotrophic vs heterotrophic conditions) was never above 3%. POM concentration and POM gross energy content showed significant differences ($P<0.05$) at the two depths, POM bulk being greater at -13 m. The oysters, sampled monthly, had an initial average size of 11.50 plus or minus 2.78 mm (0.0036 plus or minus 0.01 g dry weight) and had reached 47.50 plus or minus 12.30 mm (0.13 plus or minus 0.04 g dry weight) at -7 m and 41 plus or minus 11.43 mm (0.11 plus or minus 0.04 g dry weight) at -13 m, after 12 months. The length-weight relationship showed the best allometric coefficient for the oysters at -13 m, although the growth trends did not show significant differences. Although a correlation between food quantity and quality and somatic and valvar production in situ was not demonstrated, it is probable that the greater POM bulk at -13 m was the cause for the better growth trajectories of these specimens.

Keywords: Crassostrea gigastrophic relationships, food availability, oyster culture, MED, Tyrrenian, Seatemperature effects.

Southworth, M., and R. Mann. 2003. **Decadal scale changes in seasonal patterns of oyster recruitment in the Virginia sub estuaries of the Chesapeake B ay.** Journal of Shellfish Research. Vol. 22, no. 1, p. 355. Jun. IS: ISSN 0730-8000.

Reproductive periodicity of sessile estuarine invertebrates reflects local seasonality of both environmental (temperature, salinity) and biological (food) parameters. Estuaries are ephemeral features in geological time, but considered somewhat constant in the course of recent human history - a decadal time scale. Analysis of long term trends in oyster settlement periodicity since 1960 in three major sub estuaries (James, Piankatank and Great Wicomico Rivers) of the Chesapeake Bay show marked changes in this periodicity within the 40 year time frame with the 50th percentile of cumulative recruitment occurring between day 194 and 250 of the year depending on year and location. Significant coherence in interannual variation is observed across a wide range of sites. These are discussed in relation to pre- and post-disease (both MSX and Perkinsus) events, periods characterized by high and low river flow, varying harvest pressure, and trends arguably associated with global warming.

2.5 Scallops

Young, P.C. 1990. **Ageing of scallops- The Measurement of Age and Growth in Fish and Shellfish.** pp. 93-95. Proceedings of the Bureau of Rural Resources, Canberra. no. 12. IS: ISSN 1032-2469. Hancock, DA (ed); IB: ISBN 0642186030. Conference: Australian Society for Fish Biology Workshop, Lorne (Australia), 22-23 Aug 1990.

The shell of bivalve molluscs consists of a proteinaceous matrix, which supports calcium carbonate deposition in the form of calcite or aragonite. As the mollusc grows, cells in the margin of the mantle secrete layers of calcium carbonate along the outer margin of the shell valves, thereby enlarging them. Shell growth is manifested as numerous small ridges or striae; these striae have been used as the basis for ageing individuals of several species. The two valves are joined dorsally by a flexible ligamentous hinge, which acts to oppose the closing action of the adductor muscle. This ligament also shows annular structure as a result of growth; it has been used for ageing individuals in a few species. Larvae of the sea scallop *Placopecten magellanicus* kept in aquaria laid down their first growth line 3-4 days after fertilisation. Annular rings were produced daily on the ventral outer margin of the shell, irrespective of the light regime (12 h dark: 12 h light, or 24 h light). However, when larvae were starved for 2-6 days and were reared at lower temperatures (11 degree C rather than 14 degree C), they showed fewer striae.

2.6 Other Shellfish Aquaculture Effects References

Bacher, C. 1999. **The use of mathematical models to assess the carrying capacity of exploited ecosystems.** Journal of Shellfish Research. 18(2):708.

In carrying capacity assessments, the key notion is that there is an optimum standing stock, yielding a maximum production under some constraints due to the population dynamics, the culture practice and the food limitation. The main objectives of this paper are therefore to present the background, the interest and the limitation of the mathematical models used in carrying capacity assessments. A simple model is presented first to illustrate how the dynamics of cultured population yields the stock/production relationship. This example is analyzed more deeply to define the basic components underlying the carrying capacity modelling which are in turn illustrated with case studies. The first case study deals with the Thau lagoon (France) for which a mathematical model of the population dynamics was built to predict the evolution of the standing stock and the annual production, taking into account several sources of variability, the rearing strategy of the farmers, the fluctuation of the environmental conditions, and the growth variability between individuals. In a second case study (Aiguillon Bay, France), it is shown how the growth of cultivated filter feeders is affected by the trophic conditions. Modelling the ecophysiology, the cultured population dynamics and the ecosystem dynamics are then combined to assess the carrying capacity of the main French production area (Marennes-Oleron Bay). As a conclusion, it is stressed that i) the carrying capacity assessment is of major importance in the scope of the sustainable development of aquaculture - with an example given of an EU/China project, ii) a full understanding of the underlying biological and physical processes is needed, iii) the socio-economic component has not yet been taken into account.

Keywords: Carrying capacity, Energy flow, Fisheries, Mathematical models, Shellfish culture, MED, France, Thau lagoon, MED, France, Aiguillon Bay.

Elderfield, H. 2002. **Climate Change: Carbonate Mysteries.** Science (Washington). Vol. 296, no. 5573, pp. 1618-1621. 31 May. IS: ISSN 0036-8075.

The pH of seawater is controlled by dissolved calcium carbonate, which provides a buffer against pH perturbations--natural or manmade--that strive to change it. One such perturbation is atmospheric carbon dioxide (CO sub(2)), an acidic gas that is exchanged between atmosphere and ocean. During glacial cycles, concentrations of CO sub(2) in the atmosphere vary widely, putting the carbonate buffer through a tough test. A recent study suggests that it coped more efficiently than previously thought. A second study reaches the opposite conclusion. Other work, on the short time scale of a laboratory experiment, suggests that changes in buffer strength may be balanced by changes in biological precipitation of calcium carbonate from seawater. Who is right? The answer has considerable implications for the ability of the oceans to sequester anthropogenic CO sub(2) from the atmosphere.

Gibbs, M.T. 2004. **Interactions between bivalve shellfish farms and fishery resources.** Aquaculture. Vol. 240, no. 1-4, pp. 267-296. 27 Oct. IS: ISSN 0044-8486.

The only possible way to increase seafood yields from many coastal and continental shelf regions of the world is through aquaculture. The most ecologically efficient forms of aquaculture are those operations culturing plants and lower trophic level animals, such as bivalve molluscs. It is therefore understandable why culturing of these organisms has steadily increased over at least the last two decades. However, the expansion of large-scale aquaculture has costs in terms of loss of water space that could be used for other activities, and carbon flows directed through the bivalves that could have been used to support other marine plants and animals (predation and production foregone). The dominant present users of many, if not most, coastal and continental shelf regions are commercial and, in some cases, recreational and indigenous customary fishers. Therefore, in many cases, it is these stakeholders who will stand to pay much of the direct costs of the expansion of aquaculture. Therefore, it is inevitable that in some cases, there will be conflict between these sectors as water space becomes more in demand and, hence, more valuable. Resource managers are therefore faced with making resource allocation decisions between alternate sectors, and these decisions should be based on robust knowledge of the costs and benefits of each alternative use. In the case of allocation decisions between bivalve aquaculture and wild stock fisheries, there is presently a paucity of knowledge surrounding the interactions between these two activities. The aim of the work presented here was to develop a framework for understanding these interactions and applying the framework in a case study in New Zealand.

Iglesias-Rodriguez, M.D., R. Armstrong, R. Feely, R. Hood, J. Kleypas, J.D. Milliman, C. Sabine, and J. Sarmiento. 2002. **Progress Made in Study of Ocean's Calcium Carbonate Budget.** EOS, Transactions, American Geophysical Union. Vol. 83, no. 34, pp. 365-374. 20 Aug. IS: ISSN 0096-3941.

Many of the uncertainties in diagnostic and prognostic marine carbon cycle models arise from an imperfect understanding of the processes that control the formation and dissolution of calcium carbonate (CaCO sub(3)). On the production side of the equation, the factors that control the abundances of calcifying phytoplankton or zooplankton are largely unknown. On the dissolution side, changes in the depth of CaCO sub(3) saturation horizons for both calcite and aragonite may produce large-scale changes in dissolution of shelf and slope sediments and reefs,

with potentially significant implications for atmospheric carbon dioxide concentration and climate change, as well as for coralline organisms themselves.

Kohn, A. 2000. **Molluscan castle-building: How molluscs make their shells.** Page 266 *in* Hylleberg, J. (editor), Proceedings of the 10th International Congress and Workshop of the Tropical Marine Mollusc Programme (TMMP), 20-30 October 1999, Hanoi and Haiphong, Socialist Republic of Vietnam. Phuket Marine Biological Center, Thailand.

The shell is the mollusc's castle, but few biologists appreciate how it is constructed and how its design meets the structural demands and the mollusc's adaptation to its mode life and environment. Research on molluscan shell formation is also more broadly important: It provides a model system for studying biomineralization, the role of organic matrix in the precipitation of hard tissues, how hard tissues are remodeled, and the mechanical and functional properties of different crystal forms. In this presentation on how the mollusc's mantle forms its shell, I will describe several aspects of mantle-shell relationships, including the chemistry of calcium carbonate precipitation, the roles of protein in shell formation, and the relationship of the different mantle regions to the layers of the shell and their crystal architecture. In addition I will discuss exterior and interior remodeling shells, the basic geometry of gastropod shells, and the biological significance of shell colour patterns.

Mackenzie, F.T., L.M. Ver, and A. Lerman. 2000. **Coastal-Zone Biogeochemical Dynamics under Global Warming.** International Geology Review. Vol. 42, no. 3, pp. 193-206. Mar. IS: ISSN 0020-6814.

The coastal zone, consisting of the continental shelves to a depth of 200 meter s, including bays, lagoons, estuaries, and near-shore banks, is an environment that is strongly affected by its biogeochemical and physical interactions with reservoirs in the adjacent domains of land, atmosphere, open ocean, and marine sediments. Because the coastal zone is smaller in volume and areal coverage relative to the open ocean, it traditionally has been studied as an integral part of the global oceans. In this paper, we show by numerical modeling that it is important to consider the coastal zone as an entity separate from the open ocean in any assessment of future Earth-system response under human perturbation. Model analyses for the early part of the 21st century suggest that the coastal zone plays a significant modifying role in the biogeochemical dynamics of the carbon cycle and the nutrient cycles coupled to it. This role is manifested in changes in primary production, storage, and/or export of organic matter, its
remineralization, and calcium carbonate precipitation--all of which determine the state of the coastal zone with respect to exchange of CO sub(2) with the atmosphere. Under a scenario of future reduced or complete cessation of the thermohaline circulation (THC) of the global oceans, coastal waters become an important sink for atmospheric CO sub(2), as opposed to the conditions in the past and present, when coastal waters are believed to be a source of CO sub(2) to the atmosphere. Profound changes in coastal-zone primary productivity underscore the important role of phosphorus as a limiting nutrient. In addition, our calculations indicate that the saturation state of coastal waters with respect to carbonate minerals will decline by similar to 15% by the year 2030. Any future slowdown in the THC of the oceans will increase slightly the rate of decline in saturation state.

McNeil, B.I., R.J. Matear, and D.J. Barnes. 2004. **Coral reef calcification and climate change: The effect of ocean warming.** Geophysical Research Letters. Vol. 31, no. 22, [np]. Nov. IS: ISSN 0094-8276.

Coral reefs are constructed of calcium carbonate (CaCO sub(3)). Deposition of CaCO sub(3) (calcification) by corals and other reef organisms is controlled by the saturation state of CaCO sub(3) in seawater (Omega) and sea surface temperature (SST). Previous studies have neglected the effects of ocean warming in predicting future coral reef calcification rates. In this study we take into account both these effects by combining empirical relationships between coral calcification rate and Omega and SST with output from a climate model to predict changes in coral reef calcification rates. Our analysis suggests that annual average coral reef calcification rate will increase with future ocean warming and eventually exceed pre-industrial rates by about 35% by 2100. Our results suggest that present coral reef calcification rates are equivalent to levels in the late 19th century and does not support previous suggestions of large and potentially catastrophic decreases in the future.

3.0 EFFECTS OF SHELLFISH CULTURE ON HABITAT, VEGETATION, AND BENTHIC COMMUNITIES

3.1 Clams

Alexandre, A., R. Santos, and E. Serrão**.** 2005. **Effects of clam harvesting on sexual reproduction of the seagrass *Zostera noltii***. Marine Ecology Progress Series. 298115-122.

Seagrass declines have been reported worldwide, mostly as a consequence of anthropogenic disturbance. In Ria Formosa lagoon, southern Portugal, the intertidal meadows of *Zostera noltii* are highly disturbed by clam harvesters. The most common technique used to collect the clams consists of digging and tilling the sediment with a modified knife with a large blade. Here we present both descriptive and experimental evidence of the negative effects of clam harvest on the Z. noltii populations of Ria Formosa. A comparison between disturbed and undisturbed meadows suggests that clam harvesting activities change the species population structure by significantly reducing shoot ensity and total biomass, particularly during August, when the harvest effort is higher. Experimental harvest revealed a short-term impact on shoot density, which rapidly recovered to control levels during the following month. An experimental mainpulation of rhizome fragmentation revealed that plant survival is reduced only when fragmented rhizomes are left with 1 intact internode. Shoot production and rhizome elongation and production of fragmented rhizomes having 2 to 5 internodes were not significantly affected, even though growth and production were lower when only 2 internodes were left. Experimental shoot damage at different positions along the rhizome had a significant effect on plant survival, rhizome elongation, and production only when the apical shoot was removed. Our results show that clam harvest can adversely affect *Z. noltii* meadows of Ria Formosa while revealing a low modular integration that allows the species to rapidly recover from physical damage.

Keywords: clam, harvest, physical damage, Zostera noltii, seagrass, disturbance, population, recovery, general aquaculture.

Alpine, A.E., and J.E. Cloern. 1992. **Trophic Interactions and Direct Physical Effects Control Phytoplankton Biomass and Production in an Estuary**. Limnology and Oceanography. 37(5):946-955.

The recent invasion of San Francisco Bay by the suspension-feeding clam *Potamocorbula amurensis* has provided an opportunity to document the ecological consequences of a major biological disturbance. Previous work over the last two decades has shown that phytoplankton biomass in the upper estuary is low $(2-3 mg Chl a m^-3)$ during seasonal periods of high river flow and short residence times, and it is usually high $(peak>30 mg Chl a m^-3)$ during the summer-autumn seasons of low river flow and long residence time. However since *P. amurensis* became widespread and abundant in 1987, the summer phytoplankton biomass maximum has disappeared, presumably because of increased grazing pressure by this newly introduced species. For the period 1977-1990, mean estimated primary production was only $39 g C m^-2 yr^-1$ during years when bivalve suspension feeders were abundant $(>2,000 m^-2)$, compared to $106 g C m^-2 yr^-1$ when bivalves were absent or present in low numbers. These observations support the hypothesis that seasonal and interannual fluctuations in estuarine phytoplankton biomass and primary production can be regulated jointly by direct physical effects (e. g. river-driven transport) and trophic interactions (episodes of

enhanced grazing pressure by immigrant populations of benthic suspension feeders).

Keywords: carrying, capacity, phytoplankton, biomass, estuary, primary production

Beal, B.F. 1994. **Effects of seagrass (*Zostera marina*) cover on growth and survival of softshell clams (*Mya arenaria*).** Journal of Shellfish Research. 13(1):311-312.

In eastern Maine, intertidal beds of eelgrass, *Zostera marina*, (area = 100-400 m super(2)) are common near the mid intertidal on mudflats that receive considerable ice scour during severe winters. Water-filled depressions are colonized in the spring by seeds of this species and, once established, beds may remain stable for more than ten years. Like subtidal seagrass beds or meadows in the mid-Atlantic and further south, species richness, evenness, and total density of large (> 0.5 mm) macrofauna is higher inside these beds than outside in the unvegetated, muddy sediments. In addition, the root/rhizome mat associated with these beds is dense and relatively impenetrable compared with sediments surrounding the beds. Seagrass beds have been shown to enhance the growth of deep-burrowing bivalves such as *Mercenaria mercenaria* as well as provide a spatial refuge from large gastropods and decapods because the heterogeneous mat complex reduces predator foraging efficiency. The hypothesis was tested that intertidal eelgrass beds would, similarly, provide individuals of *Mya arenaria* a similar escape from predation as well as enhance their growth.

Keywords: Zostera marina, Mya arenariasea, grass, clam, culture, growth, survival, ANW, USA, Maine.

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

Little is known about the impacts of intensive shellfish farming on intertidal ecosystems. To assess such impacts, several indices of ecosystem structure and select geochemical characteristics were contrasted among three intertidal regions, which represented a gradient of shellfish farming activities, namely (1) no active aquaculture, (2) actively farmed for three years and (3) actively farmed for five years. All three intertidal regions were located in Baynes Sound (British Columbia, Canada) and were geographically similar. Among the three beaches, species richness, community composition, bivalve abundance, biomass, distribution, and composition and surficial sediment per cent organic matter (carbon) and silt were compared. The intertidal regions that had been used for farming for three and five years had lower species richness, different bivalve composition, abundance and distributions, and a foreshore community dominated by bivalves, as compared to the intertidal region where no active farming occurred. Beaches that were actively farmed also had greater accumulations of organic matter and silt. Simplification of the intertidal benthic community, coupled with accumulations of organic matter and increased siltation, may have altered the ecology of the foreshore region used for intense shellfish harvesting. To access the foreshore for shellfish farming in a sustainable manner, studies are needed to determine the scale to which intensive use of the foreshore for shellfish purposes alone is feasible without undue harm to the environment.

Keywords: aquaculture, biodiversity, ecological impacts, shellfish.

Boese, B.L. 2002. **Effects of recreational clam harvesting on eelgrass (*Zostera marina*) and associated infaunal invertebrates: in situ manipulative experiments.** Aquatic Botany. 73(1):63-74.

The effect of recreational clam harvesting on eelgrass (*Zostera marina L.*) was experimentally tested by raking or digging for clams in experimental 1 m2 plots located in a Yaquina Bay (Newport, OR) eelgrass meadow. After three monthly treatments, eelgrass measures of biomass, primary production (leaf elongation), and percent cover were compared between experimental and control (undisturbed) plots. Benthic macro (retained on 0.5 mm mesh sieve) and mega (retained on 3 mm sieve) infaunal samples were also taken to compare species number and abundances. Results indicated that clam raking did not appreciably impact any measured parameter. In contrast, clam digging reduced eelgrass cover, above-ground biomass and below-ground biomass in measurements made 1 month after the last of three monthly treatments. Although differences between control and treatment plots persisted 10 months after the last clam digging treatment, these differences were not statistically significant. Approximately 10% of the eelgrass of Yaquina Bay is subjected to recreational clamming and as this activity is generally less intense than that employed in this study; it is unlikely that recreational clamming has a major impact on eelgrass beds in the Yaquina estuary. This conclusion should be viewed with caution as multi-year disturbances were not investigated and there are differences in sediment characteristics and clam abundances between experimental sites and those sites that are intensively harvested by the public.

Keywords: recreational harvest, eelgrass, general aquaculture.

Cabaço, S., A. Alexandre, and R. Santos. 2005. **Population-level effects of clam harvesting on the seagrass *Zostera noltii*.** Marine Ecology Progress Series. 298123–129.

No abstract identifying these species for this category.

Carlton, J.T. 1989. **The introduced marine and estuarine mollusks of North America: An end-of-the-century perspective on four centuries of human-mediated introductions.** Journal of Shellfish Research. 8(2):465.

Four centuries of human-mediated introductions of marine and estuarine mollusks from Europe, Japan, and the Indo-Pacific to North America have resulted in strikingly different invasion patterns: the Pacific coast, with nearly 40 non-native species, has perhaps 4 times the number of introductions as the Atlantic coast which in turn, has twice the number of introduced mollusks as does the Gulf coast. Hypotheses to account for these biogeographical-ecological differences in the susceptibility and/or resistance of these regions to molluscan invasions are reviewed. The introduced mollusks on each coast that have proven to be most significant in ecological, social, or economic terms are identified. The potential for future invasions, the risks involved, and means to reduce these risks, are considered in light of the recent spectacular successes of the Asian clam *Potamocorbula* in San Francisco Bay and the European zebra mussel *Dreissena* in the Great Lakes.

Keywords: environmental impact, biogeography, Mollusca, North-America, economic aspects, sociological aspects, introduced species.

Carswell, B., S. Cheesman, and J. Anderson. 2006. **The use of spatial analysis for environmental assessment of shellfish aquaculture in Baynes Sound, Vancouver Island, British Columbia, Canada.** Aquaculture. 253(1-4):408-414. 31 Mar. IS: ISSN 0044-8486.

The Baynes Sound area accounts for a large proportion of shellfish aquaculture production in British Columbia. In response to non-industry concerns regarding impacts from this inter-tidal farming on bird populations in Baynes Sound, a quantitative inventory of aquaculture infrastructure, more specifically clam netting, was done. Low-level high-resolution air photos were taken during periods of extreme low tides, for all intertidal shellfish tenures in Baynes Sound. Images were geo-referenced and used to create a digital geographic file of clam netting. Geographic Information System (GIS) processing of this clam net coverage information combined with existing shore substrate data and new littoral bathymetry data for Baynes Sound resulted in an accurate enumeration of clam net coverages for each of Baynes Sound's major substrate types and for the farmed clam species' optimum habitat. The results showed shellfish tenures occupy 20.3% and clam netting 2.9% of the intertidal area of Baynes Sound as defined by the Baynes Sound Coastal Plan [British Columbia Ministry of Sustainable Resource Management, 2000. Baynes Sound Coastal Plan for Shellfish Aquaculture. http://srmwww.gov.bc.ca/rmd/coastal/planning south_island/baynes/docs/Baynes_Plan_Dec19_2002.pdf] boundary. Of the major substrate types in Baynes Sound, none had a clam net coverage exceeding 6%. Further analysis using optimal habitat areas, based on tidal heights, for each of three clam species [*Prothaca staminae* (native littleneck), *Nuttallia obscurata* (varnish clam), and *Tapes philippinarum* (manila clam)] revealed no clam net coverage exceeded 20% of a shore type (based on a major substrate) found within optimal habitat areas (with the average below 6%). These techniques offer a cost-effective method of assessing inter-tidal resource utilization and provide a basis for time-series evaluation and a useful tool for adaptive resource management in Baynes Sound. More generally, these techniques can be used in any region where a shoreline classification system is complete to quantify the extent of intertidal habitat modification and be used as a decision support tool.

Keywords: Clam culture, Substrate preferences, Resource management, Environmental impact, Culture effects, Mollusc culture, Environmental assessment, Marine molluscs, Aquaculture development, Regional planning, Tapes philippinarum, Nuttallia obscurata, INE, Canada, British Columbia, Baynes Sound, Japanese littleneck, Manila clam, Marine.

Chessa, L. A.,F. Paesanti, A. Pais, M. Scardi, S. Serra, and L. Vitale. 2005. **Perspectives for development of low impact aquaculture in a Western Mediterranean lagoon: the case of the carpet clam *Tapes decussates***. Aquaculture International 13: 147–155.

Some 30,000 specimens of the Mediterranean clam *Tapes decussatus* were suspended in nylon bags of two different mesh sizes and pre-grown in the Calich lagoon (Sardinia, Italy) from March to June 2001. The samples differed in size at the end of the pre-growth stage. They were then sown at a density of 650 specimens m2 in two stations of the lagoon. The growth rates in the stations were different according to the Von Bertalanffy model. Primary and secondary plankton production was calculated by field measurements as well as by modelling. The results indicate that the Calich lagoon could produce a maximum of 753.25 g m)2 yr)1 WW, with shell, for *Tapes decussatus*. Our culture experiments lasted 15 months with an estimated mortality of 50% and the yield of *T. decussatus* was 4.3 times greater than the calculated natural production.

Key words: Coastal lagoons, Mediterranean Sea, Mollusc culture, Tapes decussates.

Cigarria, J., and J.M. Fernandez. 2000. **Management of Manila clam beds. I. Influence of seed size, type of substratum and protection on initial mortality.** Aquaculture 2000. 182(1-2):173-182.

Commercial Manila clam beds in the Eo estuary (NW Spain) were studied from 1991 to 1996 to determine the influence of seed size, level of protection and substratum type on mortality early in the culture period. We detected a significant effect of size on mortality in both protected and unprotected beds, as, even with predator control, smaller seed showed poorer survival when planted in the field. A significant influence of substratum on mortality was also evident, with lowest mortality in sand gravel beds, Clams reached a size refuge at 1 g (16 mm in shell length) when protected with nets from predators and at 2 g (21 mm in length) when unprotected, showing how the net reduced the availability of clams to predators. Therefore, planting larger clams in sandgravel beds and protecting them with nets will enhance clam survival.

Keywords: Manila clam, Seed, Mortality, Predation, Sandgravel beds, NetsEo, estuary (NW Spain).

Dumbauld, B. 2002. **The Ecological Role and Potential Impacts of Molluscan Shellfish Culture in the estuarine Environment.** Work plan update.

No abstract identifying these species for this category.

Dumbauld, B.R., M. Peoples, D.A. Armstrong, and S. G. Ratchford. 1996. **A comparison of the effects of three different habitat modifications on intertidal clam populations in Pacific Northwest coastal estuaries.** Journal of Shellfish Research. 15(2):480.

A review of several field studies on the influence of epibenthic structural modifications to intertidal habitat in Pacific Northwest coastal estuaries suggests that several species of clams display similar responses to each. Three contemporary habitat modification issues are: invasion of the introduced cordgrass *Spartina alterniflora*, the distribution of large quantities of oyster shell on intertidal tideflats to enhance the population of juvenile Dungeness crab, *Cancer magister*, and application of the pesticide carbaryl to remove thalassinid shrimp prior to oyster cultivation. Settlement measured as initial density of *Mya arenaria, Tapes japonica* and *Macoma spp*. has been shown to be little affected by the physical structure of *Spartina* and shell with the exception of the large barrier presented by *Spartina* shoots in the later summer and fall. Subsequent survival of small clams however, is negatively influenced by the presence of epibenthic shell, which attracts predators such as juvenile Dungeness crab *Cancer magister*. Although tide height may preclude Dungeness crab from utilizing *Spartina*, similar declines in clam density were observed within cordgrass clones. After clams reach a size threshold, survival is less affected, but growth may be influenced depending on size of the clam, size of the structure, and hydrodynamic scaling factors.

Keywords: intertidal environment, habitat improvement, larval settlement, substrate preferences, survival growth, hydrodynamics, Mya arenaria, Tapes japonica, Macoma INE, USA – Washington.

Ferns, P. N., D. M. Rostron, and H.Y. Siman. 2000. **Effects of mechanical cockle harvesting on intertidal communities**. Journal of Applied Ecology. 37: 464-474.

1. Shellfish of marketable size can be harvested much more quickly and efficiently using mechanical methods such as tractor-powered harvesters and suction dredgers than by traditional methods. The adverse e.ects of such machines on non-target organisms need to be considered carefully before licensing such activities. **2.** A tractor-towed cockle harvester was used to extract cockles from intertidal plots of muddy sand and clean sand in order to investigate the effects on other benthic invertebrates and their predators. **3.** Harvesting resulted in the loss of a significant proportion of the most common invertebrates from both areas, ranging in the muddy sand from 31% of *Scoloplos armiger* (Polychaeta) (initial density 120 m2) to 83% of *Pygospio elegans* (Poly-chaeta) (initial density 1850 m2). Significant e.ects could not be detected in most populations with a density of less than 100 m2. **4.** Populations of *Pygospio elegans* and *Hydrobia ulvae* (Gastropoda) remained significantly depleted in the area of muddy sand for more than 100 days after harvesting, and *Nephtys hombergi* (Polychaeta), *Scoloplos armiger* and *Bathyporeia pilosa* (Amphipoda) for more than 50 days. **5.** Invertebrate populations in clean sand with relatively few cockles *Cerastoderma edule* (Pelecypoda) recovered more quickly than those in muddy sand with a more structured community, which included several tube-dwelling species such as *Pygospio elegans* and *Lanice conchilega* (Polychaeta). **6.** Bird feeding activity increased at first on the harvested areas, with gulls and waders taking advantage of invertebrates made available by harvesting. Subsequently, in the area of muddy sand, the level of bird activity declined compared with control areas. It remained significantly reduced in curlews *Numenius arquata* and gulls for more than 80 days after harvesting and in oystercatchers *Haematopus ostralegus* for more than 50 days. **7.** It is concluded from this study that tractor dredging for cockles in high density areas causes a sufficiently large mortality of non-target invertebrates that harvesters should be excluded from areas of conservation importance for intertidal communities such as invertebrates, fish and birds.

Keywords: benthic disturbance, benthic invertebrates, Burry Inlet, shorebirds.

Goodwin, L., and W. Shaul. 1978. S**ome effects of the mechanical escalator shellfish harvester on a subtidal clam bed in Puget Sound, Washington.** Progress Report.

No abstract.

Hall, S. J., and M.J.C. Harding. 1997. **Physical disturbance and marine benthic communities: the effects of mechanical harvesting of cockles on non-target benthic infauna.** Journal of Applied Ecology. 34: 497-5 17.

1. The effects of physical disturbance processes on marine benthic communities remain an issue of considerable theoretical and practical importance, particularly with respect to the impact of fisheries activity and possible conflict with wildlife conservation objectives. One area where particular concern has been raised is with respect to the effects of mechanical harvesting of cockles (*Cerastoderma edule*) on non-target benthic infauna in intertidal communities. **2.** This paper describes the results of manipulative field experiments which examine the effects of disturbance by two mechanical cockle harvesting methods, hydraulic suction dredging and tractor dredging. **3.** Although the suction dredge experiment revealed some statistically significant effects, taken as a whole the results indicated that the faunal structure in disturbed plots recovered (i.e. approached that of the un-disturbed controls) by 56 days. This occurred

against a background of consistent increases in the abundance of many taxa in both treatments, which we interpret as the normal seasonal response of the community. **4.** The tractor dredge experiment revealed fewer statistically significant effects than the suction dredge experiment, and recovery from disturbance occurred against a background of general seasonal decline in the abundance of the fauna. From the available evidence the most likely mechanism of recovery was through the immigration of adults into disturbed areas. **5.** We conclude that mechanical harvesting methods impose high levels of mortality on nontarget benthic fauna, but that recovery of disturbed sites is rapid and the overall effects on populations is probably low. Although our results suggest that tractor dredging has less effect than suction dredging, this result is most likely to be a consequence of the different times of year in which the experiments were conducted. Thus, for this location, we do not believe that a distinction can be made between the effects of the two methods. Although experimental manipulations cannot be conducted on comparable spatial scales to real fishing activity, we believe these results probably do not represent a major under-estimate of recovery times for intertidal habitats similar to the one chosen for this study.

Keywords: benthic disturbance, fishing disturbance, scale.

Higano, J., K. Adachi, and H. Kuwahara. 1997. **Environmental factors influencing clam culture on sandy shores. Interactions between cultured species and naturally occurring-species in the environment.** Keller,-B.J.;Park,-P.K.;McVey,-J.P.;Takayanagi,-Kazufumi;Hosoya,-Kazumi-eds.1997 no.24 pp.65-70.

Artificial seed productions of the Japanese surf clam *Pseudocardium sachalinensis* and the poker-chip venus *Meretrix lamarckii* are carried out at several prefectural hatcheries, where a couple of million juveniles 3 mm in shell length are produced at each hatchery. Usually, the bulk of the juveniles are released directly at sandy shores, but this has not been successful. Two approaches are being used for future success in clam mariculture on sandy shores. One is nursery culture in natural conditions. It is necessary to grow clams to a larger size because 3 mm juveniles are moved by wave action. The experimental field nursery culture of the Japanese surf clam *P. sachalinensis* is performed in an artificial pond fenced in by iron plates. The pond will protect the juveniles from waves and help them grow larger. Water exchange and food supply in the pond will be sufficient for the growth of clams. Another is the prediction of movement of the clam seed. Dispersion and migration are very significant factors in the release of clam juveniles. On sandy shores, movement by waves is most important for clams. Numerical models for the on-offshore movement in a ransaction of beach are developed on the basis of hydrodynamics. The availability of the models is recognized in comparison with the field survey and the flume experiment.

Keywords: clam, culture, Pseudocardium sachalinensis, mathematical, models, wave, effects, beaches, sediment, transport, aquaculture, techniques, Meretrix lamarckii, seed, production, INW, Japan, Honshu, Ibaraki Prefect.

Kaiser, M.J., G. Burnell, and M. Costello. 1998. **The environmental impact of bivalve mariculture: A review.** Aquaculture-'-98-Book-of-Abstracts, Louisiana State University, Baton Rouge, LA 70803. USA World Aquaculture-Society.81-82.

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 multiuser 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. Bivalve cultivation can be broadly split into three main processes: (1) seed collection, (2) seed nursery and on-growing, and (3) harvesting. In many instances, commercial species are reared as seed in hatcheries prior to seeding, with few effects on the environment. However, some species are collected from the wild using spat collectors or dredgers. 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. The nursery and ongrowing of bivalves either takes place intertidally (clams and oysters) or subtidally (mussels and scallops). 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.

Keywords: Marine, aquaculture, Mollusc, culture, Clam culture, Mussel culture, Oyster culture, Scallop culture, Culture effects, Offbottom culture, Seed collection, Harvesting, Anthropogenic factors, Filter feeders, Suspended particulate matter, Excretory products, Anoxic conditions, Degradation, Nursery grounds, Habitat, Environmental impact, Intertidal environment, Ecosystem disturbance, Trophodynamic cycle, Biological stress, Mortality causes, Biota, Marine birds, Bivalvia, British Isles, ANE, British Isles, Eire, ANE, Eire.

Kaiser, M., .J.I. Laing, S.D. Utting, and G.M. Burnell. 1998. **Environmental Impact of Bivalve Mariculture: A review.** Journal of Shellfish Research. 1759-66.

There is a pressing need to protect the ecology of nearshore marine habitats that are used for an ever increasing range of activities. In particular, fisheries managers need to consider both environmental and socioeconomic issues in coastal areas owing to the environmental changes that can occur as a result of cultivation and harvesting processes associated with mariculture.

Bivalve cultivation can be broadly split into three main processes: (1) seed collection, (2) seed nursery and on -growing, (3) harvesting. The environmental impacts of each cultivation stage will vary depending on the species in question and the techniques used. In many instances, commercial species are reared as seed in hatcheries prior to seeding, with few effects on the environment. However, while some species are collected from the wild using benign techniques such as spat collectors, others are extracted using intrusive devices such as dredges. A growing number of studies of the ecological effects of mechanical collecting devices have demonstrated direct mortality of non -target species and the destruction of suitable settlement substrata or habitats. In addition, other species, such as birds, crabs and starfish may be deprived of valuable food resources and habitat as a result of the mechanical harvesting of bivalve seed.

Keywords: Bivalve, Mariculture, ECOP.

Kaiser, M.J., D.B. Edwards, and B.E. Spencer**.** 1996. **Infaunal Community Changes as a Result of Commercial Clam Cultivation and Harvesting.** Aquat. Living Resour. 957-63.

Manila clams are cultivated beneath plastic netting, to protect them from excessive predation, and harvested after approximately 2 years. Both the on-going and harvesting process have the potential to alter benthic communities. We studied these effects.

Keywords: Clam cultivation, benthic community, harvesting, environmental impact, species culture.

Lear, D.W. 1960. **Stormy Fermenters and Coliform Bacteria in the Soft-Shelled Clam *Mya arenaria* and Its Habitat**. Chesapeake Science 1: 36-40.

Enumerations were made of coliforms, "Escherichia coli" and stormy fermenters, (presumably Clostridium perfringens), as indicators of fecal pollution in the soft-shelled clam, *Mya arenaria*, and in its habitat, through a seasonal cycle. Stormy fermenters showed a pattern similar to coliforms and *"E.* coli" in clams, but no similarities were observed among these organisms in the overlying waters, the sediment-water interface or the sediments. When examined as a function of temperature, none of the indicator microorganisms showed marked seasonal trends in bacterial density. Stormy fermenters apparently did not produce any false positive coliform reactions during the course of this study.

MacKenzie, C.L. Jr. 1997. **The natural history and habitat characteristics of softshells (*Mya arenaria*) in northern New Jersey.** Journal of Shellfish Research. Vol. 16, no. 1, pp. 310. Jun. IS: ISSN 0077-5711.

The natural history and habitats of softshell clams (*Mya arenaria*) in Raritan Bay and the Navesink and Shrewsbury Rivers, NJ, were studied from 1993-96. Settlement densities of juveniles ranged as high as 7,000/m super(2). Causes of mortality varied among beds. Juveniles that settled on impenetrable hard clay substrates did not survive. Most settled in sand sediments, fewer in mud. Within weeks after settlement, many clams emerged from the bottom (cause not identified), laid on the surface, and died in 4-6 weeks. Observed predators of clams were fishes (mainly Fundulus sp.), black ducks (Anas rubripes), and horseshoe crabs (Limulus polyphemus). Man-related causes of mortality were: 1) smothering under mats of sea lettuce (*Ulva lactuca*) (possibly caused by eutrophication); 2) large waves dislodging the clams from sediments (this followed the loss of eelgrass in the 1940's; eutrophication has since prevented eelgrass growth;

before then, the eelgrass had dampened the effects of waves on the clams); and 3) in July-August, 199 5, most clams in the two rivers died when water temperatures persisted at about 30-31 degree C for several days (global warming?). In beds with no evident causes of mortality after the clams had attained a length of at least 15 mm, the survival rate was about 50% in 21 months, September 1993 to June 1995. The clams attained market size about 2 years after settlement.

Mark, W.L., and V.W. Harry. 2004. **Linking watershed loading and basin-level carrying capacity models to evaluate the effects of land use on primary production and shellfish aquaculture.** Bulletin of Fisheries Research Agency (Japan). no. Sup. 1, pp. 123-132. IS: ISSN 1346-9894.

Aquaculture production of hard clams, *Mercenaria mercenaria*, in the lower Chesapeake Bay, Virginia, U.S.A., has increased dramatically within the last decade. In recent years concern has been raised that some growing areas may be approaching the exploitation carrying capacity for clam production. Preliminary calculations indicate that large-scale intensive clam aquaculture may be controlling nutrient and phytoplankton dynamics in this system. To date, carrying capacity models for that purpose. Moreover changing land use in the watersheds surrounding the clam-producing areas raises the need for an improved understanding of how these changes will affect water quality, primary production and shellfish production. We describe an ongoing project linking a watershed-based loading model with a physical transport-based water quality model to simulate primary production and predict carrying capacity for clam aquaculture. Extensive calibration and verification of the water quality model has demonstrated its utility for simulating primary production and water quality parameters in the Chesapeake Bay. In our present efforts, watershed loading models have been developed and tested for predicting both surface and groundwater inputs into the coastal waters. We are currently coupling the water quality and watershed loading models, and developing clam physiology and population-level sub-models. Also, under development is a sediment deposition/resuspension sub-model. Each of these components will be linked to estimate exploitation carrying capacity for clam production in this system. Our goal is to use the coupled models to predict how varying land use scenarios impact water quality, primary production and shellfish carrying capacity of coastal waters.

Murphy, R.C. 1985. **Factors affecting the distribution of the introduced bivalve, *Mercenaria mercenaria,* in a California lagoon - The importance of bioturbation**. J.-Mar.-Res. 43(3):673-692.

Quantitative surveys of the Colorado Lagoon and Marine Stadium (Long Beach, California, USA) indicated that the bivalve communities in the Lagoon and in the Stadium were dramatically different, even though water exchanged freely between the two systems for most of the year. In the Lagoon the mean total bivalve density was 143/m super(2) with a density of the introduced clam, *Mercenaria mercenaria*, of 78/m super(2). In the Stadium the mean total clam density was 57/m super(2) and *M. mercenaria* was absent. In the Lagoon, bivalve populations were dominated by suspension-feeders, while in the Stadium deposit-feeders were most abundant. Quantitative surveys of ghost shrimp, *Callianassa californiensis*, burrows suggested this shrimp was more abundant in the Stadium than in the Lagoon. This research supports the trophic group hypothesis, which states that deposit-feeding and suspension-feeding species have a positive influence on species of the same feeding type and a negative impact on species of the opposite feeding type, primarily through their effects on sediment stability. (DBO)

Keywords: INE,-USA,-California, Mercenaria mercenaria, introduced species, bioturbation competition, habitat, improvement, filter feeders, detritus feeders.

Peterson, C.H., and R. Black. 1987. **Resource depletion by active suspension feeders on tidal flats: Influence of local density and tidal elevation.** Limnology and Oceanography. 32: 143-166.

Sampling at two elevations from a tidal flat on the Shark Bay (Western Australia) shoreline at Monkey Mia revealed abundant suspension-feeding bivalves of numerous (>17) species. Their total density increased by 3 x up the tidal elevation gradient from the subtidal margin of the flat to intertidal sites -97 cm higher. Factorial field experiments were used to test the effect of site (tidal elevation), local bivalve density, and their interaction on growth and survivorship of three species of suspension-feeding bivalves. Survivorship was high and did not vary significantly with site or local density. Individual growth was generally lower at higher density for both *Anornalocardia squamosus* and *Circe lenticularis,* but growth of *Callista irnpar* never responded significantly to local density. Site effects on individual growth were far stronger than density effects and operated on all three species: growth at the intertidal site was substantially lower than at the subtidal site. The intensity of the site effect on individual growth about doubled from the first (February-June) to the second (June-December) experimental interval, probably because average daily exposure to air also doubled. Despite the success of tidal exposure in explaining seasonal variation in growth differences between sites, at a given season clams at the intertidal site grew substantially less than predicted from duration of aerial exposure and density. We hypothesize that density effects estimated locally within 1-m2 areas fail to assess the full magnitude of food depletion that occurs over broader scales and that suspension feeders low on the flat deplete suspended foods in incoming tidal flows before they ever reach clams at higher elevations.

Philippart, C.J.M.; H.M. van Aken, J.J. Beukema, O.G. Bos, G.C. Cadee, and R. Dekker. 2003. **Climate-related changes in recruitment of the bivalve *Macoma balthica*.** Limnology and Oceanography. Vol. 48, no. 6, pp. 2171-2185. Nov. IS: ISSN 0024-3590.

Population dynamics of common intertidal bivalves (*Cerastoderma edule, Macoma balthica, Mya arenaria, Mytilus edulis*) are strongly related to seawater temperatures. In northwestern European estuaries, series of mild winters followed by low bivalve recruit densities lead to small adult stocks. In this study, we examine temperature-induced effects on reproductive output (eggs m super(-2)), onset of spawning (day of the year), and the juvenile instantaneous mortality rate (per day) of M. balthica. Data analysis was based on an extensive long-term data set (1973-2001) originating from the western Wadden Sea. Our results strongly suggest that rising seawater temperatures affect recruitment by a decrease in reproductive output and by spring advancement of bivalve spawning. Apparently, global warming upsets the evolved reproductive strategy of this marine bivalve to tune its reproduction to the most optimal environmental conditions for the first vulnerable life stages, most importantly the match/mismatch of time of spawning with that of the phytoplankton bloom and the settlement of juvenile shrimps on the tidal flats. It is hypothesized that the observed density-dependent mortality of juvenile bivalves may act via competition for food, a behavioral response of shrimp to low spat densities, or be the result of the response of age and size at metamorphosis of marine bivalves to resource variability. It is to be expected that prolonged periods of lowered bivalve recruitment and stocks will lead to a reformulation of estuarine food webs and possibly a

reduction of the resilience of the system to additional disturbances, such as the depletion and disturbance by shellfish fisheries.

Piersma, T., A. Koolhasas, A. Dekinga, J. J. Beukema, R. Dekker, and K. Essink. 2001. **Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea.** Journal of Applied Ecology. 38: 976–990.

1. There is world-wide concern about the effects of bottom-dredging on benthic communities in soft sediments. In autumn 1988, almost a third of the 50-km2 intertidal system around the island of Griend in the western Dutch Wadden Sea was suction-dredged for edible cockles *Cerastoderma edule* and this study assessed subsequent effects. An adjacent area not directly touched by this fishery and an area from which the mussel *Mytilus edulis* beds were removed, served as reference areas. **2.** Sediment characteristics, together with the total stock size and settlement densities of *Cerastoderma*, Baltic telling *Macoma balthica* and soft-shelled clam *Mya arenaria*, were documented during 11 successive autumns before (August–September 1988) and after (August–September 1989–98) the suction-dredging event in fished and unfished areas. Four other areas in the Dutch Wadden Sea, where changes in densities of juvenile bivalves from 1992 to 1998 were measured, served as additional reference locations. **3.** Between 1988 and 1994, median sediment grain size increased while silt was lost from sediments near Griend that were dredged for cockles. The initial sediment characteristics were re-attained by 1996. **4.** After the removal of all *Mytilus* and most *Cerastoderma*, the abundance of *Macoma* declined for 8 years. From 1989 to 1998, stocks of *Cerastoderma*, *Macoma* and *Mytilus* did not recover to the 1988 levels, with the loss of *Cerastoderma* and *Macoma* being most pronounced in the area dredged for cockles. Declines of bivalve stocks were caused by particularly low rates of settlement in fished areas until 1996, i.e. 8 years after the dredging. **5.** A comparison of settlement in the short (1992–94) and medium term (1996–98) after cockle-dredging in several fished and unfished areas spread over the entire Dutch Wadden Sea, showed a significant negative effect of dredging on subsequent settlement of *Cerastoderma*. *Macoma* also declined, but not significantly. **6.** We conclude that suction-dredging of *Cerastoderma* had long-lasting negative effects on recruitment of bivalves, particularly the target species, in sandy parts of the WaddenSea basin. Initially, sediment reworking by suction-dredging (especially during autumn storms) probably caused losses of fine silts. Negative feedback processes appeared to follow that prevented the accumulation of fine-grained sediments conducive to bivalve settlement.

Key-words: BACI, benthic communities, conservation, fishery, soft sediments, spatfall.

Quijón, P., E. Jaramillo, and M. Pino. 1996. **Macroinfaunal Assemblages Associated with Mussel and Clam Beds in an Estuary of Southern Chile**. Estuaries 19: 62-74.

Samples were collected from September 1990 to 1992. at three subtidal sites of the middle reaches of the Queule River estuary, southern Chile, to analyze the spatial and temporal variability of the macroinfauna inhabiting substrata with different abundances of bivalves. In addition, water and sediment samples were obtained to study the relationships between temporal variability in macroinfaunal abundances, physical factors, and chlorophyll *a* content. Temperature, salinity, and chlorophyll *a* showed a rather strong seasonal variability but slight between-site differences. Sediment characteristics and bivalve abundances, by contrast, exhibited little temporal variability but large differences between sites. The macroinfauna was primarily represented by polychaetes, *Primospio (Minuspio) patagonica* being dominant in the

three areas. Most dominant species showed similar trends of temporal variability, with maximum abundances recorded during spring and fall. The appearance of recruits was restricted to the summer with little difference among sites. Multiple regression analyses showed that the temporal variability of macroinfaunal adults and recruits, was primarily associated with variability in salinity and water temperature, respectively. Spatial variability of these organisms was also explained by variations in these factors, together with those of sediment texture and organic matter content. No evidence of interactions (significant relationships) was found between the abundances of bivalves and those of the macroinfauna, nor among macroinfaunal organisms.

Spencer, B.E., M.J. Kaiser, and D.B. Edwards. 1996. **The effect of Manila clam cultivation on an intertidal benthic community: the early cultivation phase.** Aquaculture and Research. 27(4):261-276.

With increasing awareness of the use of the coastal zone, it is necessary to understand the potential environmental effects of aquaculture practices. This is especially important when nonnative species, which may be competitively superior to native species, are cultivated. A 5year experiment was established to study the environmental effects of the various stages of Manila clam, *Tapes philippinarum* Adams & Reeve, cultivation, from seeding, through ongrowing, harvesting and post harvesting. The aim was to monitor changes in biological and physical variables in the sediment which may be useful in formulating an environmental management strategy for the cultivation of this species. This paper describes the biological and physical changes that occur in the sediment during the early phase of clam cultivation. We compared the changes in netted plots (with and without clams) and unnetted control areas, 6 months before and after laying the clams. The clams were planted in April 1992 under netting at a density of 500 m super(2) (0.16 kg m super(2)), and in 6 months, had increased their weight to 3.2 kg m super(2) but decreased their number to 410 m super(2). A significant, but small increase in organic content (net only plots, 3.37%; control plots 2.42%) and in phaeopigment (netted plots, 8.6 mg m super(2); control, 5.6 mg m super(2)) of the sediment in the netted plots relative to the control areas were seen. Shortterm sedimentation rates on the netted plots were up to four times higher than in the control areas. The netting also encouraged the settlement of Enteromorpha sp. which, in turn, attracted Littorina littorea to feed on these plots. The infaunal community in the control areas was similar to that in samples 12 months earlier and continued to be dominated by the predatory polychaete *Nephtys hombergii*. Netted plots (with and without clams) had a greater abundance of deposit feeding polychaetes, particularly *Ampharete acutifrons* and *Pygospio elegans*, which were the dominant fauna in these plots. Within the clam treatments, the density of clams had a negative effect on the abundance of cirratulids, although mean abundance was generally greater than in the control areas. There were few physical changes to the experimental area after 6 months. The most important effect appears to be the increased sedimentation rate over plots with netting, which has led to an increase in productivity of those areas.

Keywords: clam, culture, environmental impact, Tapes philippinarum, intertidal.

Spencer, B.E., M.J. Kaiser and D.B. Edwards. 1997. **Ecological effects of intertidal Manila clam cultivation: Observations at the end of the cultivation phase**. J. Appl. Ecol. 34(2):444-452.

Marine aquaculture has come under close scrutiny by environmental pressure groups, fisheries managers and scientists in recent years, because of a shared concern over the physical and biological effects of farming practices on the marine environment. This paper describes the environmental effects of intertidal Manila clam (*Tapes philippinarum*) cultivation at the end of the cultivation phase immediately prior to harvesting the marketable sized clams, which were planted in ground plots 2.5 years earlier at a density of 500 m super(2). Although survival was poor, with a final density of 26 m super(2) (0.78 kg m super(2)), this still represented a significant biological presence relative to other benthic organisms. An experimental approach, using a 3 x 3 Latin Square design, was adopted. The treatments comprised net covered plots of clams, net covered plots without clams and control plots without netting or clams. An additional set of controls, 50 m distant from the Latin Square, was established for comparative purposes. The presence of the netting, rather than the clams, increased sedimentation rate which elevated the ground profile by c. 10 cm and caused a small but significant increase in percentage fines and percentage organic content of the sediment. The netting also encouraged higher densities of some species of infaunal deposit feeding worms which became the dominant fauna. During the first 6 months of the cultivation process, the fauna was dominated by the opportunistic spionid, *Pygospio elegans*. After one year, the stabilizing effect of the netting on the sediment led to the establishment of species such as *Ampharete acutifrons* and *Tubificoides benedii*, which displaced P. elegans as the community dominants. The observed biological responses indicate that organic enrichment occurs within net covered areas. However, the magnitude of community change is far less than that which occurs in association with some other marine culture practices, which create anoxic sediments and impoverished infaunal communities.

Keywords: aquaculture, aquatic communities, species, composition, sedimentation, Japanese little neck, environmental impact, ECOP.

Spencer, B.E., M.J. Kaiser, and D.B. Edwards. 1998. **Intertidal clam harvesting: benthic community change and recovery.** Aquaculture and Research. 29(6):429-437.

Mechanical harvesting of intertidal bivalve molluscs inevitably leads to the physical disturbance of the substratum and its associated fauna. Hence, it is necessary to consider the consequences of such activities for the requirements of other species (e.g. fish and birds) which utilize these areas. The present study reports a long-term experiment that studied the effects of Manila clam, *Tapes philippinarum* Adams & Reeve, cultivation on an estuarine benthic habitat and its fauna. The study began with the initial seeding of the clams, and continued through ongrowing, and finally, harvesting 30 months later. Earlier observations revealed that plots covered with netting elevated sedimentation rate, and hence, encouraged the proliferation of certain deposit-feeding worm species which persisted throughout the cultivation cycle until harvesting took place. The immediate effects of harvesting by suction dredging caused a reduction of infaunal species and their abundance by =80%. Recovery of the sediment structure and the invertebrate infaunal communities, judged by similarity to the control plots on both the harvested and unharvested but originally netted plots, had occurred 12 months after harvesting. Comparisons with other similar studies demonstrate that, in general, suction harvesting causes large short-term changes to the intertidal habitat. The rate at which recolonization occurs and sediment structure is restored varies according to local hydrography, exposure to natural physical disturbance and sediment stability. The management of clam farming procedures and other forms of mechanical harvesting should incorporate a consideration of site selection, rotational seeding,

cultivation and harvesting to create fallow areas, and seasonal harvesting to ameliorate the recovery of sites.

Keywords: species, culture, harvesting, benthic communities.

Thompson, D. S. 1995. **Substrate additive studies for the development of hardshell clam habitat in waters of Puget Sound in Washington state: An analysis of effects on recruitment, growth, and survival of the manila clam, *Tapes philippinarum*, and on the species diversity and abundance of existing benthic organisms.** Estuaries. 18: 91-107.

To meet demands of expanding tribal and recreational hardshell clam fisheries, the Washmgton State Department of Fish and Wildlife has been developing new hardshell clam habitat. In Oakland Bay, near Shelton, Washington, two artificial substrates were studied to determine the best substrate for use in improving Manila clam (*Tapes philippinarum*) production. Treatments consisted of a control of natural substrate; a 10 ***c m*** layer of nonuniform size gravel ranging from 6 mm to 19 mm in diameter; and a 10 cm layer of a 50:50 mixture of gravel and crushed oyster shell ranging from 10 mm to 30 mm in diameter. Effects of these substrates on species diversity and relative abundance of existing benthic organisms were also investigated. Recruitment of Manila clam seed, less than 10 mm shell length, was significantly higher ($p < 0.05$) in the control plots than in the gavel and gravel + shell plots, which showed no significant differences. Recruitment improved in the gravel and gravel + shell plots after a layer of organic debris and fine sediments collected on them. Manila clam survival was significantly higher in gravel and gravel + shell plots compared to control plots. No significant differences in survival were observed between gravel and gravel + shell plots. Manila clam biomass in the gravel and gravel + shell plots was significantly higher than in control plots. Between the gavel and gravel + shell plots there was no significant difference in biomass. Minor differences in species diversity and abundance of existing benthic organisms were observed among treatments. Gammarid amphipods and nemertean worms were enhanced in gravel and gravel + shell plots. Densities of polychaete worms were slightly lower in gravel and gravel + shell plots compared to control plots.

Thompson, D., and W. Cooke. 1991. **Development of Japanese littleneck (*Tapes philippinarum*) habitat by beach graveling.** Journal of Shellfish Research. 10(1):240.

The Washington Department of Fisheries (WDF) is using a process known as beach graveling to create new clam (*Tapes philippinarum*) habitat on mud and combination mud/sand beaches. Previously graveled plots, have demonstrated relatively low levels of clam production (9.0 clams/m super(2)/yr). Limiting factors are silt deposition and erosion of gravel plots, predation by crab, fish and moon snail, and thick layers of gravel producing hydrogen sulfide gas. Methods used to reduce the impact of these factors on clam production are discussed. In 1989, six 0.3 acre gravel plots were established at Oakland Bay, near Shelton, WA. Treatments of 100% gravel and a 50/50 ratio of gravel to crushed oyster shell at layer depths of 2.5 to 10.0 cm are being tested to determine the best combination for clam settlement, growth and survival.

Keywords: clam, culture, site, selection, habitat improvement, physical, Tapes, graveling.
Thompson, D.S., and W.A. Cooke. 1993. **Substrate additive studies for development of hardshell clam habitat.** Journal of Shellfish Research. 12(1):152-153.

The Washington State Dep. of Fisheries is developing new hardshell clam habitat through beach graveling. At Oakland Bay near Shelton. WA, two gravel treatments and a control are being used to evaluate clam recruitment, growth and survival and to investigate potential impacts on epibenthic and infaunal organisms. The treatments are a 10 cm layer of 6-19 mm gravel; a 10 cm layer of a 50/50 mixture of 6-19 mm gravel with crushed oyster shell. Each treatment was replicated three times. The test plots are 15 x 30 m and were sampled before graveling and annually thereafter using a 10 x 15 cm PVC core. Sediment cores were sieved through nitex screens. All clams were numerated, weighed and counted. Other invertebrates were classified and counted. Species diversity and taxa richness increased on both treatments compared to the control. Clam recruitment was highest on the control plots, however the clams did not survive past 25 mm. Survival was best on the gravel + shell plots 64.71% compared to 49.90% for the gravel plots. Clam growth was similar on both gravel and gravel + shell plots. The best treatment will be used to develop a 1.6 ha production plot for recreational and tribal use.

Keywords: habitat, improvement, physical, gravel, recruitment, growth, survival.

Whiteley, J., and L. Bendell-Young. 2007. **Ecological implications of intertidal mariculture: observed differences in bivalve community structure between farm and reference sites.** Journal of Applied Ecology. 44: 495–505.

1. Despite recent growth in shellfish aquaculture in British Columbia, Canada, the impacts of common practices on non-target species are poorly understood. Two practices employed on clam farms to increase production of the exotic clam *Venerupis philippinarum* include the addition of juvenile 'seed' clams to the sediment and covering seeded clam beds with protective netting, ostensibly to exclude large mobile epibenthic predators. **2.** We expected the effects of predator exclusion to be most evident among other bivalves, which made up more than 80% of the infaunal macrobenthos at all sites surveyed. A field study across three regions collected infaunal bivalve density and biomass data. We compared species richness, composition and abundances of communities between clam farms and reference sites, paired on the basis of physical characteristics such as sediment type, slope and aspect. **3.** *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, although an increase would be expected if netting excluded important predators. Although statistically non-significant, there were indications that biomass of species other than *V. philippinarum* may have been lower on farm sites. **4.** Bivalve species composition was not significantly different between farm and reference sites. Nevertheless, farm sites were more similar to each other as a group than reference sites, leading to a loss of regional distinctness that was evident among reference sites. **5.** *Synthesis and applications*. Our findings support the hypothesis that predation and competition play minor roles in structuring communities in soft-bottomed environments. Given the potential for cumulative effects of seeding and netting at large scales, a precautionary approach is recommended in future development of intertidal clam aquaculture.

Keywords: bivalves, clam aquaculture, community structure, predator exclusion, Venerupis philippinarum.

Wood, R., and J. Widdows. 2002. **A model of sediment transport over an intertidal transect, comparing the influences of biological and physical factors.** Limnology and Oceanography. Vol. 47(no. 3):pp. 848-855.

This paper compares modeled biotic and physical effects on intertidal sediment transport, using parameterizations that are based on laboratory and field experiments. A one-dimensional model of an intertidal transect is constructed. The model is aligned cross shore and includes movement of water and suspended sediment. Within the model, tidal currents cause erosion, and bioturbation by the clam, *Macoma balthica*, alters the erodability of the bed sediment. The concentration of chlorophyll a in the surface sediment (which is an indicator of microphytobenthos density) alters the critical erosion velocity. External sediment supply is specified as an offshore suspended matter concentration. The model is applied within Spurn Bight (Humber Estuary, UK). The effects of various tide heights, biota densities, and external suspended sediment concentrations are investigated. Offshore sediment supply dominates the net deposition below midtide level, but factors affecting intertidal sediment erosion and deposition become important at higher shore levels. Changes in erosion or deposition caused by natural variation in biota densities are as large as those caused by changes in tidal range and currents over a spring-neap cycle, or by doubling external supply. Seasonal variations in densities of stabilizing microphytobenthos can alter the magnitude of net deposition on the upper shore by a factor of two. Interannual variation in numbers of bioturbating clams can change net deposition by a factor of five. These results show that biotic influences on transport of sediment within the intertidal zone are significant and will play a role in determining sediment budgets over tidal to monthly timescales.

Keywords: British Isles, Humber Estuary, Sediment, Transport, Erosion, Model, Studies, Experimental, Data, Tidal, Currents, Deposition, Benthos, Intertidal, Areas, Clams, Budgeting, Estuaries, Sedimentation, Biotic factors, Abiotic factors, Intertidal environment, Bioturbation, Marine molluscs, Population density, Phytobenthos, Burrowing organisms, Macoma balthica, ANE, British Isles, England, Humberside, Humber Estuary, Baltic Macoma..

3.2 Geoduck

Beattie, J.H., B. Blake, and D. Herren. 1995. **Improving survival of planted juveniles of the geoduck clam (*Panopea abrupta*) using predator exclusion devices.** Triennial Meeting of Fish Culture Section of American Fisheries Society, World Aquaculture Society Nation Shellfisheries Association. 14(1):260.

Washington Department of Fish and Wildlife (Formerly Washington Department of Fisheries) personnel have been culturing the geoduck clam since the 1970s. Staff at the Point Whitney Laboratory developed techniques for larval and juvenile culture. During the 1980s the scale of culture expanded to the production of millions of 10 mm seed geoduck per year. The seed were planted into subtidal areas by broadcasting them from the stern of a slowly moving boat. Upon reaching the substrate most of the juvenile geoducks dug in successfully without being preyed upon. Two years after these broadcast plants, dive surveys for young clams revealed few had survived. In almost every case the survival estimate was less than 1 percent. In searching for a cause for this poor survival, Point Whitney biologists performed predator experiments. The most striking results of these experiments revealed that during a 48 hour exposure period, crabs (*Cancer productus* and *Cancer gracilis*) would consume 30 to 40% of all

sizes of geoduck seed tested. In testing various methods of protecting the seed from predators, hatchery personnel found an effective deterrent to predation: vertically installed PVC pipe. In 1991 on 4 State Park beaches, one foot long sections of 4-inch and 6-inch diameter PVC pipe provided protection for the geoduck seed. Average survival from these intertidal plants varied from 20 to 70% ten months after planting. Another type of protective device tested in subtidal areas was paper composite tree planting cones. These cones also proved to be effective in protecting the geoduck juveniles from predation. Recovery of geoducks planted in cones averaged 20% while recovery of geoducks planted without protection was 0%. (DBO)

Keywords: aquaculture, techniques, survival, clam, culture, predation, Panopea abrupta, Bivalvia, Cancer, productus, Crustacea, general aquaculture.

Bradbury, A., and J. V. Tagart. 2000. **Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. II. natural mortality and equilibrium yield.** Journal of Shellfish Research. 1963-70.

The natural mortality rate of geoduck clams, *Panopea abrupta* (Conrad, 1849), was estimated from data collected at 14 previously unfished sites in Washington State in order to predict the potential yield of the commercial fishery under various harvest rate strategies. The instantaneous rate of natural mortality (M) estimated by the catch curve method for geoducks of ages 20-98 was 0.0226 y^{-1}. Other important life history parameters - growth, schedules of sexual maturity, weight-at-age, and fishery selectivity - were estimated from the literature and file data. These parameter estimates were used to drive an age-based equilibrium yield model that predicted yield per recruit (YPR) and spawning biomass per recruit (SPR) over a range of fishing mortality rates. The model produced values of the instantaneous fishing mortality rate (F) for five commonly used constant harvest rate strategies. The fishing mortality rate producing maximum YPR (F_{max}) ranged from 0.053-0.100 depending on the site growth parameter, but reduced SPR to 35-37% of the unfished level. Three harvest rate strategies that reduced SPR to either 35%, 40%, or 50% of the unfished level were also evaluated, with F-values ranging from 0.018 to 0.036. The $F_{40\%}$ strategy, currently adopted by Washington managers, was achieved with F = 0.028 (averaged over all sites), corresponding to an annual harvest rate of 2.7% of the exploitable biomass. The model was most sensitive to estimates of M, Whereas growth, fishery selectivity, and sexual maturity schedules had relatively little effect on yield or SPR. Apparent shifts in recruitment during the past 30-45 y may have biased the estimate of *M*. Direct estamets of *M* and recruitment are therefore a high research priority if the model outputs are to remain useful.

Keywords: Geoduck, Panopea abrupta, population, species culture.

Cain, T.A. 1995. T**he Effects of Geoduck Fishing on *Cancer magister* and *Cancer productus* in Hood Canal, Washington.** Appendix 2.

No abstract identifying these species for this category.

Cheney, D. 2007. **Summary of Pacific Shellfish Institute 2006 Geoduck farm preliminary sampling and sorting studies – Hood Canal and South Puget Sound.** Pacific Shellfish Institute, Olympia, Washington.

During late summer and fall 2006 the Pacific Shellfish Institute (PSI) completed out pre- and post-harvest benthic surveys and other data collections at two commercial geoduck farms. The purpose of these surveys was to provide preliminary data on the effects of geoduck harvest which could be incorporated into a regional biological assessment, facilitate development of a detailed scope of work for farmed geoduck research, and assist in focusing legislative reviews during the 2007 session.

Cole, L., Beattie, J.H., and Chew, K.K. 1991. **Geoducks (*Panope abrupta*) in a sand substrate nursery.** Pp 55-56. In: Nosho, T.Y. and K.K. Chew (eds.), Remote setting and Nursery Culture for Shellfish Growers Workshop Record, WA State Sea Grant Program.

Report considers use of algae that typically coats surfaces (Tetraselmis suicica) and algaes that are typically suspended in the water column (Chaetoceros muelleri) in a sand-based nursery system for juvenile geoducks. Preliminary information suggested that substrate based food supplies translated into better growth in geoducks than did treatments with suspended food supplies. From a physiological perspective, this report was the first to consider pedal palp feeding behavior and unique physiology of post settlement geoduck clams.

Curtis, K.M., V.L. Trainer, and S.E. Shumway. 2000. **Paralytic shellfish toxins in geoduck clams (*Panope abrupta*): variability, anatomical distribution, and comparison of two toxin detection methods.** Journal of Shellfish Research 19(1): 313-319.

The geoduck clam, *Panope abrupta*, is a valuable economic resource in Washington State. Prior to the mid 1970s, the levels of paralytic shellfish poisoning (PSP) toxins in Washington State geoducks were not considered by the Washington State Department of Health (WDOH) to be a risk to public health because the viscera were presumed to be discarded. Recent monitoring information indicates that geoducks accumulate high levels of toxins, primarily in the viscera. The purposes of this study were to determine: (1) the seasonal concentration of paralytic shellfish toxins in geoduck clams at two sites and at two depths within each site; (2) the variability of PSP toxin levels among individual clams within each site; (3) the anatomical distribution of toxins: and (4) the correlation between two methods for estimating PSP toxins. From the summer of 1997 through the winter of 1998, 12-24 geoducks were collected biweekly from a shallow (7 m) and a deep (17 m) location in each of two tracts in Puget Sound, Washington: Quartermaster Harbor (QH) and Agate Pass (AP). Geoducks, dissected into siphon, mantle, and visceral portions, were assayed separately using the mouse bioassay (MBA), while only the visceral portions were assayed using the receptor-binding assay (RBA). Results indicated that toxin variability between individual clams was high in the shallow areas, with coefficients of variation (CVs) ranging from 20-98%, and lower in the deep areas (CV = 18-62%). In QH, only geoducks from the shallow water had toxin levels greater than the regulatory level of 80 mu g saxitoxinequivalents (STX eq) times 100 g shellfish tissue super(-1), while all geoducks from AP contained toxin above the regulatory level, with clams from shallow water considerably more toxic than those from deep water. Anatomically, the highest concentrations of PSP toxins were localized in the viscera of geoducks. There was a significant positive correlation between toxin levels measured by the MBA compared to values obtained using the RBA (r super(2) = 0.83). The large differences in toxicity between geoducks sampled at different depths and harvest tracts indicate that careful management plans must be designed in order to ensure public health.

Davis, J.P., C. Barenburg, and D. Pederson. 2000. **Burrowing response of juvenile geoducks (*Panopea abrupta*) to changes in temperature and salinity**. Journal of Shellfish Research. 19(1):689.

Geoduck clams, *Panopea abrupta*, are a newly cultured species and the development of geoduck culture techniques, coupled with out planting methods have not been perfected. Environmental parameters likely have a significant effect on the burrowing behavior of clams which in turn may greatly influence the level of survivorship of newly planted seed. The burrowing behavior of three size classes of juvenile geoduck clams was measured in response to exposure to a suite of temperature and salinity conditions. Seed were exposed to all combinations of six temperature (8, 11, 14, 17, 20, & 23 degree C) and six salinity (20, 22, 24, 26, 28, & 30 ppt) treatments. Three different seed classes were tested; small (4.6 mm mean shell length), medium (7.2 mm) and large (9.5 mm) geoducks. All clams were maintained under common conditions prior to testing burrowing response. Results indicate that all seed size classes showed maximal burrowing response at median temperatures (11, 14, and 17 degree C) and higher salinities (26, 28, and 30 ppt). The response for all size classes indicated a proportionate increase in burrowing rate as conditions neared ambient salinity (30-32 ppt). Size was also a significant factor as large and medium seed demonstrated high burrowing response only between 11 and 14 degree C and at higher salinities, and reduced burrowing response at low (8 and 11 degree C) and high (23 degree C) treatment temperatures. The burrowing response of small seed in all treatments was uniformly higher compared to medium and large seed across all temperature and salinity treatments; however as also seen for large and medium sized cohorts, burrowing behavior at salinities less than 26 ppt. was greatly reduced. Avoiding extremes in temperature and in particular salinities less than 26 ppt, even for short periods of time, may significantly increase overall planting success for culture operations.

Keywords: Temperature effects, Salinity effects, Burrowing organisms, Behavioural responses, Clam culture, Marine molluscs, Intertidal environment, Panopea abruptam Pacific geoduck.

Hand, C., and K. Marcus**.** 2004. **Potential impacts of subtidal geoduck aquaculture on the conservation of wild geoduck populations and the harvestable TAC in British Columbia.** Canadian Science Advisory Secretariat.

Geoduck aquaculture is viewed by many as a viable and promising new industry, and there is increasing interest by the shellfish industry to culture and enhance geoduck stocks. Federal and Provincial governments have committed to implement a phased approach to geoduck aquaculture expansion in 2005. This paper was written in response to the need to evaluate the conservation issues for wild geoduck populations and to assess the impact on the commercial fishery that may result from aquaculture activities. The objectives of this paper are to identify the factors that may compromise conservation, evaluate the potential risks and make recommendations for consideration in future decision-making. A summary of current approaches to assess and manage wild geoduck stocks and the underlying conservation strategy for the commercial fishery is provided, along with relevant available information on the genetics of geoducks, and known bio-physical requirements for recruitment and growth. A framework for phased development of aquaculture is outlined, in which site selection criteria are defined which allow a ranking of the level of impact on wild stocks and the existing commercial fishery.

To ensure that conservation objectives for natural geoduck populations are met, impacts of aquaculture need to be incorporated into assessment and management frameworks. It is further recommended that geoduck aquaculture expansion follow a phased-approach that will allow the collection of information on genetic impacts and disease issues as they relate to transfer and transplant of these animals, leading to the development of sound procedures.

Keywords: geoduck, harvest impacts, British Columbia, species culture.

Herren, D. W. 1993. **The effectiveness of predator exclusion tubes for growout of the geoduck clam, *Panopea abrupta*.** Journal of Shellfish Research. 12(1):152.

Although hatchery techniques have been developed to produce geoduck clam seed, field trials for seed growout have met with limited success. Yields of less than 1% lead to a predator study and then to testing various predator exclusion devices. This report describes the success of using biodegradable fiber pulp tubes to protect geoduck seed from predation. Implication of this technique for geoduck culture are discussed.

Keywords: clam, culture, aquaculture techniques, predation, predator, control, aquaculture, equipment, Panopea abruptaspat, seed, aquaculture, fiber pulp, tubes.

Pearce, C.M., Y.X. An, J.M. Blackburn, L.J. Keddy, D.L. Paltzat, and S.W. Williams. 2007. **Intertidal culture of juvenile geoduck clams (*Panopea abrupta*): an examination of predator protection technology and potential environmental interactions.** Pacific Biological Station, Department of Fisheries and Oceans, Canada.

No abstract identifying these species for this category.

WDFW and DNR. 2001. **Commercial Geoduck Fishery, State of Washington, Final Supplemental Environmental Impact Statement.** Washington Departments of Fish and Wildlife and Natural Resources, Olympia.

No abstract identifying these species for this category.

Ruesink, J.L. and K. Rowell, in preparation. **Geoduck clam (*Panopea abrupta*) aquaculture as press and pulse perturbations to eelgrass (*Zostera marina*).**

Experimental study of the effects of geoducks and fertilizer on eelgrass density and growth, and the pace and manner of recovery of small (1 m^2) gaps created in an eelgrass bed. Eelgrass density was depressed in summer by space competition with geoducks; growth rates were not affected. Gaps recovered over 2 years exclusively by Regrowth from the edges. When the geoducks were harvested at the end of the experiment, eelgrass shoot density dropped >70%. The results of this study should not be extrapolated widely because south Puget Sound tends to contain a very sensitive type of eelgrass – small, high-density plants with little sexual reproduction. [Funding: USDA WRAC, Shellfish industry].

Willner, G.B. 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.** Masters Thesis, Evergreen State College, Olympia, Washington.

No abstract identifying these species for this category.

3.3 Mussels

Arzul, G., M. Seguel, and A. Clement. 2001. **Effect of marine animal excretions on differential growth of phytoplankton species**. ICES J. Marine Science. 58(2):386-390.

Five phytoplankton species were cultivated in the presence of different marine animal excretions, and growth rates were compared. Growth of *Chaetoceros gracilis* was stimulated by excretion from the oyster (*Crassostrea gigas*) and inhibited by excretion from the sea bass (*Dicentrarchus labrax*). Growth of *Heterosigma akashiwo* was stimulated by excreta from the mussel (*Mytilus chilensis*) inhibited by excreta from sea bass and salmon (*Salmo salar*), and unaffected by oyster excretions. Growth of *Gymnodinium mikimotoi* was also inhibited by excreta from sea bass and unaffected by oyster excreta. Growth of *Alexandrium catenella* and *A. minutum* was not affected by animal excreta under our experimental conditions. The results indicate that the organic components of dissolved excreta were responsible for the observed effects: stimulators when excreted by shellfish, and inhibitors when excreted by finfish.

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

1. Monocultures of mussels might alter the infaunal benthic community of adjacent and interstitial sediments through provision of a complex habitat, input of organically rich material and larval removal through filter feeding. At a site of commercial seabed mussel cultivation, we aimed to determine the effect of mussels on the infaunal community of an intertidal mudflat at different spatial scales and under different stocking strategies. **2.** Mussels were laid at four different densities (2, 3, 5 and 7·5 kg m−2) on 400-m2 plots in a 4×4 Latin square. Benthic samples were collected within and 10–100 m distant from the cultivation area *c*. 7 months prior to and 18 months after seeding the plots with blue mussels. Benthic community characteristics were related to initial seeding density and to the actual surface area of mussels associated with each set of samples collected within replicate plots. **3.** 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. **4.** Species richness and the abundance of individuals per unit area also declined with increased area of mussel cover. The abundance of cirratulids and amphipods declined strongly with increasing mussel surface area. **5.** Although the species composition and abundance of individual invertebrate species were altered by the presence of mussels, the distribution of individuals among species remained relatively unchanged. **6.** *Synthesis and applications*. Overall, mussel beds changed the infaunal community, but the effects were localized (0–10 m) and not detectable at larger scales (10–100 m). Changes in benthic community composition could be reduced (but not eliminated) by lowering the stocking density of mussels to either 2 or 3 kg m−2. Given the small edge effects associated with cultivated mussel beds, the use of larger mussel beds would be preferable to many smaller mussel beds.

Keywords: community change, ecological impact, large-scale experiment, mussel cultivation, Mytilus edulis.

Bigford, T.E. 1998. **Environmental Challenges Facing the Shellfishing Industry.** NOAA Technical Report NMFS 128.157-163.

North American molluscan fisheries have been traditions since colonial times, but few specifics have been learned about effects of molluscan harvesting and culture on habitats. The relative effects of fishing gear on the seafloor remain an open question, except that government surveys on the benthos have shown that invertebrate populations are abundant and species compositions are diverse in areas where shellfish harvesting has taken place for at least 50 years. Effects of fishing gear are temporary, because even if numbers of associated invertebrates are slightly reduced they rebound when new generations settle. From an environmental viewpoint, oyster culture has modified habitats in a positive way. The presence of transplanted oysters on previously unplanted bottoms has provided much more surface area and a larger number of niches for various invertebrates to inhabit. The washing of silt off beds of shells to clean them for receiving sets of oyster spat injects silt into the water, but accounts for an inconsequential amount compared with the quantity lifted during every lengthy wind storm. Mussel culture using rafts has brought about large changes in the ecosystem of the Ria de Arousa in Spain. The infauna macrobenthos is depauperate, but the biomass of the megafauna has increased due to the food contribution provided by the mussels and their associated epifauna. Similar effects probably have taken place in areas of North America and Europe where mussels are grown on suspended lines. Consumer interest in shellfish products is growing and more shellfish will be grown by culture enterprises in the future. Facilities designed for shoreside construction are likely to elicit concerns about habitat degradation, particularly if the locations are underdeveloped. The shellfish industry needs to be wary of secondary impacts of construction and operation on water quality, but the industry can expect to be allied with other coastal enthusiasts arguing for water and sediment quality standards that will support shellfish culture.

Keywords: mussels, oysters, water quality, invertebrate, impacts, benthos, rafts, mussel, rafts, silt, sedimentation, ECOP.

Campbell, D.E., and C.R. Newell. 1998. **MUSMOD copyright, a production model for bottom culture of the blue mussel, *Mytilus edulis L*.** Journal of Experimental Marine Biology and Ecology. 219(1-2):171-203.

A mussel production model, MUSMOD copyright was developed to seed bottom culture lease sites in Maine to their carrying capacity. The process of model development is demonstrated with three models: (a) an initial conceptual model, (b) an aggregated model driven by the tidal exchange of food particles and (c) MUSMOD copyright, the final model driven by food supplied in the tidal flow of water across a site. The final model predicts mussel production using the concentrations of phytoplankton and detritus in the surface water, detritus quality, tidal current speed, water depth and temperature. Field measurements of several quantities (e.g., clearance, respiration, growth rates for shell and meat, food concentration gradient, and temporal feeding pattern) were obtained to evaluate and calibrate the final model. Model refinement using iterations of modeling and field work demonstrated the importance of food quantity and quality in explaining the observed patterns of mussel growth. Food quantity explained the first-order growth pattern, but it was necessary to account for the quality of the food to explain the second-order details of growth. Vertical mixing supplied the majority of new food particles, however, particles settling over the mussel bed during slack water accounted for 33% of the phytoplankton and 45% of the detritus entering the feeding layer from above. A sensitivity analysis of the effects of seed density on mussel growth using MUSMOD copyright identified the optimum carrying capacity for three Maine lease sites. Seeding mussels during the optimum time period

(May to early July) resulted in the harvest of marketable mussels from 40 mm seed in 8 months for a high food year and in 13 months when the food supply was low. Characterizing the food supply using particulate organic matter, POM, alone was not sufficient to explain mussel growth in the detail necessary to answer many farm management questions.

Keywords: Mussel culture, Bottom culture, Seeding (aquaculture), Food availability, Suspended particulate matter, Particulate organic matter, Detritus, Particulate flux, models, growth, USA, Maine, aquaculture, Mytilus edulis, ANW, USA, Maine, phytoplankton, seed, density, food quality, Edible blue mussel.

Cayer, D., M. MacNeil, and A.G. Bagnall. 1999. **Tunicate fouling in Nova Scotia Aquaculture: A new development.** Journal of Shellfish Research. 18327.

A significant fouling problem with the tunicate *Ciona intestinalis* developed on a suspended blue mussel (*Mytilus edulis*) aquaculture site during the 1997 growing season. *Ciona intestinalis* has subsequently colonized several aquaculture sites at varying levels of intensity. The infestation has had a serious, negative impact on at least one farm and could potentially affect the economic viability of other operations. The Aquaculture Association of Nova Scotia and the Nova Scotia Department of Fisheries and Aquaculture have been networking internationally, documenting the impacts of *C. intestinalis* on aquaculture production and searching for strategies to manage its effects. Information has been collected and contacts have been made around the world--a solution has not been found. Methods to manage this fouling problem will be species and site specific. Attempts to remove the tunicates have been cost prohibitive on a large scale. Farm management strategies must be developed as an economically viable solution. Part of this process involves studying the behaviour of *C. intestinalis* and its interactions with Nova Scotia operations. *Cliona intestinalis* biology and ecology are also being examined in an effort to prevent the further spread of these tunicates to previously unaffected aquaculture sites and to assist operations with implementing mitigative measures.

Keywords: Fouling organisms, Mussel culture, Pest-control, Marine aquaculture, Mytilus edulis, Ciona intestinalis, Ascidiacea, ANW, Canada, Nova Scotia, Ascidians, Sessile tunicates, Edible blue mussel.

Dankers, N., and D.R. Zuidema. 1995. **The role of the mussel (*Mytilus edulis L.*) and mussel culture in the dutch Wadden Sea.** Estuaries. 18(1):71-80.

Mussel populations (*Mytilus edulis*) in the Dutch Wadden Sea (intertidal mussel beds, subtidal beds and culture plots), the culture methods, the extent of mussel culture, and the ecology of the mussel are described. Mussels filter suspended matter from the water column and deposit it as feces and pseudofeces. Mussel beds consume large amounts of phytoplankton and speed up the cycle of production and breakdown of organic matter. There are indications that the consumption of phytoplankton can lead to food shortage for several animal groups. Mussels serve as an important food source for a wide range of organisms (e. g., starfish, eider ducks, and oystercatchers). Because mussel culture increased the mussel biomass in the Dutch Wadden Sea, the impact also increased. The most obvious impact of the culture is the dredging of seed mussels. Overexploitation of intertidal mussel and cockle beds and bad spatfall of both mussels and cockles since 1988 had a negative impact on bird populations. The extent of positive and negative aspects of mussel culture depends on natural and human influences. The negative

aspects may (partly) be overcome by appropriate measures.

Keywords: mussel culture, Mytilus edulis, species, culture, Wadden Sea.

DePauw, N., and J. -comps Joyce. 1991. **A methodology for the assessment of the impact of suspended mussel culture on traditionally exploited areas in the Bay of L'Aiguillon (Atlantic coasts of France).** Aquaculture and the Environment. (14):29.

Among the current techniques now available for the mussel culture, the traditional method of culturing the mussels on poles ("bouchots method") is still widely in use along the intertidal, sheltered areas of the French coasts. It resulted in a production averaging 55 000 tonnes for the last years. However, this country still imports roughly the same quantity, and there is a will for the development of this production. The implementation of long-lines in the Mediterranean Sea have already resulted in an annual production of 6 000 tonnes, and trials have been conducted in Atlantic sites, such as the Bay of l'Aiguillon. While this area produces 7 000 to 10 000 tonnes per year, large surfaces of deep water are unexploited, and may represent potential sites for suspended cultures. Therefore the preliminary tests being successful, a project of 200 long-lines of 200 metres has been designed, which may result within five years in a quantity of 5 000 tonnes of mussels. The questions are whether these mussels will compete for the available food, with the existing sites of production of mussels and oysters, within the same bay, and to assess the impact on the marine environment.

Keywords: analytica –techniques, environmental impact, mussel culture, off-bottom culture, mathematical models, ecosystem, disturbance, France.

Dolmer, P., and R.P. Frandsen. 2002. **Evaluation of the Danish mussel fishery: suggestions for an ecosystem management approach.** Helgoland Marine Research. Vol. 56, no. 1, pp. 13-20. IS: ISSN 1438-387X.

In Limfjorden, Denmark, an extensive mussel fishery exploits the wild stocks of *Mytilus edulis* with annual landings of 80,000-100,000 t of mussels. During the last 10 years the impact of mussel dredging on the ecosystem has been studied, including the effect of resuspension of sediment and nutrients and the impoverishment of in- and epi-fauna assemblages. Furthermore, dredging changes the physical structure and complexity of the seabed which affects mussel growth and interactions among zoobenthic species. The blue mussel constitutes the dominant fraction of the zoobenthic suspension feeders, and is important for the transport of material and energy from the pelagic to benthic systems and the control of phytoplankton biomass. In order to evaluate the impact on clearance capacity of a reduction in mussel densities due to mussel dredging, mussel filtration activity measured in situ has been related to the mixing of the water column and the amount of near-bed phytoplankton. Fishery practice for mussel dredging in Limfjorden is discussed in relation to its known impact on the ecosystem and the ecological role of the mussels, and modifications towards an ecosystem management approach and a more sustainable fishery are suggested. The suggested modifications include: a fishery practice where the mussel beds are thinned out when the mussels have attained good quality, and a transplantation practice of mussels from areas with a high mortality to areas with a high growth rate. Both practices intensify the production in a certain area, leaving other areas open for alternative production or for permanent closure for the benefit of the benthic flora and fauna. In addition, other shellfish species represent interesting new resources for fishing or aquaculture.

Habitat restoration, such as the relaying of mussel shells from the mussel industry, is another important management tool that should be included in an ecosystem management approach of the mussel fishery.

Geret, F., A. Jouan, V. Turpin, M. J. Bebianno, and R.P. Cosson. 2002. **Influence of metal exposure on metallothionein synthesis and lipid peroxidation in two bivalve mollusks: the oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*).** Aquatic Living Resources. Vol. 15(no. 1):pp. 61-66.

The impact of metals (silver, cadmium, copper, mercury and zinc) on metallothionein (MT) and malondialdehyde (MDA) levels of the oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*) was studied after 4 or 21 days of metal exposure. Moreover, total protein levels were determined. After 4 days of metal exposure, although C. gigas and M. edulis accumulated cadmium and mercury concentrations in the gills and digestive gland, no significant variation of total protein level was occurred. After 21 days of exposure, metals were bioaccumulated in the gills and the digestive gland of both mollusks. A decrease of total protein concentrations in the gills of oysters and the digestive gland of mussels and an increase on metallothionein concentrations in the gills of both mollusks were observed. An increase of MDA levels was noticed for the gills and the digestive gland of mussels exposed for 21 days to either cadmium, silver or mercury whereas a decrease of MDA levels was observed in the gills of the oysters exposed for the same time to the same metals. The levels of proteins, MDA and MT were metal, species or organ dependent.

Keywords: Metals, Proteins, Metallothioneins, Pollution effects, Lipids, Animal physiology, Crassostrea gigas, Mytilus edulis, Bivalvia malondialdehyde.

Heasman, K.G., G.C. Pitcher, C.D. McQuaid, and T. Hecht. 1998. **Shellfish mariculture in the Benguela system: Raft culture of *Mytilus galloprovincialis* and the effect of rope spacing on food extraction, growth rate, production, and condition of mussels.** Journal of Shellfish Research. 17(1):33-39.

Saldanha Bay forms part of the Benguela upwelling system. Here, the mussel *Mytilus galloprovincialis* is farmed by means of floating raft culture. The relationship between the food removed by mussels and the growth, condition, and production of mussels cultured on rafts with two different rope spacings was investigated. The dense culture of mussels on rafts is responsible for local limitation in food supply at the raft scale. Food depletion through a raft increased both with the age of the mussel ropes suspended from it and with decreased rope spacing and was a function of increased feeding and greater retardation of water exchange through rafts with higher mussel mass. Mussel growth rates in summer were 30% greater than in winter, and during summer, growth rates were a further 8% higher on rafts with increased rope spacing. The harvest of marketable mussels was 30% higher from ropes suspended at the increased spacing. Consequently, the harvest of mussels was 9% higher from rafts with the lower rope density.

Keywords: Marine aquaculture, Mussel culture, Aquaculture techniques, Off-bottom.

Inglis, G.J., and N. Gust. 2003. **Potential indirect effects of shellfish culture on the reproductive success of benthic predators.** Journal of Applied Ecology. Vol. 40, no. 6, pp. 1077-1089. Dec. IS: ISSN 0021-8901.

1. Environmental assessments of coastal aquaculture are concerned mostly with direct impacts on natural assemblages in the vicinity of shellfish or fin-fish farms. As the size and density of farmed sea space increases, there is greater potential for indirect effects on food webs beyond the immediate culture area. 2. We investigated the potential indirect effects of long-line mussel Perna canaliculus farms on the demography of an important benthic predator, the sea star Coscinasterias muricata. Surveys beneath four active farms, an abandoned farm and three unfarmed areas of seabed in Pelorus Sound, New Zealand, described the direct effects of mussel culture on the distribution and abundance of sea stars and other benthic consumers. These data were used to calibrate a model that simulated the fertilization success of sea star populations in farmed and unfarmed areas of the bays. 3. Deposits of living mussels and mussel shells covered up to 55% of the seafloor beneath farm sites, but were absent from soft sediments at unfarmed sites. Mean densities of sea stars were up to 39 times larger at active farm sites than in unfarmed areas and were correlated with the abundance of living mussels on the seafloor. 4. Within individual farms, the distribution of sea stars was highly aggregated at small spatial scales, with most (63%) individuals occurring within 2 m of their nearest neighbor. In unfarmed areas, sea stars were widely dispersed (< 1 80 m super(-2)). 5. Our simulations indicate that, because of the extremely clumped distributions of sea stars, spawning individuals at farm sites would on average have substantially greater fertilization success (c. 90% of eggs) than those foraging in areas where farms are absent (<< 2% of eggs), and total zygote production could be as much as 1500 times greater than in unfarmed areas. 6. Synthesis and applications. This study demonstrates the potential for significant bottom-up effects of aquaculture on surrounding ecological assemblages. If, as has been suggested, sperm limitation is a major constraint on recruitment of asteroids and other invertebrate predators, supplemental provisioning from increased farm development could result in occasional outbreaks of populations, over a broader area than the farmed location. Without appropriate monitoring such events are likely to be dismissed as rare, natural phenomena rather than a consequence of shellfish culture.

Keywords: aquaculture impacts, bottom-up control, echinoderms, fertilization models, top-down control.

Neiland, S., and T. McMahon. 1999. **A Benthic Survey of Inner Bantry Bay.** Fisheries Bulletin No. 18 – 1999, The Marine Institute, Dublin, Ireland.

In February 1993 sediment samples were collected from a total of 18 stations in Bantry Harbour, Glengarriff Harbour and along the north shore of Whiddy Island. The samples were analysed for grain size, organic carbon content and the abundance of benthic infauna. The benthic infauna were identified to family level. The sediments in Bantry Harbour and Glengarriff Harbour were comprised of fine particles with typically >80% of the dry weight being in the silt/clay (<63 μm) fraction. In contrast, the sediments close to Whiddy Island contained relatively high amounts of coarser material. In Bantry Harbour a total of 53 families with 742 individuals were identified from the ten stations sampled. Of the 53 families identified, 21 were Polychaeta, 6 Bivalvia, 7 Gastropoda, 3 Echinodermata, and 16 Crustacea. A total of 31 families with 491 individuals were identified from the five stations sampled in the Glengarriff Harbour area. Of these 16 were Polychaeta, 4 were Bivalvia, 3 were Gastropoda, 1 was Echinodermata, and 7 were Crustacea. From the three stations sampled in the vicinity of Whiddy Island 47 families with 461 individuals were identified. Of these 23 were Polychaeta, 8 Bivalvia, 4 Gastropoda, 2 Echinodermata, and 10 Crustacea. In Bantry Harbour and Glengarriff Harbour

cirratulid polychaetes were dominant and the benthic infaunal composition was indicative of stressed environmental conditions. In contrast, the sediments close to Whiddy Island exhibited a very healthy faunal composition with no one family predominating and high numbers of amphiuroid echinoderms were recorded from these sampling stations.

Quijón, P., E. Jaramillo, and M. Pino. 1996. **Macroinfaunal assemblages associated with mussel and clam beds in an estuary of southern Chile**. Estuaries 19: 62-74.

Samples were collected from September 1990 to 1992. at three subtidal sites of the middle reaches of the Queule River estuary, southern Chile, to analyze the spatial and temporal variability of the macroinfauna inhabiting substrata with different abundances of bivalves. In addition, water and sediment samples were obtained to study the relationships between temporal variability in macroinfaunal abundances, physical factors, and chlorophyll *a* content. Temperature, salinity, and chlorophyll *a* showed a rather strong seasonal variability but slight between-site differences. Sediment characteristics and bivalve abundances, by contrast, exhibited little temporal variability but large differences between sites. The macroinfauna was primarily represented by polychaetes, *Primospio (Minuspio) patagonica* being dominant in the three areas. Most dominant species showed similar trends of temporal variability, with maximum abundances recorded during spring and fall. The appearance of recruits was restricted to the summer with little difference among sites. Multiple regression analyses showed that the temporal variability of macroinfaunal adults and recruits, was primarily associated with variability in salinity and water temperature, respectively. Spatial variability of these organisms was also explained by variations in these factors, together with those of sediment texture and organic matter content. No evidence of interactions (significant relationships) was found between the abundances of bivalves and those of the macroinfauna, nor among macroinfaunal organisms.

Richard, L. 2004. **Balancing marine aquaculture inputs and extraction: Combined culture of finfish and bivalve molluscs in the open ocean.** Bulletin of Fisheries Research Agency (Japan). no. Sup. 1, pp. 51-58. IS: ISSN 1346-9894.

Enrichment of the water column with dissolved nutrients and of bottom sediments with organic matter as a result of culturing finfish in sea cages have been identified as real and potential environmental impacts of fish culture. While severe impacts have been documented in shallow, poorly flushed waters, proper siting of sea cage operations generally results in only minor localized impacts to the benthic community on the sea floor directly beneath the cages. None the less, the perception of environmental groups and regulatory agencies in the U.S.A. that fish waste and uneaten feed will impact the marine environment regardless of siting has affected the expansion of existing sites and the establishment of new sites. In order for the industry to expand to meet the growing demand for seafood, measures to mitigate these impacts must be taken. One possible solution is to balance inputs of feed with extraction of biomass of organisms such as marine plants and bivalve molluscs that do not require external feed application. In 1999, the University of New Hampshire established the Open Ocean Aquaculture Demonstration Project. Funded by the National Oceanic and Atmospheric Administration, the project was designed to provide a commercial scale demonstration and research site for open ocean aquaculture in the northeast U.S.A. The project is an integrated, multi-disciplinary, regional effort that includes biology, oceanography, engineering, sociology, economics, technology transfer, and education. While the development of technologies for finfish and shellfish

production in offshore environments is central to the mission of the project, demonstration of the environmental sustainability of open sea culture is critical to the social acceptance of industry development. Since 1999, the project has produced harvests of several species of finfish using submersible sea cages and six crops of molluscan shellfish (primarily blue mussels) using submerged longlines in close proximity to the sea cages. While not considered true polyculture, the harvest of the filter feeding bivalve molluscs represents a net removal of nitrogen, carbon and phosphorus that can be used in mass balance to offset the addition of these nutrients from finfish feeding. In this paper, data the potential for balancing inputs associated with feed application and fish wastes with extraction of fish and bivalve biomass will be examined.

Roycroft, D, Kelly, T.C. and L.J. Lewis. 2004. **Birds, seals and the suspension culture of mussels in Bantry Bay, a non-seaduck area in Southwest Ireland.** Estuarine, Coastal and Shelf Science. Vol. 61, no. 4, pp. 703-712. Dec. IS: ISSN 0272-7714.

Concerns about the environmental impacts of mariculture have grown in recent years in response to the rapid expansion of the industry. The blue mussel (*Mytilus edulis*) is the main product of shellfish mariculture in the Northeast Atlantic and Baltic Sea, with approximately one third of the harvest cultured using suspended longlines within sheltered marine areas. 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, employing a simultaneous study of culture and control sites. The study spanned a 20-month period (from November 2001 to August 2003) and encompassed six sites in Bantry Bay (Southwest Ireland).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 although control sites were generally more diverse than mussel sites, the latter particularly dominated by large numbers of Laridae. 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. Seasonal patterns of abundance were similar in mussel and control sites, with peak numbers of most species groups occurring in spring. Mussel suspension culture does not appear to have an adverse effect on the abundance of seabirds or common seals in this area. The safe perching platforms provided by suspension culture floats, combined with a number of other factors, contribute to an increased abundance of a number of seabird species, particularly Laridae. The possible interactions between vertebrate predators and mussel suspension aquaculture are discussed and possible explanations for the increased seabird abundance observed in these areas are offered.

Smit, C.J., N. Dankers, B.J. Ens, and A. Meijboom. 1998. **Birds, mussels, cockles and shellfish fishery in the Dutch Wadden Sea: How to deal with low food stocks for eiders and oystercatchers? Ecosystem Research in the Wadden Sea Area.** International Scientific Wadden Sea Symposium, Norderney, Germany, 5-8 November 1996. 29(1-6):141-153.

Intensive fishing in the Dutch Wadden Sea in the late 1980s and 1990, in combination with the effects of storms and ice and low spatfall, has led to an almost complete disappearance of intertidal mussel beds in 1990. Since then, this habitat type has re-established in only very few places, covering some hundreds hectares at the most. Lack of good spatfall in the late 1980s also resulted in low cockle stocks. These stocks were further reduced due to heavy mortality in the 1995/96 winter. These developments yielded very low food stocks for shellfish eating birds in some winters. This paper describes the fishery policy which came into force since 1993 and the

effects the low food stocks have had on Eiders (Somateria mollissima) and Oystercatchers (*Haematopus ostralegus*) which are dependent on cockles and mussels. Eiders suffered higher mortality in 1991 and partly emigrated to alternative feeding areas on the North Sea and German Wadden Sea. Oystercatchers suffered higher mortality as well, were found in lower numbers in the Dutch Wadden Sea and in higher numbers in inland feeding areas. This information, together with a comparison of quantitative data on available food stocks and food consumption by birds, indicate that in some winters the number of shellfish eating birds has exceeded the carrying capacity of the Dutch Wadden Sea. Alternative food sources, such as *Macoma balthica, Mya arenaria, Scrobicularia plana, Ensis americanus, Nereis spp*. and *Arenicola marina* cannot compensate for low mussel and cockle stocks. Before 1990, intertidal mussel beds must have acted as an important alternative food source. In the current situation, with hardly any intertidal mussel beds in the Dutch Wadden Sea, cockles represent the major food source, especially in winter. Since cockle stocks can be very low in some years they are an unreliable food source at the same time. Intertidal mussel beds represent a winter resistant and a more reliable food source. These considerations are important viewpoints in the discussion on a future fishery policy for the Dutch Wadden Sea. The most important conclusions from the present analysis is that re-establishment of intertidal mussel beds in the Dutch Wadden Sea is essential to allow the area to play its role as vitally important wetland in the East Atlantic flyway. In order to achieve this goal future fishery on intertidal mussel beds should be highly restricted.

Keywords: Fishing effort, Intertidal environment, Food availability, Marine birds, Mussel fisheries, Quota regulations, Haematopus ostralegus, Somateria mollissima, Mytilus edulis, ANE, Wadden Sea, ANE, Netherlands, storm surges, ice cover, spattotal mortality, predation, Macoma balthica, Mya arenaria, Scrobicularia plana, Ensis americanus, Nereis, Arenicola marina, Eurasian oyster catcher, Common eider Edible blue mussel.

3.4 Oysters

Arzul, G., M. Seguel, and A. Clement. 2001. **Effect of marine animal excretions on differential growth of phytoplankton species**. ICES J. Marine Science. 58(2):386-390.

Five phytoplankton species were cultivated in the presence of different marine animal excretions, and growth rates were compared. Growth of *Chaetoceros gracilis* was stimulated by excretion from the oyster (*Crassostrea gigas*) and inhibited by excretion from the sea bass (*Dicentrarchus labrax*). Growth of *Heterosigma akashiwo* was stimulated by excreta from the mussel (*Mytilus chilensis*) inhibited by excreta from sea bass and salmon (*Salmo salar*), and unaffected by oyster excretions. Growth of *Gymnodinium mikimotoi* was also inhibited by excreta from sea bass and unaffected by oyster excreta. Growth of *Alexandrium catenella* and *A. minutum* was not affected by animal excreta under our experimental conditions. The results indicate that the organic components of dissolved excreta were responsible for the observed effects: stimulators when excreted by shellfish, and inhibitors when excreted by finfish.

Beattie, H.J. 1985. **Effects of growth and mortality differentials on production among selected stocks of the pacific oyster *Crassostrea gigas* (thunberg).** Journal of Shellfish Research. 5(1):49.

A selective breeding program to establish stocks of oysters which would have high survival during summer mortality periods was established in 1976. Oysters produced at the

University of Washington Shellfish Laboratory, Manchester, WA, have exhibited variable survival and growth. In 1982, in Mud Bay, WA, 24 groups of oysters from our experimental selection project experienced survival of 60 to 90% while the control group of wild nonselected oysters showed less than 40% survival. Mean wet weights of the oyster meats, however, indicated that most of the experimental oysters were smaller than the controls. Inbred groups were particularly small. A production comparison was made by multiplying the mean wet weight by the percent survival. In all cases, except two of the inbred groups the production potential of each experimental group was higher than the controls. In addition, four of the experimental groups had mean wet-meat weights comparable to the controls and also exhibited high (80 to 90%) survival. Additional breeding experiments have been conducted with these four groups.

Keywords: summer, oyster, mortality, crassostrea gigas, pacific oyster, general aquaculture.

Bigford, T.E. 1998. **Environmental Challenges Facing the Shellfishing Industry.** NOAA Technical Report NMFS 128.157-163.

North American molluscan fisheries have been traditions since colonial times, but few specifics have been learned about effects of molluscan harvesting and culture on habitats. The relative effects of fishing gear on the seafloor remain an open question, except that government surveys on the benthos have shown that invertebrate populations are abundant and species compositions are diverse in areas where shellfish harvesting has taken place for at least 50 years. Effects of fishing gear are temporary, because even if numbers of associated invertebrates are slightly reduced they rebound when new generations settle. From an environmental viewpoint, oyster culture has modified habitats in a positive way. The presence of transplanted oysters on previously unplanted bottoms has provided much more surface area and a larger number of niches for various invertebrates to inhabit. The washing of silt off beds of shells to clean them for receiving sets of oyster spat injects silt into the water, but accounts for an inconsequential amount compared with the quantity lifted during every lengthy wind storm. Mussel culture using rafts has brought about large changes in the ecosystem of the Ria de Arousa in Spain. The infauna macrobenthos is depauperate, but the biomass of the megafauna has increased due to the food contribution provided by the mussels and their associated epifauna. Similar effects probably have taken place in areas of North America and Europe where mussels are grown on suspended lines. Consumer interest in shellfish products is growing and more shellfish will be grown by culture enterprises in the future. Facilities designed for shoreside construction are likely to elicit concerns about habitat degradation, particularly if the locations are underdeveloped. The shellfish industry needs to be wary of secondary impacts of construction and operation on water quality, but the industry can expect to be allied with other coastal enthusiasts arguing for water and sediment quality standards that will support shellfish culture.

Keywords: mussels, oysters, water quality, invertebrate, impacts, benthos, rafts, mussel, rafts, silt, sedimentation, ECOP.

Brooks, K.M. 1993. **Impacts on benthic invertebrate communities caused by aerial application of carbaryl to control burrowing shrimp in Willapa Bay, WA.** Journal of Shellfish Research. 12(1):146.

The broad spectrum pesticide carbaryl is used to control burrowing shrimp (*Callianassa californiensis* and *Upogebia pugettensis*) on oyster beds in Willapa Bay and Gray's Harbor

Washington. These shrimp can liquefy the substrate making it too soft and unstable to support oyster culture. In addition to providing a substantial portion of U.S. oyster production, these estuaries are important nurseries for numerous valuable fisheries. An understanding of the short and long term impacts to the invertebrate food web is essential to developing an Integrated Pest Management Plan for long term shrimp control while maintaining the estuaries other important ecological functions. Epibenthic and benthic invertebrates were sampled, by epibenthic pump and modified van Veen dredge, two days before and two, fourteen, and fifty-one days following aerial application. Results indicate significant short term impacts to arthropods on a species specific basis. Some important salmonid prey species suffer significant decreases immediately following application. Other, closely related species appear very tolerant. Within 51 days most populations recovery to or exceed pre-spray numbers. However, some species did not recover within the period of observation. This information is essential to developing a long term integrated pest management program to control burrowing shrimp with minimal impacts on non-target species.

Keywords: pest control pesticides, environmental impact, zoo benthos, Callianassa californiensis, Upogebia pugettensis, INE, USA, Washington,,Willapa Bay Invertebrata, oyster culture, burrowing organisms, USA, Washington, Willapa Baynon, target species.

Buhle, E.R. and J.L. Ruesink. **Impacts of invasive oyster drills on Olympia oyster (*Ostrea conchaphila* Carpenter) recovery in Willapa Bay, Washington, USA.** Journal of Shellfish Research, in review.

Includes estimates of feeding rates on both cultured and native oysters, showing preferences for smaller oysters and per capita consumption rates of ~2 oysters/week.

Capone, D. G., D. P. Weston, V. Miller and C. Shoemaker. 1996. **Antibacterial residues in marine sediments and invertebrates following chemotherapy in aquaculture.** Aquaculture. 145(1-4):55-75.

Salmon net-cage culturists in the USA use oxytetracycline, and to a lesser extent Romet registered 30 and amoxycillin, to prevent or treat bacterial disease. This study examined the environmental fate of oxytetracycline and Romet registered 30 at three farm sites and in flow-through, sediment microcosms dosed with antibacterials at rates intended to mimic farm conditions. The frequency of detection of oxytetracycline in sediments beneath the farms paralleled drug usage, with residues rarely detected beneath a farm that used very little oxytetracycline (8.5 kg active ingredient), and concentrations commonly between 0.5 and 4 mu g g-1 at a farm that used 186 kg in a single prophylactic treatment period. The presence of oxytetracycline residues in surficial and subsurface sediments even before that treatment indicated persistence since at least the prior summer (10 months previous) or possibly longer. The area of sediments containing measurable oxytetracycline residues was very localized, however, with residues detectable only under the cages and to a distance of 30 m, but absent from a 100 m site. In laboratory microcosms, one-fourth to one-half of the oxytetracycline remained in microcosm sediments after 60 days, and the one treatment in which loss of the drug approximated an exponential curve indicated a 36-day half-life. Sulfadimethoxine and ormetoprim, the active ingredients in Romet registered 30, appeared to be very short-lived in marine sediments, based on preliminary data. Residues of both drugs at concentrations slightly above the analytical level of detection were found in one microcosm 2 days after the cessation of

treatment, but no residues were found in microcosms 22-34 days after treatment or 21-62 days after treatment at two farm sites. We also collected crabs and oysters from the area surrounding the one farm that relied upon antibacterials most heavily. No more than trace oxytetracycline residues (about 0.1 mu g g-1) were found in oysters (*Crassostrea gigas*) or Dungeness crab (*Cancer magister)* collected under the farm, but about half the red rock crab (*Cancer productus*) collected under the cages during and within 12 days of oxytetracycline treatment contained oxytetracycline in meat at concentrations of 0.8 to at least 3.8 mu g g-1, well in excess of the US Food and Drug Administration limit for commercially sold seafood of 0.1 mu g g-1.

Keywords: disease, control, antibiotics, environmental impact, aquaculture effluents, pollution effects, sediment pollution, Salmonidae cage culture, bioaccumulation, oxytetracycline, Romet amoxycillin.

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.** In: Benaka, L.R. (Ed.), Fish Habitat: Essential Fish Habitat and Rehabilitation. Amer. Fish. Soc., Symp. 22(438–454).

No abstract identifying these species for this category.

Coen, L.D., E.L. Wenner, and D.M. Knott, et al. 1997. **Intertidal oyster reef habitat use and function: What have we learned after two years?** Journal of Shellfish Research. 16(1):336.

In 1994, we initiated a long-term Oyster Habitat Study (OHS) to examine the importance of intertidal oyster reefs in southeastern estuarine ecosystems. We utilized an experimental approach, constructing three replicate experimental reefs (each similar to 24 m super(2)) at each of two sites, paired with equivalent-sized natural reefs to better understand habitat development and functioning. One site is "undeveloped" and open to harvesting; the other is a "developed" area adjacent to a marina and closed to harvesting. We have now completed two years of sampling and a preliminary analysis of the transient and resident reef fauna collected and enumerated since 1995. We have also begun to analyze an extensive long-term environmental and oyster life history dataset (e.g., recruitment, disease onset in SPF-oysters, mortality and growth, monthly intensity and prevalence of Dermo and MSX) on the experimental, as well as adjacent natural reefs. For resident sampling, within-site species richness appears to be similar between experimental and natural reefs six months post-construction. Faunal biomass values showed a different pattern, with large numbers of mussels (e.g., *Geukensia*) on natural reefs contributing significantly to biomass differences observed through year 1; significant between-site mussel biomass differences were also observed. Faunal densities were also similar between the two reef types at the developed site; however, the natural reefs at the undeveloped site supported greater resident densities. These findings are discussed as they relate to previous studies using mussels as "sentinels" of environmental quality. For the transient community, no significant differences were detected between experimental and natural reef areas for either overall abundance or species richness, averaged over the three replicate reefs per site. By initiating and following the long-term reef development, we will be able to explore potential changes in reef habitat status and function during reef succession.

Keywords: Summary, only oyster, reefs, intertidal environment, artificial reefs, biomass, aquatic communities, man induced effects.

Crawford, C. 2003. **Environmental management of marine aquaculture in Tasmania, Australia.** Aquaculture. Vol. 226, no. 1-4, pp. 129-138. 31 Oct. IS: ISSN 0044-8486.

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 farms 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. Research related to management of aquaculture wastes is ongoing. Studies include investigating appropriate inexpensive measures for an industry-wide long-term monitoring program. Mitigation measures against excessive loadings of organic matter from fish farms, mainly by fallowing, i.e. rotating the position of fish pens around a lease, are currently being researched. Rates of recovery of a heavily impacted salmon lease area after the removal of fish have also been studied. A new project is investigating system-wide effects of salmon farming on the environment, in particular, increased release of nutrients into waterways. This includes monitoring dissolved oxygen, nutrients and phytoplankton, modelling the system, and investigating ecological indicators of eutrophication.

Crawford, C., I. Mitchell, and C. Macleod. 2001. **Effects of shellfish farming on the environment.** Affiliation - Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Aquaculture 2001: Book of Abstracts. 143 p. Conference - Aquaculture 2001, Lake Buena Vista, FL (USA), 21-25 Jan 2001.

The production of shellfish, mainly *Crassostrea gigas*, in Tasmania, Australia is approximately 2,500 metric tons per annum, which is small by world standards. Nevertheless, there is considerable community opposition to the expansion of the industry, partly because of concerns about possible detrimental effects on the environment. As a consequence, several projects were instigated to investigate the interactions between shellfish farming and the environment. The effects of shellfish farming on the benthic environment were investigated in detail at three deep water shellfish farms in Tasmania which have had a relatively high level of production. Benthic samples collected from within and outside the farm area were analyzed for physical/chemical variables, and composition and abundance of the invertebrate faunal community. Rates of sediment deposition were measured, and sections of the seabed were recorded using a video camera. 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.

Keywords: Marine aquaculture; Shellfish culture; Oyster culture; Environmental effects; Benthic environment; Ecosystem disturbance; Disease transmission; Eutrophication; Sedimentation; Suspended particulate matter; Particulate organic matter; Particulate flux; Man-induced effects; Aquaculture; Human impact; Population-environment relations; Sediments; Risk assessment; Pests; Pathogens; Coastal zone; Estuaries; Filter feeders; Nutrients; Environmental impact; Crassostrea gigas; Australia, Tasmania; PSE, Australia, Tasmania.

DeAlteris, J.T., B.D. Kilpatrick, and 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. (23:3) 867–874.

(fish populations in oyster cages many times greater than eelgrass – better diversity)

Duarte, P., R. Meneses, A.J.S. Hawkins, M. Zhu, J. Fang, and J. Grant. 2003. **Mathematical modelling to assess the carrying capacity for multi-species culture within coastal waters.** Ecological Modelling. 168(1):109-143.

In the context of aquaculture, carrying capacity is generally understood as the standing stock of a particular species at which production is maximized without negatively affecting growth rates. The estimation of carrying capacity for aquaculture is a complex issue. That complexity stems from the many interactions between and among cultivated and non-cultivated species, as well as between those species and their physical and chemical environments. Mathematical models may help to resolve these interactions, by analyzing them in a dynamic manner. Previous carrying capacity models have considered the biogeochemical processes that influence growth of cultivated species in great detail. However, physical processes tend to have been addressed very simplistically. Further, most modelling has been for monocultures, despite the increasing importance of multi-species(=polyculture) systems. We present here a two-dimensional coupled physical–biogeochemical model implemented for Sungo Bay, Shandong Province, People's Republic of China. Sungo Bay is used for extensive polyculture, where bivalve shellfish and kelp are the most important cultivated species. Data collected over 13 years (1983–2000) was available for modelling. Our main objectives were to implement the model, achieving reasonable calibration and validation with independent data sets, for use in estimating the environmental carrying capacity for polyculture of scallops and oysters. Findings indicate that the model successfully reproduces some of the main features of the simulated system. Although requiring some further work to improve predictive capability in parts, predictions clearly indicate that Sungo Bay is being exploited close to the environmental carrying capacity for suspension-feeding shellfish. Comparison of different culture scenarios also indicates that any significant increase in yield will depend largely on a more optimal spatial distribution of the different cultivated species.

Keywords: carrying, capacity, aquaculture, coastal waters.

Dumbauld, B., J. Ruesink, H. Macrellis, F., Oyarzun, and S. Hacker. 2003. **Interactions between oyster aquaculture and seagrass (*Zostera marina*) in estuaries along the coast of North America.** Presentation at 17th Biennial Conference of the Estuarine Research Federation Conference.

We examined both direct and indirect effects of oyster aquaculture on seagrass in Willapa Bay, Washington. Surveys suggest direct negative effects of harvest dredge operations while handpicking and longline culture operations appear compatible with high seagrass cover. Dredging experiments led to immediate declines in eelgrass, but recovery occurred in a few months to a year. Indirect effects of filter feeders on seagrass may also occur via changes in water quality, sediment nutrients or effects on seed recruitment. Results of manipulative experiments suggest that low to moderate density of oysters enhances growth of adjacent seagrass. Although the interaction between oyster culture and seagrass is widely perceived to be negative (for seagrass), we found the relationship to be more complex and study results will hopefully lead to improved management.

Keywords: seagrass, oyster, general aquaculture.

Dumbauld, B., D. Armstrong, C. Roegner, K. Feldman, L. Loggerwell, and S. Rumrill. 2001. **Implementing a study to determine the value of molluscan shellfish culture areas as fish habitat in West Coast estuaries.** Journal of Shellfish Research. Vol. 20, no. 3, p.1196. Dec. Conference-Annual Meeting of the National Shellfisheries Association Pacific Coast Section and Pacific Coast Shellfish Growers Association, Warm Springs, OR (USA), 27-29 Sep 2000.

The ecological role of bivalve molluscs in estuarine systems has recently been recognized in other areas including Europe and eastern North America where studies have been completed and in some cases shellfish restoration efforts initiated. Comparable studies are lacking however from estuaries on the West Coast, where bivalve (particularly oyster and clam) aquaculture often dominates the intertidal landscape. Due to increasing interest, especially with regard to the potential impacts of oyster aquaculture activities on juvenile salmonids (driven by the listing of several stocks under the Endangered Species Act), we are initiating a study designed to quantify both adverse, but also beneficial impacts of shellfish farming on selected estuarine fauna and flora. We will focus our initial efforts on oyster ground culture and on eelgrass as benthic habitats given the extent and previously documented value of these habitats respectively. Field and laboratory objectives include: 1) utilizing remote sensing and ground-truthing to document annual variability in eelgrass cover in oyster culture and eelgrass meadows in Willapa and Coos Bay estuaries; 2) compare species diversity, density and biomass in culture areas as well as eelgrass meadows; 3) conduct field experiments to examine the impacts of various culture activities on eelgrass and associated infaunal and epifaunal communities; and 4) conduct surveys of fish utilization in oyster beds and eelgrass meadows. Finally, we hope to prepare guidelines to assist both shellfish farmers and estuarine managers in avoiding and/or reducing adverse impacts on estuarine habitat while maximizing the potential beneficial impacts of aquaculture activities.

Keywords: Shellfish culture; Oyster culture; Culture effects; Brackishwater aquaculture; Environmental impact; Community composition; Sea grass; Benthos; Intertidal environment; Nursery grounds; Estuaries; Man-induced effects; Ecosystem disturbance; Biological stress; Ecosystem management; Anadromous species; Salmonidae; Zostera marina; Crassostrea gigas; INE, USA, West Coast; INE, USA, Oregon, Coos Bay; INE, USA, Washington, Willapa Bay.

Dumbauld, B.R. 1997. **A review of studies on the impact of oyster aquaculture to west coast benthic invertebrate communities.** Journal of Shellfish Research. 16(1):312.

A review of several field studies on the influence of aquaculture practices on the benthic macroinvertebrate community in west coast estuaries suggests that the addition and removal of oysters as structural habitat plays a more important role than disturbance due to dredging and even chemical application to remove burrowing shrimp as pests. Species abundance, biomass, and diversity are often enhanced in areas where oysters are cultured versus the open mud or eelgrass dominated habitat that is replaced. Shifts in the dominant species are usually due to the presence of the oysters themselves which add structure for macroalgal attachment as well as mussels and barnacles which in turn provide protection and/or food for juvenile Dungeness crab, shore crabs Hemigrapsus, tube building gammarid amphipods such as Amphithoe and Corophium, caprellid amphipods, tanaids, and some annelids such as the scaleworm Harmothoe. Other species including the burrowing amphipod Eohaustorius and the commensal clam *Cryptomya*, which are adapted to live in an open sandy habitat dominated by thalassinid shrimp, are less abundant in oyster culture areas. A slightly different case is presented for off bottom culture where the structure is less likely to directly influence the benthic community, but may influence the abundance of epibenthic predators and have other structural effects. For the estuarine manager, the functional result of these species shifts and the temporal and spatial scale of disturbance are important considerations and to date little has been done to estimate functional effects at the larger estuarine ecosystem scale.

Keywords: Oyster, Shrimp, Biomass, Abundance, Diversity, Community, Composition, Benthic macroinvertebrate, Dredging, Chemical, Action, Esuarine, Ecosystem.

Dumbauld, B.R., K.M. Brooks, and M.H. Posey. 2001. **Response of an estuarine benthic community to application of the pesticide carbaryl and cultivation of Pacific oysters (*Crassostrea gigas*) in Willapa Bay, Washington.** Marine Pollution Bulletin. 42(10):826-844.

Oyster culture operations on the West coast of North America have developed into complete farming operations fro the introduced Japanese oyster, *Crassostera gigas*, which now covers vast areas of the intertidal landscape particularly in Washington State where the pesticide carbaryl has also been used to control burrowing thalassinid shrimp for more than 30 years. Field experiments were conducted to examine the effects of these habitat modifications on the benthic community in Willapa, Bay Washington (124*06'W, 46*24'N) where 50% of the state's oyster production occurs. Results indicated that the primary long-term effect of carbaryl application was removal of the two species of thalassinnid shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*), which dominated the community at the start of the experiment and clearly influenced community composition themselves. Small pericarid crustaceans like the amphipods Corophium acherusicum and Eohaustorius estuarius experienced the most significant short-term mortalities, but generally recruited back to treated sites within 3 months, and were often more abundant on treated than untreated sites 1 year after carbaryl application. Results for molluscs were mixed, with no significant effect on *Macoma spp*, but a significant effect on the commensal clam *Crytomya californica* and mixed results for the cockle *Clinocardium nutalli*. Polychaetes were the least susceptible to carbaryl and the with the exception of a short-term effect on oligochaets, no significant negative effects were observed. The addition of oysters did not affect the infaunal community in this study; however greater abundance of epifaunal organisms like mussels, scaleworms, and the amphipod Amphithoe valida, which builds tubes in algae attached to shells, was observed. carbaryl, which is currently applied to roughly 242 ha (<6% of the intertidal) in Willapa Bay on an annual basis, as a variable but relatively short-term effect on the

benthic community, which should be viewed in the context of the other oyster culture operations like the addition of oyster themselves to a community often dominated by burrowing shrimp which clearly control its dynamics.

Keywords: crassostera gigas, oyster, shrimp, mud shrimp, sand shrimp, Willapa, bentic, carbarylsevinneotry, paeaupogebia, benthos

Dumbauld, B.R., S.P. Ferraro, and F.A. Cole. 2000. **Oyster aquaculture and benthic invertebrate communities in west coast estuaries: An update.** Journal-of-Shellfish-Research. 19(1):608-609.

A review of a limited number of field studies suggests that oyster aquaculture practices play a key role in structuring the benthic macro -invertebrate community in west coast estuaries. Oysters are "bioengineers" as they change the structure of the substrate and create habitat for other organisms. Macroinvertebrate communities are typically enhanced in intertidal ground culture oyster habitat as compared to other estuarine habitats, in particular intertidal mud and burrowing thalassinid shrimp dominated habitats. Oysters add structure for macro-algal, mussel and barnacle attachment which in turn provide protection and/or food for juvenile Dungeness crab, shore crabs Hemigrapsus, tube building gammarid amphipods such as Amphithoe and Corophium, caprellid amphipods, tanaids, and some annelids such as the scale-worm Harmothoe. Two other bioengineers, the ghost shrimp *Neotrypaea californiensis* and the mud shrimp *Upogebia pugettensis*, dominate large portions of the intertidal in some west coast estuaries and compete for space with oysters. These thalassinid shrimp create a soft, highly burrowed habitat suitable for other burrowing organisms like the amphipods Eohaustorius and Eobrolgus, the polychaete Mediomastus, and some commensal organisms like the clam *Cryptomya*, but support fewer filter feeders and much lower species diversity than oyster habitat. Preliminary results of a recent study in Willapa Bay, WA comparing the macro-infaunal community in ground culture oyster habitat with that in six other estuarine habitats are presented along with a review of previous studies in West coast estuaries. To date, little has been done to estimate functional effects of these changes at the larger estuarine ecosystem scale, but some proposed work aims to investigate the functional role of these habitats for the estuarine fish community.

Keywords: Oyster, culture, Environmental impact, Zoobenthos, Species diversity, Blue mud shrimp, Estuaries, Community composition, Hemigrapsus, Amphithoe, Corophium, Harmothoe, Neotrypaea californiensis, Upogebia pugettensis, Eohaustorius, Eobrolgus, Mediomastus, Cryptomya.

Dumbauld, B.R., S. Booth, D. Cheney, A. Suhrbier, and H. Beltran. 2006. **An integrated pest management program for burrowing shrimp control in oyster aquaculture.** Aquaculture 26:976-992.

Burrowing thalassinid shrimp clearly cause oysters to sink under the surface of the sediment and die. Further defining a threshold density of shrimp at which this occurs and applying this on a broader estuarine scale for pest management is difficult because shrimp recruitment to the estuary and oyster beds varies interannually, oysters are a perennial crop, and culture practices vary with location and market influences. Nonetheless, a burrowing shrimp program which examines recruitment is proposed.

Dupuy, C., A. Pastoureaud, M. Ryckaert, P.G. Sauriau, and H. Montanie. 2000. **Impact of the oyster *Crassostrea gigas* on a microbial community in Atlantic coastal ponds near La Rochelle.** Aquatic Microbial Ecology. 22(3):227-242.

To assess the in situ impact of oysters *Crassostrea gigas* on *planktonic protist* and bacteria communities and the potential contribution of protozoa to their food resource intake, the abundance and the diversity of protists and bacteria were followed in 2 Atlantic coastal ponds, with and without oysters. The protist biomass in such ponds was high, with a maximum in spring of 982 mug C l(1) and a minimum in winter of 179 pg C l(1). Whatever the season, the presence of oysters (20 m(2) corresponding to an average of 23 mg dry weight m(2)) induced a significant decrease in >5 pm protist abundance. On the contrary, planktonic organisms 5 pm particles. In spring, oyster grazing triggered dramatic changes in the protist community by lowering the taxonomic diversity. In autumn and winter, the presence of oysters deeply influenced the taxonomic structure of the protist communities: > Fun protists could only develop in the control pond, whereas they were removed by filtration in the oyster pond; on the contrary, >5 Fun protists that were not retained were favored in the oyster pond. The result showed that hetero/mixotrophic protists represent an important potential resource in coastal ponds: flagellates >5 pm were the main protist resource for C. gigas; ciliates represented the second resource, with a substantial contribution in autumn; diatoms and dinoflagellates, though efficiently removed, represented a weak carbon resource. Our study supports the hypothesis that oysters may access the strong bacterioplanktonic production through hetero/mixotrophic protists, which would thus allow the transfer of carbon from the microbial loop towards C. gigas.

Keywords: Oyster (Crassostrea gigas), Protists, Bacteria, Protozoa, Diversity, Food, Community, Composition.

Escapa, M., J.P. Isacch, and P. Daleo, et al. 2004. **The distribution and ecological effects of the introduced Pacific oyster, *Crassostrea gigas* (Thunberg, 1793) in northern Patagonia.** Journal of Shellfish Research. 23(3):765-772.

No abstract identifying these species for this category.

Everett, R., G. Ruiz, and J. Carlton. 1995. **Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary**. Marine Ecology Progress Series. 125205-217.

The effects of commercial culture of oysters, *Crassostrea gigas*, on submerged aquatic vegetation (SAV), *Zostera marina*, were examined with replicated field experiments in the South Slough estuary, Oregon, USA. Both stake and rack methods of oyster culture resulted in significant decreases in the abundance of SAV compared to undisturbed reference areas. SAV cover in both stake and rack treatments was less than 25% of that in reference plots after 1 yr of culture, and was absent from rack treatments after 17 mo of culture. Field experiments using marked plants revealed no difference in growth between plants in stake and reference plots. Comparisons of sediment surface topography demonstrated that oyster culture resulted in significantly greater sediment deposition in stake plots and greater erosion in rack plots. Silt-clay fractions and carbon content of sediments tended to increase with stake culture and decrease with rack culture, but only for carbon content at racks were the differences significant between culture and reference plots. Stake culture likely affected SAV via increased sedimentation and direct physical disturbance during placement and harvest, while increased erosion and perhaps shading

resulted in the marked decrease in SAV coincident with rack culture. These results indicate the potential for significant loss of SAV from estuarine ecosystems where these methods of oyster culture and SAV coincide.

Keywords: ECOP, squatic, vegetation, oysters.

Feldman, K.L., D.A. Armstrong, B.R. Dumbauld, T.H. DeWitt, and D.C. Doty. 2000. **Oysters, crabs, and burrowing shrimp: Review of an environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries.** Estuaries. 23(2):141-176.

Washington State's coastal estuaries are productive shallow water environments that support commercial fisheries for Dungeness crabs (*Cancer magister*) and English sole (*Parophrys vetulus*) by providing 0+ (settlement to age 1) populations with critical refuge and foraging habitats until subadults migrate to the nearshore coast. Intertidal mudflats also constitute prime areas for commercial oyster (*Crassoscrea gigas*) culture, an important industry for the coastal communities of Willapa Bay and Grays Harbor that supply much of the nation's oysters. Conflicts over natural resources and estuarine utilization have arisen over the last 37 yr due to the use of carbaryl (an organocarbamate pesticide) by oyster growers on their grounds to control populations of burrowing thalassinidean shrimp (*Neotrypaea californiensis* and *Upogebia pugettensis*). Burrowing shrimp, which have an indirect negative effect on oyster survival and growth through bioturbation and sediment destabilization, are killed by carbaryl, as are 0+ and subadult Dungeness crabs, 0+ English sole, and other non target species present on the tideflats at the time of application. The pesticide is delivered at 9 kg ha(1) directly to the mudflat as a wetable powder during low tides in July and August. Commercial crabbers and other groups who have economic, recreational, and environmental interests in the estuaries have generally opposed use of the chemical that oyster growers maintain is essential to sustain production levels. For years, government natural resource agencies that regulate the use of carbaryl lacked critical information needed to effectively manage the program. An Environmental Impact Statement (EIS) and Supplemental EIS have provided much of that data and helped shape management decisions with regard to establishing carbaryl concentration rates and total allowable spray area. Additional research is needed to develop more economically and environmentally sound policies for shrimp control based on burrowing shrimp oyster interactions on an estuarine wide scale. In this paper we review issues pertaining to oyster culture, the use of carbaryl to control burrowing shrimp populations, and effects on nontarget species, drawing upon research from published articles as well as unpublished data collected by the authors. We also discuss what is known of burrowing shrimp life history and ecology and emphasize the importance of integrating information on shrimp, such as timing of recruitment, variability in year class strength, and patterns of habitat use, into carbaryl control policies or alternative strategies that may be developed in the future. We recommend controlled experimentation be done to examine the ecological effects of delaying carbaryl application to some ghost shrimp beds until October after peak recruitment of 0+ ghost shrimp has occurred, allowing the number of hectares treated each year to vary based on fluctuations in pest population densities, and modifying the substrate by applying a dense layer of oyster shell to the mudflat (shell pavement) to reduce recruitment of ghost shrimp.

Keywords: Dungeness crabs (Cancer magister), English sole (Parophrys vetulus), Oyster (Crassoscrea gigas), Burrowing Shrimp, Pest Control, Environmental Impact, Predation, Regulation, Washington State.

Ferraro and Cole (2001) **More species in bottom cultured oyster habitats than in eelgrass**.
No abstract identifying these species for this category.

Gangnery, A. C. Bacher, and D. Buestel. 2001. **Assessing the production and the impact of cultivated oysters in the Thau lagoon (Mediterranee, France) with a population dynamics model.** Canadian Journal of Fisheries and Aquatic Sciences. Vol. 58, no. 5, pp. 1012-1020. May.

The Thau lagoon (France) has been studied for many years because of its ecological interest related to economic activities: shellfish cultivation, tourism, and industry. The standing stock of cultivated filter feeders is around 20 000 t and consists of two main species, the Japanese oyster *Crassostrea gigas* and the Mediterranean mussel *Mytilus galloprovincialis*. To predict changes in the standing stock and the annual production, a mathematical model of the population dynamics was defined. It was based on the continuous equation of the density as a function of the mortality rate, the individual growth rate, and the interindividual variability. The daily growth rate was derived from field surveys and depended on the phytoplankton concentration and individual weight. The model also took into account the rearing strategy of the producers defined by the timetable of seeding and harvesting, obtained by an inquiry among the producers and used to simulate real cases of standing stock changes. The model was also used to assess the potential impact on the environment through the computation of the food consumption, which was compared with the residence time and the primary production.

Keywords: Aquaculture; Population dynamics; Models; Lagoons; Man-induced effects; Oyster culture; Brackishwater aquaculture; Biomass; Filter feeders; Carrying capacity; Ecosystem management; Coastal lagoons; Crassostrea gigas; Mytilus galloprovincialis; France; MED, France, Languedoc-Roussillon, Thau lagoon.

Gangnery, A., C. Bacher, and D. Buestel. 2004. **Modelling oyster population dynamics in a Mediterranean coastal lagoon (Thau, France): sensitivity of marketable production to environmental conditions.** Aquaculture. 230(1-4):323-347.

A population dynamics model was used to simulate variations in the standing stock of the Pacific oyster, *Crassostrea gigas*, to assess the marketable production in Thau Lagoon (France) and to evaluate the sensitivity of this production to environmental conditions. The model is based on a continuous equation of the oyster abundance as a function of individual growth rate, inter-individual growth variability and mortality rate. The growth model depends on water temperature, particulate organic matter concentration and total individual mass. Inter-individual growth variability was introduced into the general population dynamics equation by a diffusion coefficient K that was set to 0.05. The population dynamics model took into account the two culture methods (i.e. "collees" and "pignes" oysters) and rearing strategies of oyster farmers by using timetables of seeding and harvesting obtained through interviews of oyster farmers. Distributions of standing stocks were obtained through assessments conducted in the lagoon in March 2000, October 2000 and March 2001 and were used to calibrate the model. The model estimated the total marketable production at ca. 17,900 t between March 2000 and March 2001. The major part of the production (ca. 70%) was in spring. Seventy percent of the annual

production came from "collees" oysters. Sensitivity analyses showed that the key parameters are those related to harvesting. The model was used to evaluate the effects of different environmental conditions (e.g. a decrease in the oyster growth rate, a harvesting closure due a toxic algae bloom, a massive summer mortality due to an anoxic crisis) on short- and long-term variations in the standing stock and the production for both culture methods. A decrease in the growth rate of ca. 20% resulted in losses of 18% in the first year of production for both culture methods. Long-term simulations showed that the production of "pignes" oysters was more affected than that of the "collees" oysters (reductions of 26% and 4%, respectively). Simulated scenarios included a 2-month long harvesting closure (i.e. November and December) or a massive summer mortality (i.e. 45% and 20% for "collees" and "pignes" oysters, respectively). No long-term effect was predicted for either event, although losses of ca. 10% were estimated in the first year of production for both culture techniques. The model can be a useful tool for predicting marketable production of oysters as a function of rearing strategy and environmental conditions.

Geret, F., A. Jouan, V. Turpin, M. J. Bebianno, and R. P. Cosson. 2002. **Influence of metal exposure on metallothionein synthesis and lipid peroxidation in two bivalve mollusks: the oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*).** Aquat. Living Resour. vol. 15(no. 1):pp. 61-66.

The impact of metals (silver, cadmium, copper, mercury and zinc) on metallothionein (MT) and malondialdehyde (MDA) levels of the oyster (*Crassostrea gigas*) and the mussel (*Mytilus edulis*) was studied after 4 or 21 days of metal exposure. Moreover, total protein levels were determined. After 4 days of metal exposure, although C. gigas and M. edulis accumulated cadmium and mercury concentrations in the gills and digestive gland, no significant variation of total protein level was occurred. After 21 days of exposure, metals were bioaccumulated in the gills and the digestive gland of both mollusks. A decrease of total protein concentrations in the gills of oysters and the digestive gland of mussels and an increase on metallothionein concentrations in the gills of both mollusks were observed. An increase of MDA levels was noticed for the gills and the digestive gland of mussels exposed for 21 days to either cadmium, silver or mercury whereas a decrease of MDA levels was observed in the gills of the oysters exposed for the same time to the same metals. The levels of proteins, MDA and MT were metal, species or organ dependent.

Keywords: Metals, Proteins, Metallothioneins, Pollution effects, Lipids, Animal physiology, Crassostrea gigas, Mytilus edulis, Bivalvia malondialdehyde.

Gerritsen, J., A.F. Holland, and D.E. Irvine. 1994. **Suspension-feeding bivalves and the fate of primary production: an estuarine model applied to Chesapeake Bay.** Estuaries 17 (2), 403–416.

A probabilistic mathematical model of bivalve suspension-feeding in estuaries is based on bivalve abundance, filtering capacities, and water mixing parameters. We applied the model to five regions of the upper Chesapeake Bay, ranging from shallow tidal fresh habitats to deep mesohalie habitats, for the years 1985 to 1987. Model results indicated that existing suspension-feeding bivalves could consume more than 50% of annual primary production in shallow freshwater and oligohalie reaches of the upper Chesapeake Bay and Potomac River. In deep mesohaline portions of the Chesapeake Bay and Potomac River, suspension-feeding bivalves

could consume only 10% of primary production. Independent estimates of benthic carbon demand based on benthic production supported the model predictions. Hydrodynamics of large estuaries restrict the potential of benthic suspension-feeders to crop phytoplankton production because the width and depth of these estuaries limit transport of pelagic waters to the littoral flanks of the estuaries where benthic suspension-feeders can be abundant. Benthic suspension-feeders are dominant consumers in shallow segments of the Chesapeake Bay system, but are suppressed in deeper segments. The suppression is below that set by hydrodynamic limits, and may be due to periodic hypoxia or other factors. Our results suggest that the proposed use of suspension-feeding bivalves to improve water quality of large estuaries will be limited by the depth and width of the estuary, unless the bivalves are suspended in the water column by artificial means.

Heral, M., C. Bacher, G. M. Feuillet, and P. S. Sauriau. **Benthic effects of biodeposition of oyster culture in mesotidal estuarine conditions.** Copenhagen-Denmark ICES.14.

No abstract identifying these species for this category.

Hilgerloh, G., J. O'Halloran, T. Kelly, and G.S.O.Burnell. 2001. **A preliminary study on the effects of oyster culturing structures on birds in a sheltered Irish estuary.** Hydrobiologia. Vol. 465, no. 1-3, pp. 175-180. Dec.

This study investigated the species composition, numbers and behaviour of birds in an intertidal oyster culture area in Cork Harbour. These data were compared to a nearby area free of aquaculture within the same estuary in March 1999. Species which occurred in the aquaculture free area were also observed in the trestle-area. The most abundant species were oystercatcher *Haematopus ostralegus*, redshank *Tringa totanus*, dunlin *Calidris alpina*, curlew *Numenius arquata*, black-headed gull *Larus ridibundus* and common gull *Larus canus*. Oystercatcher, curlew, black-headed gull and common gull occurred in significantly lower numbers in the trestle area, while for redshank and dunlin the differences were not significant. The percentage of birds feeding did not differ between the two areas. Oystercatcher, redshank, dunlin and curlew mostly fed in both areas. In contrast, black-headed gull and common gull generally did not feed, but surveyed the area. Whether the trestles were covered by oyster bags or not did not have any effect on the number of birds except for the dunlin. Dunlin were significantly more frequent beneath the trestles with bags compared with those without bags. In general, the percentage of birds feeding did not differ between areas. Interspecies differences occurred with regard to the position occupied by birds at the trestles. Oystercatcher, redshank and curlew spent more time underneath the trestles. Dunlin, black-headed gulls and common gulls did not differ in numbers underneath or on top of the trestles. These preliminary observations at a single time period give some insight as to the potential interactions between shellfish aquaculture and intertidal birds.

Keywords: Oyster culture; Off-bottom culture; Culture effects; Aquaculture systems; Man-induced effects; Environmental impact; Aquatic birds; Community composition; Species diversity; Population number; Feeding behaviour; Intertidal environment; Estuaries; Aquaculture; Species composition; Abundance; Oysters; Intertidal Areas; Data Collections; Food Habits; Waterfowl; Aves; ANE, Eire, Munster, Cork, Cork Harbour.

Langan, R. 1997. **The effect of dredge harvesting on oysters and the associated benthic community. Effects-Of-Fishing-Gear-On-The-Sea-Floor-Of-New-England.**

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)

Keywords: trawling, dredging, marine, molluscs, benthos, man induced effects, oyster bottom culture, harvest, harvesting.

Lenihan, H.S., and C.H. Peterson. 1997. **Effects of oyster harvesting on the habitat value of restored oyster reefs: An experimental analysis.** Journal of Shellfish Research. 16(1):270.

We conducted a field experiment to test whether various oyster harvesting techniques, dredging, hand-tonging, and diver-collecting, cause differences in (1) oyster reef morphology, (2) incidental mortality to unharvested oysters, and (3) sedimentation rate across experimental restored oyster reefs located in the Neuse River, NC. We also compared catch per unit effort for each harvest treatment in order to evaluate economic efficiency. In order to mimic the effect of an actual harvest season, professional oyster fisherman were employed to conduct harvest treatments and replicate experimental reefs were harvested until no further returns were made. Reefs harvested with dredges experienced the greatest reduction of reef height (-29 plus or minus 12 cm) and highest sedimentation rates compared to other treatments. Incidental mortality was lowest and catch per unit effort was highest on reefs that were harvested by divers. Alteration of the physical structure of oyster reefs caused by harvest disturbance has important ecological implications because reef height controls local hydrodynamic flow, which, in turn, influences recruitment, growth, and survival of oysters. Long-term production of oysters and other ecosystem services performed by oyster reefs are also controlled by interaction between harvest-related reef degradation and reduced estuarine water quality. Our results provide further evidence for why management of oysters and their reef habitat should be transferred from fisheries to

ecosystem managers. (DBO)

Keywords: Summary, only, oyster, fisheries, harvesting, catching methods, comparative studies, oyster reefs, environmental impact, ecosystem disturbance, USA North Carolina, Neuse R Harvest, oyster.

Lewitus, A.J., M.S. Wetz, E.T. Koepfler, K.C. Hayes, and R.F. Dame. 2001. **Effects of oyster reefs on microbial community structure and production.** Aquaculture-2001:-Book-of-Abstracts, Louisiana State University, Baton Rouge, LA 70803. World Aquaculture Society. 370.

Oyster reefs can influence microbial communities through grazing and nutrient regenerative activities. Each process can be selective. Therefore the net effect of oyster reefs on microbial food webs is a function of the combined influences of oyster reef feeding preference and microbial uptake ability for regenerated nutrients (e.g. NH sub(4)). We compared a) microbial community composition and biomass in intertidal creeks with (+Oys) and without (-Oys) oyster reefs, b) the potential for nutrient or grazing limitation of phytoplankton from those creeks using bioassays, and c) changes in microbial communities in water flowing across oysters in linear flumes. When comparing all +Oys to -Oys creeks, no significant differences in NH sub(4) or chlorophyll a (chl) were found, nor did the responses of chl to nutrient additions or reduced grazing pressure differ in bioassays. However, when geomorphologically similar +Oys and -Oys creeks were paired, differences in NH sub(4), chl, and bioassay responses were evident, suggesting that the influence of oyster reefs on phytoplankton growth and nutrient availability depends on creek geomorphology. A consistent effect of oyster reefs on phytoplankton composition was seen in summer; when +Oys creeks contained significantly fewer phototrophic flagellates, but not heterotrophic flagellates, ciliates, bacteria, cyanobacteria, or diatoms. Flume experiments demonstrated preferential removal of phototrophic flagellates, but not other groups, by live oysters but not dead oyster shells. Thus, oyster reefs can exert control over microbial food web structure, but their impact on microbial community production apparently depends on tidal creek morphology and hydrography. When examined across a range of creek types, the influence of oyster reefs on microbial community composition and nutrient availability did not affect overall nutrient concentration or phytoplankton biomass, suggesting that other grazers (e.g. zooplankton, nekton) or nutrient sources (e.g. zooplankton, nekton, groundwater) may override or compensate for the effects of oyster reefs.

Keywords: Oyster reefs, Microorganisms, Population, structure, Biomass, Uptake, Feeding, behaviour, Food webs, Grazing, Phytoplankton, Rivers, Intertidal, environment, Fluvial, morphology, Hydrography, Flume experiments, Intertidal creeks.

Laffargue, P., M.L. Be´gout, and F. Lagarde`re. 2006**. Testing the potential effects of shellfish farming on swimming activity and spatial distribution of sole (*Solea solea*) in a mesocosm**. ICES Journal of Marine Science 63: 1014-1028.

Restructuring coastal fish nursery habitats by extensive shellfish farming in the French part of the Bay of Biscay could influence fish physiology and behaviour and affect the ecological performance of the species. The influence of oyster-trestle cultivation installations on sole (Solea solea) swimming behaviour was investigated using an experimental pond mesocosm. A pen was constructed with three interconnected zones (two with bags of live oysters or oyster shells on

trestles, and one free zone). Water renewal depended on the tide. Environmental variables were recorded continuously (temperature, oxygen, pH, meteorological data), every 3e5 days (salinity, samples taken for water analysis and estimation of sedimentation rate) or intermittently (illumination). Sediment cores were taken in each zone before and after the experiment, for sediment redox and water content, plus an evaluation of potential prey. Fish movements (nine sole collected in the wild and tagged with electronic transmitters) were registered during three fortnight-long sessions in spring 2002. In addition to shading from the oyster trestles, water and sediment properties changed significantly in the live oyster zone. Environmental changes and sole swimming behaviour were linked by direct or indirect effects: swimming activity for eight of nine sole followed a diel cycle, with greater travelling distance by night. All the environmental variables modulated swimming activity, but temperature increase, water renewal, and climatic events were associated with key changes between sessions or individual sole. A multilinear regression analysis suggested strongest links with oxygen, atmospheric pressure, light level, water column height, and pH. All sole moved around the enclosure at night, probably to forage. By day, except during gale-force wind, sole returned to the same resting zones. Under the oyster-rearing structures appeared to be the most attractive resting sites. Sole seemingly can occupy an entire nursery in a shellfish farming basin that has moderate habitat changes.

Keywords: acoustic telemetry, behavioural responses, environmental constraints, fisheries, flatfish habitat, shellfish farming, tidal pond experiment.

David L. Meyer, D. L., and E. C. Townsend. 2000. **Faunal utilization of created intertidal eastern oyster (*Crassostrea virginica*) reefs in the southeastern United States**. Estuaries 23: 34-45.

Oyster cultch was added to the lower intertidal marsh-sandflat fringe of three previously created *Spartina alternifora* salt marshes. Colonization of these created reefs by oysters and other select taxa was examined. Created reefs supported numerous oyster reef-associated faunas at equivalent or greater densities than adjacent natural reefs. Eastern oyster (*Crassostrea Yirginica*) settlement at one site of created reef exceeded that of the adjacent natural reefs within 9 mo of reef creation. After only 2 yr, harvestable-size *C. yirginica* (>75 mm) were present in the created reefs along with substantial numbers of *C. Yirginica* clusters. The created reefs also had a higher number of molluscan, fish, and decapod species than the adjacent natural reefs. After 2 yr the densities of *C. Yirginica*, striped barnacle (*Balanus amphih-ite*), scorched mussel (*Brachidontes ejcustus),* Atlantic ribbed mussel (*Geukensia demissa*), common mud crab (*Panopeus herbsh'i*), and flat mud crab (*Eurypanopeus dtpressus*) within the created reefs were equivalent to that of adjacent natural reefs. From these data it is evident that created oyster reefs can quickly acquire functional ecological attributes of their natural counterparts. Because the demand for oysters continues to increase in the face of dwindling natural resources, habitat creation techniques need to evolve and these approaches need to consider the ancillary ecological benefits reef creation may provide. Reef function as well as physical and ecological linkages of oyster reefs to other habitats (marsh, submerged aquatic vegetation, and bare bottom) should be considered when reefs are created in order to provide the best use of resources to maintain the integrity of estuarine systems.

Nugues, M.M., M.J. Kaiser, B.E. Spencer, and D.B. Edwards. 1996. **Benthic community changes associated with intertidal oyster cultivation.** Aquaculture and Research. 27(12):913-924.

A study of the environmental effects associated with the trestle cultivation of Pacific oysters, *Crassostrea gigas* Thunberg, was conducted at a commercial cultivation site in the River Exe estuary, Devon, England. Small, but significant, changes were detected in the macrofaunal community sampled beneath oyster trestles compared with that found in adjacent uncultivated areas. These changes were associated with an increase in organic and silt composition and a reduction in the depth of the oxygenated layer of the sediment beneath the trestles. Water velocity was decreased by the presence of the trestles which probably led to the increase in sedimentation rate observed beneath them. Although biological and physical changes were observed, they were relatively minor compared with the extreme environmental changes associated with the suspended culture techniques used for other bivalve species and fishes. However, other studies suggest that the environmental effects associated with oyster cultivation become more severe in areas of large-scale (hectares) cultivation.

Keywords: species, culture, intertidal, oyster, cultivation, benthic community.

Peterson, C.H., J.H. Grabowski, and S.P. Powers. 2003. **Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation.** Marine Ecology Progress Series. 264, 249–264

No abstract identifying these species for this category.

Posey, M.H., T.D Alphin, H.D. Harwell, and T. Molesky. 2004. **Effects of reef complexity on habitat function for intertidal oysters.** Journal of Shellfish Research. 23(1):307-308.

Oyster reefs are increasingly recognized for their habitat and ecosystem functions. Oyster reefs provide forage and refuge habitat for fauna, affect local nutrient dynamics, impact water column particulates, and indirectly influence adjacent sandflat habitats. With the decline of oyster reefs along the Atlantic and Gulf coasts, efforts are increasing to conserve existing oyster areas and to restore lost oyster habitat. However, these efforts have often been based on a presence/absence approach without consideration of landscape aspects that may influence oyster health and ecosystem function. Location of oyster reefs relative to other habitats, size of reefs, oyster density, fragmentation, and reef architecture may all influence faunal use and other ecosystem functions. For intertidal reefs, vertical complexity and edge convolution are important landscape aspects influencing habitat quality. Vertical complexity refers to the 3-dimensional roughness of the reef, with greater complexity providing more diverse spatial structure and refugia. Because the reef edge is the point of initial contact for water flow and nekton on a flood tide, varying edge characteristics may affect flow around the reef and nekton use of boundary areas. Over the past 2 years, we have examined the influence of edge complexity, vertical complexity and reef fragmentation on faunal use of intertidal reefs, oyster recruitment, growth and survival, and the influence of these parameters on the adjacent sandflat community. Interactive and main effects of vertical complexity, edge convolution and reef fragmentation were examined using created reefs providing replicate sets of each treatment as well as sampling of natural reefs with varying surface complexity and fragmentation. Results to date indicate that the various biotic components respond differentially to aspects of reef architecture. Epifauna, especially xanthid crabs, are more abundant on high surface complexity reefs. Oyster recruitment

and initial survival is greatest on low surface complexity reefs, possibly representing an indirect influence of xanthid distributions. Nekton respond more strongly to reef fragmentation than either surface or edge complexity, with greater diversity and abundances of certain taxa on fragmented reef complexes. In contrast, connections between reefs and adjacent sandflat habitats, including influences on organic content, porewater N, sediment characteristics, and microalgal biomass, are affected more by reef edge characteristics than vertical complexity. These results indicate the potential importance of landscape factors for reef habitat function and indicate the necessity of considering reef characteristics in restoration and conservation efforts.

Keywords: Reefs, Oyster reefs, Marine molluscs, Substrate preferences, Surface roughness, Larval settlement, Recruitment, Community composition, Species diversity, Colonization, Coastal currents, Coastal zone, Suspended particulate matter, Marine crustaceans, Zoo benthos, Habitat, Nature conservation, Ecosystem management, Environment management, Restoration, Ostreidae.

Pregnall, M., Pregnall, and S.S. Rumril. 1993. R**egrowth 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 invertebrates, 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.

Keywords: eelgrass, oysters, interactions, oregonzostrea marina, Dungeness, Cancer magister, Cryptomya californica, recruitment.

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).

No abstract identifying these species for this category.

Rheault, R.B. 2001. **Eelgrass is Great, but Shellfish Aquaculture is Better. Marine Aquaculture and the Environment:** A Meeting for Stakeholders in the northeast Tlusty.Cape Cod Press Falmouth, Massachusetts pp. 203-210.

In response to federal regulations established by the National Marine Fisheries Service, states are now required to "preserve, protect and where possible, restore submerged aquatic vegetation" (SAV), especially eelgrass. In recent years, eelgrass beds have been declining up and down the Atlantic coast. The causes of these declines are well documented. Since the federal laws protecting SAV came out, several aquaculture operations have come under fire. Large clam

farms in Virginia and oyster farms in Washington State have come under heavy regulatory pressure to cease or move because of perceived interference with eelgrass.

Keywords: Environmental impact; Marine aquaculture; Phytobenthos; Shellfish culture; Aquaculture regulations; Environmental protection; Zosteraceae; Zostera marina; USA Coasts, eelgrass.

Ruesink, J.L., B.E. Feist, C.J. Harvey, J.S. Hong, A.C. Trimble, and 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.

Multiple stressors in estuaries can cause declines in native species and impairment of ecosystem goods and services. In contrast, one stressor—the introduction of non-native species—actually leads to higher local richness. We examined the changes in ecosystem function associated with introductions into Willapa Bay, Washington, USA, a relatively undeveloped estuary with 45 documented exotic marine species. The replacement of native oysters by 2 new bivalve species has increased secondary production of harvested suspension feeders by 250% over peak historic values (3.3 × 105 vs. 0.9 × 105 kg dry wt yr–1), based on >150 yr of records of harvested biomass. Key aspects of aquaculture—particularly planted area—have remained constant over time, so we attribute much of the altered secondary production to higher growth rates of non-native species. The addition of 2 tracheophytes has increased primary production on the tideflats by >50% (5.3 × 107 vs. 3.5 × 107 kg dry wt yr–1), which we calculated by scaling up local measurements of plant growth to the total area occupied by each species. These changes in production are also associated with altered detritus, water filtration, and biogenic habitat. Because other stressors are largely absent from Willapa Bay, the addition of particular exotic species has dramatically enhanced system production, while fundamentally reshaping the ecological character of the estuary. These strong ecological impacts of introduced species have rarely been measured at whole-ecosystem scales, and they occur in part because new species occupy habitats where similar native species were not present.

Keywords: Crassostrea gigas, Invasion, Ostreola conchaphila, Spartina alterniflora, Ruditapes philippinarum, Zostera marina, Zostera japonica..

Rumrill, S.S., and V.K. Poulton. 2003. **Ecological impacts of commercial oyster long-line culture in Humboldt Bay, CA.** Presentations at "Applying Science and Information to Sustainability to Pacific Coast Estuaries.

Ecological impact assessment activities were carried out in Humboldt Bay (Arcata Bay), CA to identify the potential impacts of commercial oyster mariculture activities (*Crassostrea gigas*) on tideflat habitats, eelgrass beds, and invertebrate communities. The objectives of the investigation are: (1) compare eelgrass beds and benthic communities among experimental oyster long-line plots and control areas, (2) determine the impacts of long-line spacings on benthic tideflat communities, and (3) assess the capacity of oyster cultivation areas to serve as forage areas for Dungeness crabs and estuarine fish. The project examines oyster density, grow-out period, and hand-harvesting associated with the transition from bottom culture to long-line culture. The research investigation was carried out during 2001-03 in cooperation with Coast Seafoods Co. at several study sites located along the Eureka Channel and Arcata Channel. Preliminary results indicate that eelgrass metrics (% cover, shoot density) were consistently high

within control sites and lowest within the narrow (1.5 ft) oyster line-spacing plot. Greatest variability in eelgrass communities was observed within the oyster bottom culture plot. Intermediate oyster line-spacing plots (2.5, 5, 10 ft) exhibited eelgrass metrics that fall within the range of variation observed in a series of reference areas located throughout Arcata Bay.

Keywords: species, culture, oyster, long-line, culture, Humboldt Bay, CA.

Rumrill, S., and J. Christy. 1996. **Ecological impacts of oyster ground culture within estuarine tidelands: South Slough National Estuarine Research Reserve 31.**

No abstract identifying these species for this category.

Rumrill, S.S., and V.K. Poulton. 2003. **Ecological role and potential impacts of molluscan shellfish culture in the estuarine environment of Humboldt Bay, CA**. Journal of Shellfish Research. 22(2):607.

The intertidal mudflats of Humboldt Bay, CA, provide habitat for eelgrass (*Zostera marina*), invertebrates, shellfish, finfish, and birds. Humboldt Bay is also the leading producer of Pacific oysters (*Crassostrea gigas*) in California. We have completed the first year of a 3-year project to identify and quantify the effects of commercial oyster mariculture in tideflat habitats, eelgrass beds, and invertebrate communities. Experimental oyster long-line spacing plots were established for comparison to a ground culture site and 6 reference sites (no oysters). We sampled study plots quarterly between Aug 2001-Aug 2002 for presence of eelgrass, oysters, and other cover types. We collected infaunal cores, deployed fish traps, and measured water quality, sedimentation, light intensity, and oyster growth characteristics. Eelgrass shoot density and percent cover were consistently highest in an eelgrass bed control site, lowest at the 1.5-ft. long-line spacing plot, and most variable at the ground culture site. Eelgrass metrics in the other long-line spacing plots were generally lower but within the range of variation exhibited by the reference sites. Preliminary analysis of invertebrate cores has produced a species list of over 70 taxa, many of which are known prey items for estuarine fish. Sedimentation measurements showed no consistent patterns among experimental long-line plots. Oyster growth measurements did not differ substantially between long-line plots; oysters grew 20-35 mm in length and 16-22 mm in width between May and Aug 2002. Light intensity was lower beneath oyster long-lines, but did not differ substantially between the 1.5 and 5 ft. spacing plots.

Keywords: Marine aquaculture, Mollusc culture ,Marine molluscsm, Environmental impact, Estuarie,s Commercial species, Environmental effects, Crassostrea gigas, Zostera marina, INE, USA, California, Humboldt Bay,general aquaculture.

Rumrill, S.S., and V.K. Poulton. 2004. **Ecological Role and Potential Impacts of Molluscan Shellfish Culture in the Estuarine Environment of Humboldt Bay, CA.** Western Regional Aquaculture Center, Annual Report, November 2004, Humboldt Bay, California.

The potential ecological effects of commercial oyster mariculture activities on eelgrass beds (*Zostera marina*) and estuarine tideflat communities are the focus of regional concern for several natural resource agencies throughout Washington, Oregon, and northern California. In particular, empirical studies are currently underway at several locations throughout the Pacific Northwest to evaluate alternative shellfish farming practices and develop policies designed to minimize degradation to eelgrass beds and still allow for oyster cultivation on a commercial

scale that is profitable to the mariculture industry. Pacific oysters (*Crassostrea gigas*) have been grown in the intertidal zone of Humboldt Bay, CA for over 60 years, and recent management steps have been taken to discontinue the practices of bottom-culture and harvesting with a mechanical dredge in an effort to reduce damage to eelgrass beds. To further understand the potential ecological effects of off-bottom (long- line) oyster culture on eelgrass communities, we worked in cooperation with the Humboldt Bay - Mariculture Monitoring Committee to establish a series of experimental oyster long- line plots and eelgrass reference areas (controls). The experimental design included evaluation of Best Management Practices (BMPs) for the spacing between off-bottom oyster long- lines. Experimental oyster plots (30 m X 30 m) were established at line spacing distances of 1.5 ft (narrow), 2.5 ft (standard), 5 ft (wide) and 10 ft (very wide). We sampled the study plots quarterly between 2001-03 for the presence of eelgrass, residual oysters, algae, shell rubble, and other cover types, and we collected benthic infauna cores, deployed baited fish traps and measured water quality, sedimentation, light intensity, and oyster growth. After a period of two years, eelgrass spatial cover and shoot density were consistently high within the control (reference areas) and lowest within the 1.5 ft oyster line spacing plot. Eelgrass metrics generally scaled directly with oyster density, and the spatial cover and density of eelgrass plants within the 10 ft spacing plot were within the range of variability observed in the reference (control) study plots. Preliminary analysis of benthic infauna cores produced a species list of over 100 taxa, including several invertebrates that are known prey items for estuarine and anadromous fish. Comparisons of incident light levels inside and outside oyster cultivation areas suggest that factors other than light availability are probably responsible for the reduced abundance of eelgrass in closely-spaced off-bottom oyster culture sites. Results from this set of field experiments indicate that eelgrass beds and commercial oysters can coexist in Pacific Northwest estuaries, and that implementation of BMPS for reduced density of oysters may aid the recovery and restoration of eelgrass communities.

Tallman, J.C., and G.E. Forrester. 2007. **Oyster grow-out cages function as artificial reefs for temperate fishes.** Transactions of the American Fisheries Society. (in Press) (oyster grow-out cages provide good quality habitat for fishes).

No abstract identifying these species for this category.

Watson-Capps, J.J., and J. Mann. 2005. **The effects of aquaculture on bottlenose dolphin (Tursiops sp.) ranging in Shark Bay, Western Australia.** Biological Conservation. Vol. 124, no. 4, pp. 519-526. Aug. IS: ISSN 0006-3207.

The increasing presence of aquaculture in coastal waters calls for a better understanding of its environmental effects. Currently little information is available on the impact of shellfish farms on cetaceans. Here we compare long-term ranging patterns of adult female bottlenose dolphins (Tursiops sp. in Shark Bay, Western Australia) before and during full-scale pearl oyster farming operations, to determine if they were displaced. When the exact location of the oyster farm was determined, the dolphins decreased their use of that area after the farm was in place. Tracks of adult female dolphin movement near the oyster farm were compared to tracks of dolphin movement near an ecologically similar area where no oyster farm existed. Tracks near the oyster farm were less likely to enter the oyster farm itself than tracks near an ecologically similar location. This suggests that shellfish aquaculture could have a large impact on small cetaceans. The analytical techniques discussed apply broadly to aquatic and terrestrial animals.

Keywords: Farms; Aquaculture; Conservation; Pearls; Environmental effects; Coastal waters; Tursiops; Australia, Western Australia..

3.5 Scallops

Crawford, C., I. Mitchell, and C. Macleod. 2001. **Effects of shellfish farming on the environment.** Affiliation - Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Aquaculture 2001: Book of Abstracts. 143 p. Conference - Aquaculture 2001, Lake Buena Vista, FL (USA), 21-25 Jan 2001.

The production of shellfish, mainly *Crassostrea gigas*, in Tasmania, Australia is approximately 2,500 metric tons per annum, which is small by world standards. Nevertheless, there is considerable community opposition to the expansion of the industry, partly because of concerns about possible detrimental effects on the environment. As a consequence, several projects were instigated to investigate the interactions between shellfish farming and the environment. The effects of shellfish farming on the benthic environment were investigated in detail at three deep water shellfish farms in Tasmania which have had a relatively high level of production. Benthic samples collected from within and outside the farm area were analyzed for physical/chemical variables, and composition and abundance of the invertebrate faunal community. Rates of sediment deposition were measured, and sections of the seabed were recorded using a video camera. 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.

Keywords: Marine aquaculture; Shellfish culture; Oyster culture; Environmental effects; Benthic environment; Ecosystem disturbance; Disease transmission; Eutrophication; Sedimentation; Suspended particulate matter; Particulate organic matter; Particulate flux; Man-induced effects; Aquaculture; Human impact; Population-environment relations; Sediments; Risk assessment; Pests; Pathogens; Coastal zone; Estuaries; Filter feeders; Nutrients; Environmental impact; Crassostrea gigas; Australia, Tasmania; PSE, Australia, Tasmania.

Duarte, P., R. Meneses, A.J.S. Hawkins, M. Zhu, J. Fang, and J. Grant. 2003. **Mathematical modelling to assess the carrying capacity for multi-species culture within coastal waters.** Ecol. Model. 168(1):109-143.

In the context of aquaculture, carrying capacity is generally understood as the standing stock of a particular species at which production is maximized without negatively affecting growth rates. The estimation of carrying capacity for aquaculture is a complex issue. That complexity stems from the many interactions between and among cultivated and non-cultivated

species, as well as between those species and their physical and chemical environments. Mathematical models may help to resolve these interactions, by analyzing them in a dynamic manner. Previous carrying capacity models have considered the biogeochemical processes that influence growth of cultivated species in great detail. However, physical processes tend to have been addressed very simplistically. Further, most modelling has been for monocultures, despite the increasing importance of multi-species(=polyculture) systems. We present here a two-dimensional coupled physical–biogeochemical model implemented for Sungo Bay, Shandong Province, People's Republic of China. Sungo Bay is used for extensive polyculture, where bivalve shellfish and kelp are the most important cultivated species. Data collected over 13 years (1983–2000) was available for modelling. Our main objectives were to implement the model, achieving reasonable calibration and validation with independent data sets, for use in estimating the environmental carrying capacity for polyculture of scallops and oysters. Findings indicate that the model successfully reproduces some of the main features of the simulated system. Although requiring some further work to improve predictive capability in parts, predictions clearly indicate that Sungo Bay is being exploited close to the environmental carrying capacity for suspension-feeding shellfish. Comparison of different culture scenarios also indicates that any significant increase in yield will depend largely on a more optimal spatial distribution of the different cultivated species.

Keywords: carrying capacity, aquaculture, coastal waters

3.6 Eelgrass and Macroalgae

Cabaço, S., A. Alexandre, and R. Santos. 2005. **Population-level effects of clam harvesting on the seagrass *Zostera noltii***. Marine Ecology Progress Series298: 123–129.

Seagrass declines have been reported worldwide, mostly as a consequence of anthropogenic disturbance. In Ria Formosa lagoon, southern Portugal, the intertidal meadows of *Zostera noltii* are highly disturbed by clam harvesters. The most common technique used to collect the clams consists of digging and tilling the sediment with a modified knife with a large blade. Here we present both descriptive and experimental evidence of the negative effects of clam harvest on the *Z. noltii* populations of Ria Formosa. A comparison between disturbed and undisturbed meadows suggests that clam harvesting activities change the species population structure by significantly reducing shoot density and total biomass, particularly during August, when the harvest effort is higher. Experimental harvest revealed a short-term impact on shoot density, which rapidly recovered to control levels during the following month. An experimental manipulation of rhizome fragmentation revealed that plant survival is reduced only when fragmented rhizomes are left with 1 intact internode. Shoot production and rhizome elongation and production of fragmented rhizomes having 2 to 5 internodes were not significantly affected, even though growth and production were lower when only 2 internodes were left. Experimental shoot damage at different positions along the rhizome had a significant effect on plant survival, rhizome elongation, and production only when the apical shoot was removed. Our results show that clam harvest can adversely affect *Z. noltii* meadows of Ria Formosa while revealing a low modular integration that allows the species to rapidly recover from physical damage.

Keywords: Clam harvest, Physical damage, Zostera noltii, Seagrass, Disturbance, Population recovery.

Craig, C.A.,* K. Rowell, and J.L. Ruesink. 2006. **How does geoduck aquaculture affect eelgrass in south Puget Sound?** Presented at the annual meeting of the Pacific Estuarine Research Society, February 16-18, 2006, Friday Harbor, Washington. * Department of Biology, University of Washington, Seattle, WA. *cac25@u.washington.edu.*

Geoduck (*Panopea abrupta*) aquaculture happens on a large scale in south Puget Sound in some of the same areas that harbor eelgrass (*Zostera marina*), a protected species in Washington. It is crucial to understand the impacts of geoduck aquaculture on eelgrass to make informed management decisions. In long-term surveys, eelgrass showed strong seasonal patterns in the following variables: prolific branching of the rhizome in spring; high density, individual plant biomass, and internode length in summer; and high growth rates in summer, except during periods of heat stress. We experimentally tested how eelgrass responded to nutrients, disturbance, and geoducks by manipulating each of these factors. The presence of geoducks reduced eelgrass densities by 50%, but only in summer. Recovery of small (1 m_2) removals of eelgrass occurred slowly (>17 mo) and exclusively by vegetative growth. There was no detectable effect of any treatment on eelgrass growth, although the presence of geoducks increased porewater ammonium by 20%. The overall porewater nutrients were high and possibly not limiting for eelgrass. Our small-scale results were mirrored in samples from aquaculture beds, which had higher porewater nutrients than with eelgrass. Our results suggest limited impacts on eelgrass of geoducks themselves, but lingering effects of aquaculture practices that involve substantial disturbance of eelgrass.

Crawford, C.M., C.K. Macleod, and I.M. Mitchell. 2003. **Effects of shellfish farming on the benthic environment.** Aquaculture. Vol. 224, no. 1-4, pp. 117-140. 30 Jun. IS: ISSN 0044-8486.

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 coverage of fine filamentous algae and patchy bacterial mats directly under some longlines and this algae is thought to have fallen off the mussel longlines. At another farm dense beds of seagrass were observed in the videos 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.

De Casabianca, M-L., T. Laugier, and D. Collart. 1997. **Impact of shellfish farming eutrophication on benthic macrophyte communities in the Thau lagoon, France.** Aquaculture International. Vol. 5, no. 4, pp. 301-314. Jul.

In a large marine lagoon (Thau lagoon, southern France) with a shellfish farming dominant eutrophication, the macrophyte communities were sampled by six transects of three depths (1.5, 2.5 and 5 m) and their characteristics (species composition, diversity and biomass) were described in relation to environmental and sediment parameters. With increasing eutrophication (total inorganic nitrogen, 0.140-0.295 mg/l; dissolved reactive phosphorus, 0.045-0.110 mg/l; and N/P atomic ratio, 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% dry wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in SW sites and could be distinguished by their sedimentary features. In sites (NE) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfish tables, and a *Gracilaria bursa-pastoris* community in the shellfish tables (lower incident light).

Keywords: lagoons; marine environment; shellfish farming; eutrophication; macrophytes; benthic flora; algae; degradation; biological sampling; aquaculture effluents; shellfish culture; environmental impact; marine pollution; coastal lagoons; Zostera; Gracilaria; France, Thau lagoon; France; MED, France.

Dewey, W.F. 2000. **The various relationships between shellfish and water quality.** Affiliation- Taylor Shellfish Company, Inc., Journal of Shellfish Research. Vol. 19, no. 1, p. 656. Jun. Conference - 92. Annual Meeting of the National Shellfisheries Association, Seattle, Washington (USA), March 19-23, 2000.

Shellfish Growers dedicate considerable resources to protect and restore clean water to produce wholesome shellfish which are safe to consume raw. This is the foundation of the National Shellfish Sanitation Program. Recognized as equally important is the role that filter feeding molluscan shellfish play in cleansing water. Touted as keystone species, significant efforts have been made to reintroduce oysters to New York Harbor and the Chesapeake Bay to improve water quality in these systems. Aside from the valuable function the oysters physically serve as habitat and refuge is their ability to filter huge volumes of phytoplankton which, in heavy blooms, can cause low dissolved oxygen problems when the blooms die off as well as blocking critical sunlight for seagrasses and macroalgae. In the Pacific Northwest a citizens group, organized in opposition to mussel farm expansion on the basis of the aesthetic impact, is attempting to change the water-cleansing image of shellfish into a water-polluting image. The group recently filed suit in federal court claiming the feces, pseudofeces, mussel shell debris and escaped mussel spat from propagating mussels are a point source of pollution and require a National Pollution Discharge Elimination System (NPDES) permit under the Clean Water Act. This paper discusses the dichotomy between the views of shellfish as polluters versus the view of shellfish as capable of improving water quality and habitat.

Keywords: Water quality; Aquaculture effluents; Environmental impact; Shellfish culture; Filter feeders; Filtration; Pollution control; Oyster fisheries; Mussels; Water Pollution Effects; Effluents; Aquaculture; Oysters; Shellfish; Seafood; Water quality (Natural waters); Bivalves (Mussels); Pollution (Water); Effluent; Bivalves (Oysters); Food (see also Animal foodstuffs).

Dumbauld, B., D. Armstrong, C. Roegner, K. Feldman, L. Loggerwell, and S. Rumrill. 2001. **Implementing a study to determine the value of molluscan shellfish culture areas as fish habitat in West Coast estuaries.** Journal of Shellfish Research. Vol. 20, no. 3, p.1196. Dec. Conference: Annual Meeting of the National Shellfisheries Association Pacific Coast Section and Pacific Coast Shellfish Growers Association, Warm Springs, OR (USA), 27-29 Sep 2000.

The ecological role of bivalve molluscs in estuarine systems has recently been recognized in other areas including Europe and eastern North America where studies have been completed and in some cases shellfish restoration efforts initiated. Comparable studies are lacking however from estuaries on the West Coast, where bivalve (particularly oyster and clam) aquaculture often dominates the intertidal landscape. Due to increasing interest, especially with regard to the potential impacts of oyster aquaculture activities on juvenile salmonids (driven by the listing of several stocks under the Endangered Species Act), we are initiating a study designed to quantify both adverse, but also beneficial impacts of shellfish farming on selected estuarine fauna and flora. We will focus our initial efforts on oyster ground culture and on eelgrass as benthic habitats given the extent and previously documented value of these habitats respectively. Field and laboratory objectives include: 1) utilizing remote sensing and ground-truthing to document annual variability in eelgrass cover in oyster culture and eelgrass meadows in Willapa and Coos Bay estuaries; 2) compare species diversity, density and biomass in culture areas as well as eelgrass meadows; 3) conduct field experiments to examine the impacts of various culture activities on eelgrass and associated infaunal and epifaunal communities; and 4) conduct surveys of fish utilization in oyster beds and eelgrass meadows. Finally, we hope to prepare guidelines to assist both shellfish farmers and estuarine managers in avoiding and/or reducing adverse impacts on estuarine habitat while maximizing the potential beneficial impacts of aquaculture activities.

Keywords: Shellfish culture; Oyster culture; Culture effects; Brackishwater aquaculture; Environmental impact; Community composition; Sea grass; Benthos; Intertidal environment; Nursery gr ounds; Estuaries; Man-induced effects; Ecosystem disturbance; Biological stress; Ecosystem management; Anadromous species; Salmonidae; Zostera marina; Crassostrea gigas; INE, USA, West Coast; INE, USA, Oregon, Coos Bay; INE, USA, Washington, Willapa Bay.

Dumbauld, B.R. and S. Wyllie-Echeverria. 2003. **The influence of burrowing thalassinid shrimps on the distribution of intertidal seagrasses in Willapa Bay, Washington, USA.** Aquatic Botany 77:27-42.

Experiments to investigate the effect of oyster shell and the pesticide carbaryl used to control burrowing shrimp on tideflats in Willapa Bay showed that removal of shrimp with the pesticide causes eelgrass (particularly *Zostera japonica* but also *Z. marina* where present) to survive and expand its distribution. The shrimp cause seeds to be distributed to depth, but the effect appears to be due to seedling survival which is greatly reduced when shrimp bioturbation is present. [Funding: USDA WRAC].

Hosack, G.R., B.R. Dumbauld, J.L. Ruesink, D.A. Armstrong. 2006. **Habitat associations of estuarine species: comparisons of intertidal mudflat, seagrass (*Zostera marina*) and oyster (*Crassostrea gigas*) habitats.** Estuaries and Coasts 29:1150-1160.

Compares densities of several types of organisms across habitat types in Willapa Bay. Density and diversity of epibenthos (small surface-dwelling invertebrates) was higher in structured habitats (eelgrass and oyster) than open mud. Infauna (invertebrates living in the

sediment) were most abundant in eelgrass. Nekton (fish and crabs funneled into hoop nets set on the tideflat) densities did not differ by habitat type though patterns were apparent for some species and diversity was highest in structured habitats. [Funding: USDA WRAC. GRH at UW SAFS].

MacKenzie, C.L. Jr. 1997. **The natural history and habitat characteristics of softshells (*Mya arenaria*) in northern New Jersey.** Journal of Shellfish Research. Vol. 16, no. 1, pp. 310. Jun. IS: ISSN 0077-5711.

The natural history and habitats of softshell clams (*Mya arenaria*) in Raritan Bay and the Navesink and Shrewsbury Rivers, NJ, were studied from 1993-96. Settlement densities of juveniles ranged as high as 7,000/m super(2). Causes of mortality varied among beds. Juveniles that settled on impenetrable hard clay substrates did not survive. Most settled in sand sediments, fewer in mud. Within weeks after settlement, many clams emerged from the bottom (cause not identified), laid on the surface, and died in 4-6 weeks. Observed predators of clams were fishes (mainly Fundulus sp.), black ducks (Anas rubripes), and horseshoe crabs (Limulus polyphemus). Man-related causes of mortality were: 1) smothering under mats of sea lettuce (*Ulva lactuca*) (possibly caused by eutrophication); 2) large waves dislodging the clams from sediments (this followed the loss of eelgrass in the 1940's; eutrophication has since prevented eelgrass growth; before then, the eelgrass had dampened the effects of waves on the clams); and 3) in July-August, 199 5, most clams in the two rivers died when water temperatures persisted at about 30-31 degree C for several days (global warming?). In beds with no evident causes of mortality after the clams had attained a length of at least 15 mm, the survival rate was about 50% in 21 months, September 1993 to June 1995. The clams attained market size about 2 years after settlement.

Field studies have also shown that shellfish populations promote seagrass productivity. (Peterson and Heck 1999

Rheault, R.B. 2001. **Eelgrass is Great, but Shellfish Aquaculture is Better. Marine Aquaculture and the Environment:** A Meeting for Stakeholders in the northeast Tlusty.Cape Cod Press Falmouth, Massachusetts pp. 203-210.

In response to federal regulations established by the National Marine Fisheries Service, states are now required to "preserve, protect and where possible, restore submerged aquatic vegetation" (SAV), especially eelgrass. In recent years, eelgrass beds have been declining up and down the Atlantic coast. The causes of these declines are well documented. Since the federal laws protecting SAV came out, several aquaculture operations have come under fire. Large clam farms in Virginia and oyster farms in Washington State have come under heavy regulatory pressure to cease or move because of perceived interference with eelgrass.

Keywords: Environmental impact, Marine aquaculture, Phytobenthos, Shellfish culture, Aquaculture regulations, Environmental protection, Zosteraceae, Zostera marina, USA Coasts, eelgrass.

Ruesink, J., and S. Hacker. 2005. **Scale-dependent and indirect effects of filter feeders on eelgrass: Understanding complex ecological interactions to improve environmental impacts of aquaculture**. Annual Progress Report, Western Regional Aquaculture Center, University of Washington, Seattle.

No abstract identifying these species for this category.

Ruesink, J.L. and K. Rowell, in preparation. **Geoduck clam (*Panopea abrupta*) aquaculture as press and pulse perturbations to eelgrass (*Zostera marina*).**

Experimental study of the effects of geoducks and fertilizer on eelgrass density and growth, and the pace and manner of recovery of small (1 m^2) gaps created in an eelgrass bed. Eelgrass density was depressed in summer by space competition with geoducks; growth rates were not affected. Gaps recovered over 2 years exclusively by Regrowth from the edges. When the geoducks were harvested at the end of the experiment, eelgrass shoot density dropped >70%. The results of this study should not be extrapolated widely because south Puget Sound tends to contain a very sensitive type of eelgrass – small, high-density plants with little sexual reproduction. [Funding: USDA WRAC, Shellfish industry].

Rumrill, S.S. and V.K. Poulton. 2003. **Ecological role and potential impacts of molluscan shellfish culture in the estuarine environment of Humboldt Bay, CA.** Journal of Shellfish Research. Vol. 22, no. 2, p. 607. Sep. IS: ISSN 0730-8000.

The intertidal mudflats of Humboldt Bay, CA, provide habitat for eelgrass (*Zostera marina*), invertebrates, shellfish, finfish, and birds. Humboldt Bay is also the leading producer of Pacific oysters (*Crassostrea gigas*) in California. We have completed the first year of a 3-year project to identify and quantify the effects of commercial oyster mariculture in tideflat habitats, eelgrass beds, and invertebrate communities. Experimental oyster long-line spacing plots were established for comparison to a ground culture site and 6 reference sites (no oysters). We sampled study plots quarterly between Aug 2001-Aug 2002 for presence of eelgrass, oysters, and other cover types. We collected infaunal cores, deployed fish traps, and measured water quality, sedimentation, light intensity, and oyster growth characteristics. Eelgrass shoot density and percent cover were consistently highest in an eelgrass bed control site, lowest at the 1.5-ft. long-line spacing plot, and most variable at the ground culture site. Eelgrass metrics in the other longline spacing plots were generally lower but within the range of variation exhibited by the reference sites. Preliminary analysis of invertebrate cores has produced a species list of over 70 taxa, many of which are known prey items for estuarine fish. Sedimentation measurements showed no consistent patterns among experimental long-line plots. Oyster growth measurements did not differ substantially between long-line plots; oysters grew 20-35 mm in length and 16-22 mm in width between May and Aug 2002. Light intensity was lower beneath oyster long-lines, but did not differ substantially between the 1.5 and 5 ft. spacing plots.

Tallis, H.M., J.L. Ruesink, B.R. Dumbauld, S.D. Hacker, L.M. Wisehart, in preparation. **Oysters and aquaculture practices affect eelgrass density and productivity in a Pacific Northwest estuary.**

Observational study of *Z. marina* density, biomass, and relative growth rates in 4 habitat types: mechanically-harvested ground, hand-picked ground, longline aquaculture, and nearby eelgrass beds in two regions of Willapa Bay. Eelgrass density was 30-70% lower on aquaculture beds than in nearby eelgrass beds. While aquaculture may promote eelgrass at the expense of burrowing shrimp at the landscape scale, eelgrass appears susceptible to space competition and disturbance at the bed scale. In Willapa bay, eelgrass is resilient to this disturbance and able to recover in about 2 years. Interestingly, eelgrass was not able to compensate for lower densities by producing larger plants – in fact, the opposite occurred, indicating that both individual and

population parameters are affected by some aquaculture practices. Oysters appear neither to enhance nor reduce shoot growth, suggesting they are not fertilizing or eutrophying sediments. All aquaculture practices allow co-existing eelgrass, but at different levels – higher under longlines and in hand-picked ground culture than in dredged beds. Statistical analyses are still on-going, so the numbers and relative values reported here should not be quoted yet. [Funding: USDA WRAC, Budweiser Foundation].

Tsai, C.C. et al. **Undergraduate thesis research on the reciprocal effects of *Z. japonica* and *R. philippinarum*** – field work ends September 2007.

Results to date indicate that introduced eelgrass reduces water flow and facilitates its own growth (possibly by trapping water and reducing desiccation). [Funding: Howard Hughes Medical Institute, UW Department of Biology].

Wagner, E.L., et al. in preparation.

Experimental study involving live oyster, oyster shell, and fertilizer addition to *Z. marina* beds in two regions of Willapa Bay. Confirms space competition from oysters at cover >25%. Neither fertilizer nor oyster addition affected eelgrass relative growth rate. Preliminary results suggest *lower* ammonia concentrations in porewater due to oysters (denitrification by associated microbes?). [Funding: USDA WRAC].

Ward, D.H., A. Morton, T.L. Tibbitts, D.C. Douglas, and E. Carrera-Gonzalez. 2003. **Long-term Change in Eelgrass Distribution at Bahia San Quintin, Baja California, Mexico, Using Satellite Imagery.** Estuaries. 26(6):1529-1539.

Seagrasses are critically important components of many marine coastal and estuarine ecosystems, but are declining worldwide. Spatial change in distribution of eelgrass, *Zostera marina L.*, was assessed at Bahia San Quintin, Baja California, Mexico, using a map to map comparison of data interpreted from a 1987 Satellite Pour 1'Observation de la Terre multispectral satellite image and a 2000 Landsat Enhanced Thematic Mapping image. Eelgrass comprised 49% and 43% of the areal extent of the bay in 1987 and 2000, respectively. Spatial extent of eelgrass was 13% less (-321 ha) in 2000 than in 1987 with most losses occurring in subtidal areas. Over the 13-yr study period, there was a 34% loss of submerged eelgrass (-457 ha) and a 13% (+136 ha) gain of intertidal eelgrass. Within the two types of intertidal eelgrass, the patchy cover class (85% cover) declined (-114 ha). Most eelgrass losses were likely the result of sediment loading and turbidity caused by a single flooding event in winter of 1992–1993. Recent large-scale agricultural development of adjacent uplands may have exacerbated the effects of the flood. Oyster farming was not associated with any detectable losses in eelgrass spatial extent, despite the increase in number of oyster racks from 57 to 484 over the study period.

(Ward et al 2003) concluded that oyster farming was not associated with any detectable losses in eelgrass spatial extent, despite an increase in oyster racks from 57 to 484 between the years 1987 and 2000.

Wisehart, L.M., S.D. Hacker, B.R. Dumbauld, and J.L. Ruesink. 2006. **Oyster aquaculture may positively affect eelgrass (*Zostera marina L.*) through enhanced seed production and germination.** Abstract. National Shellfish Association. Monterey, CA.

No abstract identifying these species for this category.

Wisehart, L.,* and S. Hacker. 2006. **Assessing the importance of early life history stages of eelgrass (*Zostera marina* L.) in response to aquaculture disturbance.** Presented at the annual meeting of the Pacific Estuarine Research Society, February 16-18, 2006, Friday Harbor, Washington. *Dept of Zoology, Oregon State University, Corvallis, OR. *wiseharl@science.oregonstate.edu.*

The interactions between oyster aquaculture and eelgrass need to be explored to assist shellfish growers in the development of sustainable farms while ensuring ecological integrity in aquaculture areas. Past studies have identified negative effects on eelgrass density and cover but the interactions between aquaculture and eelgrass recruitment have not been addressed. We conducted surveys in Willapa Bay, WA and found higher seedling densities in dredged beds than in longlines or reference areas. To test the hypothesis that dredging positively influences germination we added seeds to each aquaculture type in paired control and eelgrass removal plots. March germination was highest in dredged beds and removal of adults had a positive effect, although by April there was no difference between dredged beds and reference areas and no removal effect. In August we found a negative relationship between seedling biomass and adult density. We also estimated seed density by counting the number of seeds produced per shoot in each habitat type and found this to be highest in dredged beds and lowest in longlines. Our data suggest that although eelgrass in a dredged bed may be reduced following harvest, rapid recovery may be possible due to enhanced recruitment resulting from the lack of competition with adult plants.

Wisehart, L.M., S.D. Hacker, H.M. Tallis, J.L. Ruesink, F. Oyarzun, and B.R. Dumbauld. 2004. **The effects of different aquaculture techniques on *Zostera marina* biomass, density, and growth rates in Willapa Bay, Washington.** Journal of Shellfish Research. Vol. 23, no. 2, p. 660. Aug. IS: ISSN 0730-8000.

Influence of shellfish aquaculture on eelgrass has been understudied in Pacific Northwest estuaries. In an effort to quantify possible positive and negative effects of shellfish aquaculture, we investigated the relationship between oyster culture type and eelgrass at three sites in Willapa Bay, Washington. At each site, we sampled an off-bottom long-line culture area, a dredged ground culture area, a handpicked ground culture area, and an area without aquaculture. We measured the standing biomass, percent cover and growth rate of eelgrass, as well as the density of vegetative and flowering shoots. In general, we found the largest growth rates in areas with off-bottom culture and those without aquaculture; these areas also had the greatest eelgrass biomass, density, and percent cover. Eelgrass growth and biomass were lower in handpicked and dredged culture areas and did not significantly differ from one another. Interestingly, there were significant site and culture type interactions for most variables suggesting that site-specific conditions may be as influential as culture technique in determining eelgrass growth.

Wisehart, L.M., B.R. Dumbauld, J.L. Ruesink, S.D. Hacker. 2007. **Importance of eelgrass early life history stages in response to oyster aquaculture disturbance.** Marine Ecology Progress Series 344:71-80.

Compares seed production and germination in eelgrass, mechanically-harvested, and longline aquaculture in Willapa Bay. Seed production and germination were highest in dredged beds. Because the experimental removal of adults locally enhanced germination, the response on

dredged beds is at least in part due to reduction of competition among eelgrass shoots. [Funding: USDA WRAC; LMR at Oregon State University].

3.7 Other Shellfish Aquaculture Effects References

Barrington, S., S. Long, S. Thompson, and C. Wendorf. **Pollution and coastal zone management: a case study of shellfish bed closures in St. Margaret's Bay, Nova Scotia.**

Current research attributes land-based development as the major cause of marine pollution. Shellfish, with their ability to filter large amounts of water, are considered an indicator species for declining water quality due to chemical and bacterial contamination from point and non-point source pollution. The Head of St. Margaret's Bay has experienced a great increase in the size of its shellfish closure area in the past two years. Yet between 1995 and 2001, the closure area essentially remained unchanged. It is unknown whether this dramatic increase is the result of cumulative environmental impact and/or a significant pollution event occurring sometime in 2002. The report concerns the recent large increase in shellfish closures in the St. Margaret's Bay area. Although there is reason to believe that leaking septic tank systems in older residential developments are the likely source of increased levels of fecal coliform, there is an interest in expanding the scope of probable causes by investigating other contributing factors from both land and water use practices. Accordingly, this report will examine a variety of land and water use activities that may be linked to fecal coliform related shellfish closures in the St. Margaret's Bay area. It will also explore a broad range of issues pertaining to coastal zones that are applicable to St. Margaret's Bay, including legislation, marine environmental quality indicators, community involvement and education, and integrated coastal zone management.

Keywords: legislation, coastal zone management, shellfish bed closures, Nova Scotia.

Blanc, G. 1997 . **Introduced pathogens in European aquatic ecosystems: theoretical aspects and realities. Species-introduction-in-the-freshwater-aquatic-environment.** Proceedings of the seminar. Les Introductions D' Especes Dans Les Milieux Aquatiques Continentaux En Metropole. Bergot, F. coord.;Vigneux, E. coord.(344-345):471-487.

The multiplicity of fish and shellfish introductions or translocations was amplified in the last few decades and was accompanied by the introduction of pathogens in inland hydrosystems. However, the analysis of pathogens origins revealed that some paths remain underestimated. The progress in the methodologies and technics of identification lead to recent advances in the analysis of pathogens introductions but with this progress arose the problem of perception threshold. A review of the literature yields to the facts that almost one hundred pathogen species were introduced in European hydrosystems. The characters in favour of the establishment of the pathogens are described. The diversity and the apparent non -predictability of the introduced pathogens impacts are detailed both in field and theoretical contexts. A conceptual framework of risk analysis and propositions are provided.

Keywords: introduced species, pathogens, identification check, lists, environmental –impact, economics, methodology, inland water, environment, estuaries, risks.

Bower, S.M., and S.E. McGladdery. **A scientific review of the potential environmental effects of aquaculture in aquatic ecosystems Volume II**.

This paper reviews the knowledge available on the wild-cultured host dynamics of shellfish infectious agents. As with finfish, shellfish health profiles are based mainly on knowledge derived from cultured stocks. This reflects an ease of access to cultured stock, which can introduce a sampling bias that complicates accurate pinpointing of disease sources.

Keywords: Canada, DFO, Mollusc, Culture, Shellfish, Disease, Environmental Impacts, shellfish sanitation.

Buhle, E.R., M. Margolis, J.L. Ruesink. 2005. **Bang for buck: cost-effective control of invasive species with different life histories.** Ecological Economics 52:355-366.

Matrix population model representing *Ocinebrina inornata* (Japanese oyster drill), which demonstrates that manual control of this invasive species is most cost-effective when it targets several life-history stages simultaneously – both adults and egg capsules (but during the summer when the latter are found easily). An additional manuscript in preparation compares *O. inornata* with *Urosalpinx cinerea*, the eastern oyster drill, which has higher adult survival, lower reproduction, and overall similar population growth rate. [Funding: NOAA Sea Grant].

Carver, C.E., A. Chisholm, and A.L. Mallet. 2003. **Strategies to mitigate the impact of *Ciona intestinalis (L.)* biofouling on shellfish production.** Journal of Shellfish Research. Vol. 22, no. 3, pp. 621-631. Dec. IS: ISSN 0730-8000.

A sudden increase in the population of the solitary ascidian *Ciona intestinalis (L.)* is causing serious biofouling problems for shellfish growers on the Atlantic coast of Nova Scotia, Canada. The objective of the present study was to document the growth, spawning, and recruitment patterns of this species, and to develop strategies to minimize its impact on the culture of European oysters at two locations in Lunenburg Bay, Nova Scotia. Profiles of condition index, which may be indicative of spawning activity, suggested that the *C. intestinalis* population at the Bayport site spawned from mid-May through June, whereas the population at Mason's Beach spawned from mid-July to mid-August. Histological assessment of reproductive status indicated a period of gametogenesis in March-April (>3 degree C) followed by spawning from mid-May to mid-August (>8 degree C). Although mature eggs were observed in the ovary in July-August, spawning trials suggested a decline in the fecundity of the Bayport population during this period. Two main recruitment events were observed at Mason's Beach (June and August), but only one at Bayport (June). From the data on fecundity and settlement rates, it was estimated that a 100-mm long *C. intestinalis* (0.6 g dry w eight) may produce 12,000 eggs in a season and that recruitment intensity may reach 3,000 individuals m super(-2). Laboratory predation trials indicated that rock crabs (*Cancer irroratus*) consumed significantly more *C. intestinalis* than did green crabs (*Carcinus maenas*). A maximum predation rate of 11 individuals per day per rock crab (80 mm carapace width) was recorded at peak water temperatures of 18 degree C. In a series of chemical width eradication trials, exposure to 5% acetic acid was found to be a more effective strategy for eliminating *C. intestinalis* than hydrated lime, saturated brine, or hypochlorite solution. Total mortality was observed following exposure to 5% acetic acid for 15 to 30 s, with no corresponding mortality in the control mussels or oysters. Initial field trials indicated that spraying with acetic acid might prove to be an effective means of eliminating *C. intestinalis* under commercial conditions.

Chopin, T., C. Yarish and C. Neefus, et al. 2001. **Aquaculture from a different angle: The seaweed perspective, and the rationale for promoting integrated aquaculture. Marine Aquaculture and the Environment: A Meeting-for Stakeholders in the northeast** Tlusty, Cape Cod Press Falmouth, Massachusetts pp. 69-72.

Aquaculture, especially in the Western World, is very often conducted in a monotypic manner without employing a balanced approach for long-term sustainability, which would take into consideration the assimilative capacity of the ecosystem. To develop innovative, effective and responsible practices - maintaining the health of coastal waters, and, consequently, of the cultured organisms - fed aquaculture types (e.g. finfish, shrimp) and organic or inorganic extractive aquaculture types (e.g. shellfish or seaweed) need to be integrated to avoid pronounced shifts in coastal processes. Most impact studies on aquaculture operations typically have focused on organic matter/sludge deposition. However, the inorganic output of aquaculture is presently emerging as a pressing issue as nutrification of coastal waters is a worldwide phenomenon, which has not spared the Bay of Fundy (Chopin et al. in press). Conversion, not dilution, is the solution so that the "wastes" of one resource user become a resource (fertilizers) for the others.

Keywords: Polyculture, Marine aquaculture, Environment management, Pollution control.

Crawford, C., M. Catriona, C. Macleod, and I. Mitchell. 2003. **Effects of shellfish farming on the benthic environment.** Aquaculture. 224(1-4):117-140.

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 coverage of fine filamentous algae and patchy bacterial mats directly under some longlines and this algae is thought to have fallen off the mussel longlines. At another farm dense beds of seagrass were observed in the videos 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.

Keywords: Shellfish farming, Environmental impact, Benthic environment, general aquaculture.

Davis, R.C., and F.T. Short. 1997. **Restoring eelgrass, *Zostera marina L.*, habitat using a new transplanting technique: The horizontal rhizome method.** Aquatic Botany. 59(1-2):1-15.

Using a technique we call the 'horizontal rhizome method', we recently transplanted 2.52 ha of eelgrass in the Great Bay Estuary, New Hampshire, to mitigate for port expansion impacts to an existing eelgrass population. The project represents the largest, most northerly eelgrass transplanting ever attempted on the east coast of the United States. For our revised method, we created a planting unit (PU) by overlapping the rhizomes of two eelgrass shoots in opposite

directions and securing them horizontally into the sediment with a bamboo staple. A variation of the bare-root technique, the horizontal rhizome method reduces the number of plants required by up to 80%, has less impact on the donor site, and provides survival rates that equal or exceed that of other methods. One-year survival rates at three subtidal transplant sites were 75-95% for 1993 transplants, and were 98-99% at four of the five subtidal sites planted in 1994. One-year survival rates varied tremendously; low percent survivals resulted from ice damage at all intertidal sites and animal disturbance at some subtidal sites. We found that intertidal transplanting in this tidally dynamic estuary was not successful (sites had 0-15% survival). Sea ice damage, in conjunction with tidal action, caused this lack of success, although natural intertidal eelgrass beds occur both up- and down-estuary of our transplant sites. At the less successful subtidal sites, low survival rates of 1-5% resulted from disturbance of newly transplanted shoots by crabs and clam worms. Overall survival rates for subtidally transplanted eelgrass using the horizontal rhizome method equaled or exceeded those reported for other methods. Shoot density at one transplant site (234 shoots m-2 +/- SE 52.0) exceeded that of the control site (162 shoots m-2 +/- 20.6) within 1 yr of transplanting. Shoot density at all subtidal transplant sites surpassed that of the control site (100 shoots m-2 +/- 11.6) within 2 yr. The horizontal rhizome method is a successful, minimum-impact technique for large scale eelgrass transplanting efforts in a northern New England cold water environment.

De Casabianca, L., T. Laugier, E. Marinho-Soriano, and D. Collart. 1998. **Environmental impact of shellfish farming in a Mediterranean lagoon (Thau, south France).** World Aquaculture Society. Aquaculture '98 Book of Abstracts99.

The French Mediterranean lagoon of Thau is characterized by an important shellfish farming dominated eutrophication (ca 15 times the terrestrial inputs). On the basis of increasing eutrophication, six areas were identified and monitored for one year (sediments features, overlying and sediment pore water nutrients, macrophytic biomass, species composition and diversity of macrophytes). With increasing eutrophication (total inorganic dissolved nitrogen: 0.140-0.295 mg l-1; dissolved reactive phosphorus: 0.045-0.110 mg l-1 and N/P atomic ratio: 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% d.wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in S-W sites and could be distinguished by their sediments features. In sites (N-E) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfishes tables, and a *Gracilaria bursa-pastoris* community among the shellfish tables (lower incident light).

Keywords: Brackishwater, aquaculture, Shellfish culture, Culture effects, Aquaculture effluents, Eutrophication, Ecosystem disturbance, Sediment pollution, Pollution effects, Community composition, Sea grass, Seaweeds, Zostera marina, Ulva rigida, Gracilaria bursa-pastoris, MED, France, Languedoc-Roussillon, Thau lagoon.

De Casabianca, M. L., T. Laugier, and D. Collart. 1997. **Impact of shellfish farming eutrophication on benthic macrophyte communities in the Thau lagoon, France.** Aquaculture International. 5(4):301-314.

In a large marine lagoon (Thau lagoon, southern France) with a shellfish farming dominant eutrophication, the macrophyte communities were sampled by six transects of three depths (1.5, 2.5 and 5 m) and their characteristics (species composition, diversity and biomass) were described in relation to environmental and sediment parameters. With increasing eutrophication (total inorganic nitrogen, 0.140-0.295 mg/l; dissolved reactive phosphorus, 0.045-0.110 mg/l; and N/P atomic ratio, 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% dry wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in SW sites and could be distinguished by their sedimentary features. In sites (NE) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfish tables, and a *Gracilaria bursa-pastoris* community in the shellfish tables (lower incident light).

Keywords: France, Thau lagoon, lagoons, marine, environment, shellfish, farming, eutrophication, macrophytes, benthic, floraalgae, degradation ,biological, sampling, ffluents, shellfish, culture, environmental impact, marine pollution, coastal, lagoons, Zostera, Gracilaria, France, MED, France.

Doty, D. C., D. A. Armstrong, and B. R. Dumbauld. 1989. **The benefits of improved refuge associated with commercial oyster culture for the survival of juvenile Dungeness crab.** Journal of Shellfish Research 8: 319-320.

Ground culture of the Pacific oyster (Crassostrea gigas) in Washington State estuaries such as Willapa Bay and Grays Harbor appears to benefit the Dungeness crab (*Cancer magister*) resource, and possibly the fishery, by providing critical habitat for 0+ crab newly settled to the intertidal zone of such estuaries. However, culture practices over the last 25 years have included the use of an insecticide Sevin sprayed to control burrowing shrimp whose activities inhibit oyster survival and growth. There is growing evidence that crab loss during treatment with Sevin are substantially replaced during subsequent years of oyster culture by virtue of an increase in optimal shell habitat for 0+ crab. Measurements of intertidal 0+ crab density suggest that shell habitat supports higher densities (2-16 crab/m super(2)) of crab than does eelgrass (0-3 crab/m super(2)) or open ground. In addition, growout beds with 2-3 year old oyster support higher densities of crab than do newly planted seed beds.

Dowd, M. 2006. **Modeling approaches to assess the potential effects of shellfish aquaculture on the marine environment. Perspectives on the Use of Mathematical Models for Assessing Environmental Effects of Bivalve Aquaculture. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Draft**.

No abstract identifying these species for this category.

Drake, P., and A.M. Arias. 1997. T**he effect of aquaculture practices on the benthic macroinvertebrate community of a lagoon system in the Bay of Cadiz (southwestern Spain).** Estuaries. 20(4):677-688.

Monthly quantitative Ekman-Birge grab sampling was used to characterize and compare the composition and structure of the benthic macroinvertebrate community inhabiting semi-

enclosed polyculture lagoons (SPL) (three sampling sites) and enclosed monoculture ponds (EMP) (two sampling sites) of a lagoonal system of the Bay of Cadiz. The two areas differed considerably in habitat characteristics and aquaculture management. The SPL area was characterized by low rates of water exchange, low fish densities, and the presence of a macroalgal cover. In the EMP area, there was a complete exchange of water daily (by pumping) and a supply of food pellets, density of fish was high, and no vegetative cover was present. There were considerable differences in species composition between habitats with different culture methods: 11 of the 21 most abundant species were exclusive to one or the other. Several epibenthic species were abundant in the polyculture lagoon but were low in density or were absent in monoculture ponds. Some infaunal species, on the other hand, were more abundant in the monoculture ponds. Univariate measures of community structure (abundance and biomass, Margalef's species richness, Shannon-Wiener diversity, and Pielou's evenness indices) did not indicate significant differences between the SPL and EMP areas. Conversely, the abundance-biomass comparison (ABC) method indicated that, on average, the macrobenthic community was moderately disturbed in the SPL and undisturbed in the EMP areas. Multidimensional scaling (MDS) ordination and hierarchical cluster analysis (Bray-Curtis similarity measure) revealed the occurrence of two main benthic assemblages that corresponded to the aquaculture methods. The different rates of water exchange for the two aquaculture practices seem to have contributed to differences in the composition and structure of the benthic communities.

Keywords: Spain, Bay of Cadiz, Aquaculture, Lagoons, Macroinvertebrates, Benthic, Environment, Species, Composition, Water, Exchange, Comparison, Studies, Ponds, Pollution effects, Environmental impact, Aquaculture effluents, Polyculture,Coastal lagoons, Community structure, Benthos, Invertebrata, Macrofauna, Species diversity.

Dumbauld, B. R., and D. A. Armstrong. 1987. **Potential Mitigation of Juvenile Dungeness Crab Loss during Dredging through Enhancement of Intertidal Shell Habitat in Grays Harbor, Washington**. Final Report for Seattle District, U.S. Army Corp of Engineers, FRI-UW-8714, University of Washington, Seattle.

This report covers the results of the recommended shell mitigation experiment and a field survey conducted to determine the extent and localization of natural shell covered areas in Grays Harbor and the degree of utilization by 0+ crab. The shell field survey objective was to map amount of shell cover in Grays Harbor and determine the characteristics of the best suited shell for crab habitat. Also, a shell mitigation experiment was conducted to study the efficacy and implementation of future shell mitigation.

[Bottom-line: Juvenile crab recruited to and utilized shell habitat more than barren habitat]

Dumbauld, B. R., D. A. Armstrong, D. A., and T. L. McDonald. 1993. **Use of oyster shell to enhance intertidal habitat and mitigate loss of Dungeness crab (*Cancer magister*) caused by dredging.** Canadian Journal of Fisheries and Aquatic Sciences 50: 381-390.

Juvenile Dungeness crab (*Cancer magister*) recruit to intertidal areas in estuaries along the Pacific Northwest coast of the United States in May and June of each year and survive best through their first summer in shell or eelgrass habitat. Experiments were initiated in Grays Harbor, Washington, to investigate the potential of using shell to enhance intertidal crab habitat as a means to augment the crab resource and mitigate losses from the subtidal population that

occur during dredging. Experimental plots (225 m super(2)) were constructed prior to crab settlement at each of three intertidal locations using three configurations of oyster shell (heavy layer, light scattering, and small piles of shell). Resulting crab densities were comparable with those found in naturally occurring shell with high numbers (20-60 crab/m super(2)) observed during settlement that declined to a relatively stable density of 10 crab/m super(2) in July and August. Crab survival was highest in both heavy and pile configurations, but the heavy shell configuration remained intact the longest. This enhancement experiment has become the impetus for a large-scale (8 ha) mitigation program in 1992 as part of a dredging project completed in 1990 in Grays Harbor.

Dumbauld, B. R., E. P. Visser, D. A. Armstrong, L. Cole-Warner, K. L. Feldman, and B. E. Kauffman. 2000. **Use of oyster shell to create habitat for juvenile Dungeness crab in Washington coastal estuaries: Status and prospects.** Journal of Shellfish Research 19: 379-386.

The deployment of oyster shell in estuarine intertidal areas to create habitat for juvenile Dungeness crab (*Cancer magister*) is now used routinely as mitigation for "unavoidable losses" of crab during dredging operations in Grays Harbor and Willapa Bay along the southwest coast of Washington State. Feasibility studies were conducted in 1986 to 1987 for a U.S. Army Corps of Engineers project to widen and deepen the navigation channel in Grays Harbor. Since that time, several studies have elucidated the ecology of crab and other organisms that recruit to the created shell reefs. Studies have also refined the procedures used to calculate crab losses caused by dredging and crab production in the shell habitat. The shell does serve as crab habitat; however, initial assumptions about the longevity of the shell have proved to be overly optimistic, because the shell can sink or be covered with silt before the end of the first summer after deployment. In addition, competition with the shore crab, *Hemigrapsus oregonensis*, has displaced juvenile Dungeness crab. We summarize results of these studies and present initial results from an ongoing mitigation effort that seeks to produce a more persistent living oyster reef in Willapa bay.

Gowen, R.J., H. Rosenthal, T. Maekinen, and I. Ezzi. 1990. **Environmental impact of aquaculture activities.** Special Publication, European Aquaculture Society. 1990.

In many countries throughout the world the scale of aquaculture development is causing concern about the environmental impact of this industry on freshwater and marine ecosystems. The range of potential impacts is large, some have been studied in detail and others must be regarded as potential. In general the cultivation of finfish and shellfish can cause changes in aquatic ecosystems; finfish farming, by enrichment of the receiving water and associated changes in water quality, and shellfish farming by altering the structure of the marine food web. Other impacts relate to the use of chemicals and the interaction between cultivated and wild stocks. The scale of environmental impact is dependent on the size of the operation and the physical, chemical, and biological characteristics of the receiving water. In some instances the level of impact is sufficient to result in feedback which affects the aquaculture operation itself. Knowledge of the requirements of the operation and identification of likely impacts, together with information on the site, can be used to minimize environmental change and reduce the potential for such change to affect the operation.

Keywords: environmental impact, aquaculture, facilities, aquaculture development, aquatic environment, aquaculture effluents, mathematical models, Europe, general aquaculture.

Gowen, R.J., H. Rosenthal, T. Makinen, and I. Ezzi. 1989. **Environmental impact of aquaculture activities.** Aquaculture Europe '89. Presented at the International Aquaculture Conference held in Bordeaux, France,-2-4 -October,-1989. Billard, R.; Pauw, N. de-comps. (10):300.

In many countries throughout the world the scale of aquaculture development is causing concern with respect to the impact of this industry on freshwater and marine ecosystems. In general cultivation of finfish and shellfish can cause changes in aquatic ecosystems: fish farming by enrichment of the receiving water and associated changes in water quality, and shellfish farming by altering the flow of energy through the marine food web. Other impacts relate to the use of chemicals and the interaction between cultivated and wild organisms. The scale of any environmental impact will depend on the size of the operation. In addition the physical, chemical and biological charcteristics of the receiving water have a significant influence on the intensity and scale of the impact.

Keywords: aquaculture development, culture, effects, environmental impact, ecosystem disturbance, environmental protection, pollution control, fish culture, shellfish culture, France, shellfish.

Hasbrouck, E.G. 1998. **The impact of a shellfish nursery on ambient chlorophyll-a concentrations.** Journal of Shellfish Research. 17(1):355.

Filter feeders such as clams, oysters, mussels and scallops, obtain their food source by filtering surrounding waters. In an open environment there are many animals, but there is also generally a large enough food source to support these animals. In heavily populated areas, such as dense clam or mussel beds, growth, breeding and larval life can be severely affected by the availability of food. When large numbers of filter feeders are introduced into a limited source environment, the effect on the already existing population could be drastic. The Cornell Cooperative Extension Marine Program operates a shellfish hatchery and nursery in Southold, Long Island, NY, where they spawn, grow, and eventually release into the wild, a number of different types of shellfish. The nursery operation utilizes a flow through system to draw in bay water with its associated microalgae as a food source for the shellfish. The nursery produced approximately 4 million hard clams, oysters and bay scallops during the 1997 growing season. This study was designed to determine the impact of the nursery's algal removal on the ambient algal concentrations of Cedar Beach Harbor. A chlorophyll a sampling program was established. Sampling stations were setup at different locations in Cedar Beach Harbor, Peconic Bay and at both the intake and effluent of the nursery. The samples collected in Cedar Beach Harbor were compared with those collected in the Peconic Bay. The effluent of the nursery was compared to those samples taken in Cedar Beach Harbor. Samples in this study were analyzed for only chlorophyll-a concentrations as an approximation of microalgal density. Algae were not identified as to species or diversity. The seven sampling stations were sampled a total of nine times during the time period between 6797 and 101697.

Keywords: Shellfish culture, Hatcheries, Environmental effects, Aquaculture, shellfish, impacts.

Holsman, K.K., D.A. Armstrong, D.A. Beauchamp, J.L. Ruesink. 2003. **The necessity for intertidal foraging by estuarine populations of subadult Dungeness crab *Cancer magister*: evidence from a bioenergetics model.** Estuaries 26:1155-1173.

While the critical role of structured intertidal habitat for 0+ young-of-the-year Dungeness crab had been previously evaluated, little was known about use by sub-adult 1+ and >1+ crab. Abundance surveys indicated that these crab were most abundant in lower side channels in the estuary. A bioenergetics model suggested that the subtidal habitat in these areas could not possibly satisfy energetic demand and the crab must therefore use extensive intertidal flats to meet their daily requirements. A second paper (Holsman et al. 2007, Marine Ecology Prog. Ser, 308:183-195) demonstrates that extensive, mostly nocturnal migrations are made to intertidal areas of the estuary and that *unstructured* habitat is critical for these larger animals. [Funding: NOAA – Coastal Ocean Program. Washing Sea Grant, USDA WRAC].

Hosack, G. 2003. **Effects of *Zostera marina* and *Crassostrea gigas* culture on the intertidal communities of Willapa Bay, Washington.** 102.

Estuaries in the Pacific Northwest are thought to provide both prey resources and refuge from predators for juvenile fish such as salmonids (Simenstad et al. 1982, Thorpe 1994). The intertidal flats of these estuaries are considered favorable foraging habitat for many juvenile nekton, such as English sole and Dungeness crab (Toole 1980, Gunderson et al. 1990, Rooper 2002, Rooper et al. 2002). Within estuaries, eelgrass provides a complex habitat for juvenile fish and crab, as well as epifaunal and infaunal communities, relative to unvegetated mudflat (Orth et al. 1984). Because species abundance and diversity are often enhanced in eelgrass meadows, the state of Washington manages eelgrass as a protected habitat by limiting or mitigating direct impacts (Pawlak and Olson 1995). But how do other intertidal habitat types affect juvenile fish and crab within these productive estuarine environments? For example, oyster ground culture commonly occurs in Pacific Northwest estuaries that also contain expansive eelgrass meadows. These two habitats are characterized by vastly different forms of structure: the flexible, dense canopy of eelgrass meadows versus the stable, low-lying structure created by oyster clusters. Unknown is whether the complexity created by oyster is of greater or lesser value for nekton compared to eelgrass. Habitat complexity and structure have been studied extensively for eelgrass and coral reefs, but less attention has been paid to oysters. The diversity and abundance of estuarine organisms may depend on the presence or absence of structure, the form and extent of complexity, or a combination thereof. Perhaps a better understanding of how structure affects estuarine organisms in general will shed light on the effects of structure created by oysters. Some species of submerged aquatic vegetation other than eelgrass, for example, also support greater nekton abundance compared to unvegetated areas (Sogard and Able 1991, Murphy et al. 2000, Castellanos and Rozas 2001). In this introduction, I review the literature on estuarine habitat structure to provide background on the possible mechanisms and outcomes of form and degree of complexity in determining estuarine species assemblages. For example, habitat structure may benefit juvenile nekton by providing refugia from foraging predators or producing prey resources. Is the presence of habitat structure enough for increased abundance and diversity, or does the form of complexity matter as well?

Hosack, G.R. Ph.D., Dept. of Fish and Wildlife, **Oregon State University thesis research on the use of intertidal habitats by juvenile pacific salmon**. Density of juvenile salmonids (primarily Chinook, but also coho and chum) caught using tow nets did not differ by habitat type

(oyster, eelgrass, open tideflat) but varies instead by location within Willapa Bay estuary. Gut content samples revealed that Chinook salmon were feeding primarily on neuston and not benthic organisms typically associated with bottom habitat. Laboratory experiments with hatchery Chinook smolts and a mock heron predator suggest that structured habitat (particularly eelgrass) is important for protection from predators. [Funding: USDA WRAC].

Iribarne, O., D. Armstrong, and M. Fernandez. 1995. **Environmental impact of intertidal juvenile Dungeness crab habitat enhancement: Effects on bivalves and crab foraging rate.** Journal of Experimental Marine Biology and Ecology. 192(2):173-194.

An intertidal oyster shell habitat has been created and used to mitigate the subtidal dredging impact on Dungeness crab (*Cancer magister Dana*) population resulting from widening and deepening of the Grays Harbor navigation channel (47 degree N, 124'W, USA). This paper addresses the effect of this artificial habitat on soft bottom species, focusing in particular on: growth rate of the suspension feeder bivalve *Mya arenaria L.*; both settlement and survival of the bivalve *Macoma balthica* (Linne); and the effects of habitat heterogeneity, clam density, and crab density on the foraging rate of juvenile Dungeness crabs preying on *Macoma balthica*. Epibenthic shells did not affect the growth rate of *Mya arenaria* transplanted into oyster shell habitat. Recruitment of the bivalve *Macoma balthica* was not affected by shell either, but mortality rate was higher in areas covered by shell when compared with open mud. Laboratory experiments showed a positive density-dependent (Type III) functional response, indicating that *Macoma balthica* finds refuge at low clam density. At increased crab density in shell habitats interaction among juvenile crabs effects consumption rate of clams. Tethering experiments showed that juvenile crab mortality was higher in open mud, intermediate at the border of the shell plots, and lower in the center. This pattern of crab mortality suggests that juvenile Dungeness crabs only affect local clam populations in shell covered areas. These results indicate that although the artificial shell habitat successfully enhances settlement and survival of juvenile Dungeness crabs, it affects the ecology of some non-target species, in part through intensified predator-prey dynamics due to the increased local densities of young-of-the-year crabs.

Keywords: environmental impact, habitat improvement, physical, juveniles, predation, Cancer, magister, Macoma, balthica, Mya, arenaria, INE, USA, Washington, Grays Harbor, population, dynamics, oyster bottom, bottom culture.

Islam, M., M. Wahab, and M. Tanaka. 2004. **Seed supply for coastal brackishwater shrimp farming: environmental impacts and sustainability.** Marine Pollution Bulletin. Vol. 48, no. 1-2, pp. 7-11. Jan. IS: ISSN 0025-326X.

Globally, shrimp farming has been a significant agro-based economic activity since the early 1970s. Because it offered a huge immediate economic return, shrimp farming showed a booming expansion and soon became a multimillion dollar industry. However, it has been under extreme criticism because of its devastating ecological and socio-economic impacts. Because seed is the primary input, the impact from farming has started from the source of seed supply, so that not only are natural stocks of shrimp seeds now overexploited worldwide but seed collection activities also significantly reduce stocks of other living resources. Although hatcheries were developed as potential alternative and have replaced the natural seed source to a great extent, large-scale hatchery productions provide a potential source of coastal pollution. However, this area is still poorly studied. The present paper provides a review of the environmental impacts of

the wild shrimp seed fishery as well as the possibility of environmental degradation from artificial shrimp seed production in hatcheries.

Ji, R., X. Mao, and M. Zhu. 1998. **Impacts of coastal shellfish aquaculture on bay ecosystem.** Affiliation - 1st Institute of Oceanography, SOA Qingdao 266003 People's Rep. China. Journal of oceanography of Huanghai and Bohai Seas/Huangbohai Haiyang. Qingdao. Vol. 16, no. 1, pp. 21-27. 1998.

The major ecological characteristics of high-density cultured shellfish including biodeposition and filter feeding control on phytoplankton and impacts on population of zooplankton and their ecological effect are described. The subsequent impacts on bay ecosystem is analyzed according to the recent literature in this field and our in situ investigation. The importance of this study on sustainable shellfish aquaculture development protection was pointed out and some techniques used in this field were proposed for further study.

Keywords: Eutrophication; Aquaculture effluents; Shellfish culture; Ecosystems; Environmental impact.

Keen, D.M., D.R. Maynard, and Department of Fisheries and Oceans Canada, Charlottetown, PEI (Canada) Oceans Habitat Divis. 2005. **Prince Edward Island shellfish aquaculture: the NWPA-CEAA assessment process.** Canadian Manuscript Report of Fisheries and Aquatic Sciences/Rapp.Manuscr. Can. Sci. Halieut. Aquat. 272865.

In 1999, the Department of Fisheries and Oceans determined that the existing 426 surface and/or off bottom aquaculture sites in Prince Edward Island required formal review and approval for compliance with the Navigable Waters Protection Act. This document details the cooperative process developed between the Government of Prince Edward Island, the Prince Edward Island Aquaculture Alliance, the Canadian Environmental Assessment Agency, and DFO's Regional Sections of Fish Habitat, Navigable Waters protection, and Aquaculture Leasing to bring those aquaculture sites into compliance with the Navigable Waters Protection Act. This resulted in Approval Documents being issued for all 426 sites in February of 2002. Ancillary benefits included the development of a unique "bay by bay" environmental assessment and review process and a monitoring program through an Adaptive Management process. TR: CA0500305

MacFarlane, S., and G. Flimlin. 2005. **Shellfish aquaculture on the East Coast: A snapshot.** Journal of Shellfish Research. Vol. 24, no. 1, p. 327. Jan. IS: ISSN 0730-8000.

The authors conducted a survey of all East Coast states through their extension agents to determine the extent and diversity of the East Coast shellfish aquaculture industry. The survey was conducted for the East Coast Shellfish Growers Association as a prelude to developing best management practices or an environmental management system for the shellfish aquaculture industry. Respondents answered questions relative to the number of leases, sizes, species cultivated, methods and gear used, number of people employed, and other pertinent questions concerning growout. The survey also requested information on leasing and regulatory frameworks, constraints to expanding aquaculture, problems perceived by either growers or licensing agencies, and comments. Survey revealed that the shellfish industry on the East Coast is diverse in size and scope of operations, but there are common threads as well that overlap state jurisdictions.

McKindsey, C.W., M.R. Anderson, P. Barnes, S. Courtenay, T. Landry, and M. Skinner. 2006. **Effects of Shellfish Aquaculture on Fish Habitat.** Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Moncton, NB.1-88.

No abstract identifying these species for this category.

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.

Estimates the annual production of 6 important native and non-native species in Willapa Bay ~1850 vs. ~2000 [Funding: Mellon Foundation, USDA WRAC]

Species	Scientific name	Native/ Non	1850 Prod'n (kg dry wt yr^{-1})	2000 Prod'n (kg dry wt yr^{-1})
Eelgrass	*Zostera marina*	Native	Similar to 2000	3.53×10^7
Dwarf eelgrass	*Zostera japonica*	Non	0	4.79×10^6
Spartina cordgrass	*Spartina alterniflora*	Non	0	1.31×10^7*
Native oysters	*Ostrea lurida***	Native	9.15×10^4	Small
Pacific oysters	*Crassostrea gigas*	Non	0	3.23×10^5
Manila clams	*Ruditapes philippinarum***	Non	0	6.94×10^3

* Value likely to have declined in recent years due to herbicide control
** Scientific name under review

Semmens, B.X. 2006. PhD Department of Biology, University of Washington.

Hatchery-raised smolts of **Chinook salmon** were released into a large intertidal pen containing **eelgrass** (*Z. marina* and *Z. japonica*), **oyster clusters**, unstructured sediment, and Spartina cordgrass. They were implanted with acoustic tags that allowed their movements to be tracked in 2-dimensions at sub-meter accuracy. After effects of tidal elevation and enclosure were accounted for, smolts responded only to native eelgrass, where they moved more slowly than in other habitat types. Smolts never entered Spartina. [Funding: USDA WRAC].

Simenstad, C.A.. and J.R. Cordell. 1989. **Effects of Sevin application on littoral flat meiofauna : preliminary sampling in Willapa Bay, June-July 1988**. 57 p. ill, map ; 28 cm.

No abstract identifying these species for this category.

Simenstad, C.A., and K.L. Fresh. 1995. **Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: Scales of disturbance.** Estuaries. 18(1A):43-70.

We reviewed the scale and intensity of disturbance, and the response of benthic and epibenthic communities, to intertidal aquaculture activities in Pacific Northwest estuaries. Available data indicate a spectrum of influences on the ability of estuaries to sustain biota unrelated to the cultured species. Certain disturbances, such as adding gravel to mudflats and sandflats to enhance clam production, may subtly impact certain benthic and epibenthic invertebrates without changing the carrying capacity for estuarine-dependent taxa, such as juvenile Pacific salmon (Oncorhynchus spp.). However, habitat shifts might alter the relative suitability for different salmon species. In contrast, acute disturbances that produce large-scale changes in community dominants, such as manipulation of burrowing shrimp or eelgrass with pesticide or mechanical harvesting and manipulation of oyster grounds, strongly influence the

carrying capacity for many fish and macroinvertebrates. Ensuring that estuarine ecosystems are sustainable for the breadth of processes and resources requires a comprehensive assessment of both natural and anthropogenic disturbance regimes, landscape influences, and the effects of local management for particular species on other resources.

Keywords: INE, USA, Pacific Northwest, intertidal environment aquaculture, development ecosystem, disturbance, environmental impact, estuaries, benthos, benthic, environment, environmental effects, ECOP.

Thuringer, P.L. 2004. **Documenting Pacific sand lance (Ammodytes hexapterus) spawning habitat in Baynes Sound, east coast Vancouver Island, and the potential interactions with intertidal shellfish aquaculture.** Masters Abstracts International. Vol. 42, no. 6, p. 2098. Dec. IS: ISSN 0898-9095.

Intertidal beach spawning finfish, such as the Pacific sand lance (Ammodytes hexapterus), are vulnerable to potential impacts to upper intertidal habitats from various foreshore activities, including intertidal shellfish aquaculture. This short-lived species is an important forage fish in the Pacific Northwest that rely on ecologically functioning beaches to sustain their populations. This research documented characteristics of some of the beach spawning habitat in Baynes Sound and interactions between clam tenure operations and beach spawning activity, and evaluated potential approaches to managing these interactions. Pooled data (n = 5) indicates that A. hexapterus tend to spawn on medium (50%, 0.25-0.5mm grain size) to coarse sand (30%, 0.5-2mm) substrate with <3% finer material (silt/fine sand <0.25mm). The greatest potential for interactions between predator netting and sand lance beach spawning activity is in the lower limit of spawning range and the upper limit of net placement (tidal elevation +2.7m to +3.0m CD).

Tidwell, J.H., and G.L. Allan. 2003. **The Relative Contributions and Ecological Impacts of Aquaculture and Capture Fisheries.** Bulletin of the Aquaculture Association of Canada. 103(2):12-18.

Historically, the oceans were considered limitless and thought to harbor enough fish to feed an ever-increasing human population. However, the demands of population growth, particularly in poorer countries, now far outstrips the sustainable yield of the seas. At the same time as fishing has become more industrialized, and wild fish stocks increasingly depleted, aquaculture production-fish and shellfish farming-has grown rapidly to address the shortfalls in capture fisheries. With this rapid growth, aquaculture has come under intense scrutiny and criticism as environmentalists fear that it could cause significant environmental problems and further impact wild species that are already over exploited. Indeed, both capture fisheries and aquaculture have environmental costs, all human activities of significant scale do, but it is necessary to fairly evaluate and compare the ecological and economic impact of both. In fact, a thorough analysis shows that the ecological threat of aquaculture is much lower than continuing to supply the majority of fish protein from wild capture owing to aquaculture's greater control over production, harvest, processing and transport, which results in less wastage and reduced energy demands.

Whitlatch, R.B., R.W. Osman, and S.E. Shumway. 2005. **Invasive ascidian biofouling in aquaculture: An increasing problem and can it be controlled?** Journal of Shellfish Research. Vol. 24, no. 2, pp. 682-683. Aug. IS: ISSN 0730-8000.

Data and observations strongly suggest that the increasing number and high abundances of introduced fouling species, especially ascidians, represent an increasing threat to cultured populations of shellfish. Firstly, these species are found in greatest abundance in protected bays, harbors, and estuaries where aquaculture operations are often located. Secondly, the invaders compete for the same food and spatial resources as shellfish as well as foul them. Thirdly, the use of aquaculture gear (e.g., cages, nets) provides additional surfaces for the invaders to grow upon. Fourthly, various methods of off-bottom aquaculture that provide benefits to shellfish from predators and sedimentation, also extends the same benefits to the invaders. Finally, even if the invaders have no direct impact on the shellfish, their fouling of the shellfish and gear results in added costs associated with gear maintenance and cleaning of harvested shellfish. There currently exists a variety of options for removing, killing, or controlling the invaders, but many methods (especially chemical applications) are most restricted when applied to cultured shellfish. Any method must be targeted at the invaders while avoiding deleterious effects to the shellfish. An alternate and preferred treatment approach is to eliminate the problem before it starts and involves some form of biological control (e.g., predators and parasites) agent. To be effective these species to remain with the shellfish population and continually remove the invaders. Recent studies suggest that several species of small (4-15 mm) gastropods might be effective candidates f or controlling the abundance newly settled invasive ascidians.

4.0 EFFECTS OF SHELLFISH CULTURE ON PHYSICAL PROCESSES (SEDIMENT, TRANSPORT, EROSION)

4.1 Clams

Badino, G., F. Bona, A. Maffiotti, O. Giovanardi, and F. Pranovi. 2004. **Impact of mechanical clam harvesting on a benthic habitat: evaluation by means of sediment profile imaging.** Aquatic Conservation: Marine & Freshwater Ecosystems. 14

Manila clam (*Tapes philippinarum*) harvesting in the Venice Lagoon has increased considerably in the last decade, owing to recently developed collection methods. However, these techniques have negative effects on benthic communities and on the structural and functional characteristics of the sediments. A field survey was carried out in 2000 in the central basin of the Venice Lagoon to evaluate the efficacy of sediment profile imaging (SPI) in investigating disturbances caused by fishing activities and to compare the modifications of bottom sediments induced by different fishing gear (the, currently used by local fishermen, and a rotating drum). An environmental index, the organism-sediment index, derived from SPI analysis was applied. The efficacy of the SPI camera method in evaluating the disturbance of soft bottoms caused by clam harvesting was confirmed, as was the high degree of disturbance of sediment and benthic communities by mechanical clam harvesting. The experimental hauls strongly modified the sediment features by resuspending the top layer of sediment and bringing the deep anoxic layer near the bottom. These effects could have a severe impact on the biogeochemical cycles and on the possibility of recolonization by benthic organisms in the short term. However, there was less disturbance when the rotating drum fishing gear was used.

Keywords: clam harvesting, sediment quality, sediment profile, imaging,, benthic disturbance, Venice Lagoonspecies, culture.

Beal, B.F., and M.G. Kraus. 2002. I**nteractive effects of initial size, stocking density, and type of predator deterrent netting on survival and growth of cultured juveniles of the soft-shell clam, *Mya arenaria L.*, in eastern Maine.** Aquaculture. 208(1-2):81-111.

Recent declines in commercial harvests of soft-shell clams, *Mya arenaria L*., in Maine, USA, have prompted state and local officials to consider enhancing wild stocks with hatchery-reared seed. We conducted two manipulative field experiments in the soft-bottom intertidal zone during 1990-1991 in eastern Maine to assess effects of predation, intraspecific competition, and initial planting size on the survival and growth of cultured individuals of *Mya*. Experiment I (23 June 1990 to 13 June 1991) tested interactive effects of two planting sizes (small=8.5 mm shell length (SL); LARGE=11.8 mm SL) and protective netting on fate and growth of clams. Animals of each size were added to separate experimental units within each of 60 1-m2 areas delimited by a wooden box. To deter predators, 50 boxes were covered with a specific type of plastic netting that differed in aperture size (4.2, 6.4 and 12.8 mm) and degree of rigidity (flexible vs. extruded) while 10 boxes served as controls (without netting). Small clams grew at a faster rate than large clams, but both added approximately 18 mm of new shell by the end of the study. Growth was unaffected by netting size and rigidity, but 13% more clams were recovered alive after a year in protected vs. unprotected treatments (84% vs. 71%). Survival was independent of netting type. The presence of netting resulted in nearly a 3 x enhancement of wild spat (-2). This result suggests that the decline of wild stocks in eastern Maine may not be related to recruitment

failure, but to post-settlement events, such as predation, which remove clams from the intertidal. In Experiment II (15 April to 6 October 1991), clam (14.6+/-0.2 mm SL) density was manipulated across four levels from 333 to 2664 m-2 in protected (extruded netting, 12.8 mm aperture) and unprotected 1-m2 boxes. Survival within unprotected boxes was independent of stocking density (79%), but was inversely density-dependent in protected boxes (77% in the lowest density treatment increasing to a mean of 88% in the other three treatments). A negative cubic relationship explained the effect of density on growth. We present the first mariculture strategy for public stock enhancement or private entrepreneurs interested in rearing M. arenaria in Maine and the northeast US. Hatchery-reared juveniles 8-10 mm SL should be planted in the spring near or below mid tide levels at densities between 333 and 666 m-2 and protected with flexible netting (6.4 mm aperture) raised several centimeters above the sediment surface. Netting should be removed from mud flats in the late fall before the threat of ice and severe winter storms. Animals should attain sizes between 25 and 30 mm SL during this time and reach a size refuge from burrowing and other predators. Growth to legal, commercial size (50.8 mm SL) should take another 2-4 years depending on geographic location and mean seawater temperature.

Keywords: general aquaculture, predator deterrent, soft-shell clam, Mya arenaria L. Maine.

Beal, B.F., M.R. Parker, and K.W. Vencile. 2001. **Seasonal effects of intraspecific density and predator exclusion along a shore-level gradient on survival and growth of juveniles of the soft-shell clam, *Mya arenaria L.*, in Maine, USA**. Journal of Experimental Marine Biology and Ecology. 264(2):133-169.

The relative roles that predation and competition play in regulating populations of infaunal marine bivalves in soft-bottom systems are strikingly different. Exploitative competition for food typically occurs at elevated densities, but crowding rarely results in mortality and competitive exclusion. Predation by decapods, gastropods, and, sometimes asteroids, is more important in controlling patterns of distribution and abundance. Most field tests leading to this synthesis have been conducted between 35[deg]N and 35[deg]S and/or with bivalves in the families Veneridae and Tellinidae. To test the robustness of these ecological processes at another geographic setting (45[deg]N) using a species from another family within the suspension-feeding guild (Myidae), we performed a short-term field manipulation at an intertidal mud flat in eastern Maine, USA. We followed survival and growth of 10,080 juveniles (12.4-mm shell length (SL)) of the soft-shell clam, *Mya arenaria L.*, in field enclosures with and without predator-deterrent netting at three densities (330, 660 and 1320 m-2) along a tidal gradient over four sampling intervals from April to December 1996. We used a generalized completely randomized block design to assess variation in these dependent variables within a given tidal height (high, mid, and low) on a particular date. Mortality varied seasonally, peaking (13.6%) between August and September when seawater temperatures were warmest. No significant mortality occurred after September, when mean (+/-95% CI) percent survival pooled over all treatments was 72.9+/-8.5%. Netting (6.4-mm aperture) effectively excluded predators along the tidal gradient as overall mean clam survival, independent of tidal position, was 88.7+/-4.1% in protected units (plastic plant pots with AREA=181 cm2), but decreased from upper and mid tide levels (82.9+/-6.1%) to lower on the shore (66.3+/-9.7%) in unprotected units. Density-dependent mortality resulted in reduced survival (-4.6%) in clams stocked at the two highest levels ($P<0.001$); however, numbers of dead clams with undamaged valves provided little evidence that this effect was due to starvation. Incremental growth also varied seasonally with greatest amounts of shell

added during June-August at all tidal levels. Shell growth stopped or slowed significantly after September at all tidal positions. Mean SL increased with decreasing tidal height (December sizes: HIGH=20.6+/-2.9 mm, MID=24.1+/-1.0 mm; LOW=28.2+/-1.2 mm); however, submergence time alone failed to explain completely these differences. Density-dependent growth was detected once (August-September). Animals at the two highest densities experienced a growth depression of ca. 7%. We conclude predation, rather than competition, is more important in regulating populations of soft-shell clams in this intertidal location.

Keywords: clam, mya arenaria maine, predation, mortality, exclusion, distribution, densities, general aquaculture.

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

Little is known about the impacts of intensive shellfish farming on intertidal ecosystems. To assess such impacts, several indices of ecosystem structure and select geochemical characteristics were contrasted among three intertidal regions, which represented a gradient of shellfish farming activities, namely (1) no active aquaculture, (2) actively farmed for three years and (3) actively farmed for five years. All three intertidal regions were located in Baynes Sound (British Columbia, Canada) and were geographically similar. Among the three beaches, species richness, community composition, bivalve abundance, biomass, distribution, and composition and surficial sediment per cent organic matter (carbon) and silt were compared. The intertidal regions that had been used for farming for three and five years had lower species richness, different bivalve composition, abundance and distributions, and a foreshore community dominated by bivalves, as compared to the intertidal region where no active farming occurred. Beaches that were actively farmed also had greater accumulations of organic matter and silt. Simplification of the intertidal benthic community, coupled with accumulations of organic matter and increased siltation, may have altered the ecology of the foreshore region used for intense shellfish harvesting. To access the foreshore for shellfish farming in a sustainable manner, studies are needed to determine the scale to which intensive use of the foreshore for shellfish purposes alone is feasible without undue harm to the environment.

Keywords: aquaculture, biodiversity, ecological impacts, shellfish.

Chicharo, L., J. Regala, M. Gaspar, F. Alves, and A. Chicharo. 2002. **Macrofauna spatial differences within clam dredge-tracks and their implications for short-term fishing effect studies.** Fisheries Research. 54(3):349-354.

In situ observations of clam dredging showed that the effects of the dredge on the benthic macrofauna may not be constant during a tow. A sand buffer forms in front of the gear approximately 10 m after the beginning of a tow, and this pushes the sediment partially aside. In this study, we analyze differences in abundance, the number of taxa present, diversity, and evenness within sections of dredge-tracks in a disturbed, fished area and a non-fished area along the southern coast of Portugal. These areas were sampled by divers before and after dredge-fishing activity. At each site, three dredge-tracks were produced. These tracks were divided in three longitudinal sections (start, middle and end) and two transverse sections (track and edge). Six quadrats were used to sample macrofauna in each section of every track and edge. Our

results show differences exist in macrofaunal distribution and abundance across sections of a dredge-track. These differences should be considered in any assessment of the short-term ecological impact of dredges on benthic macrofauna.

De Casabianca, L., T. Laugier, E. Marinho-Soriano, and D. Collart. 1998. **Environmental impact of shellfish farming in a Mediterranean lagoon (Thau, south France).** Aquaculture '98 Book of Abstracts. p. 99.

The French Mediterranean lagoon of Thau is characterized by an important shellfish farming dominated eutrophication (ca 15 times the terrestrial inputs). On the basis of increasing eutrophication, six areas were identified and monitored for one year (sediments features, overlying and sediment pore water nutrients, macrophytic biomass, species composition and diversity of macrophytes). With increasing eutrophication (total inorganic dissolved nitrogen: 0.140-0.295 mg l-1; dissolved reactive phosphorus: 0.045-0.110 mg l-1 and N/P atomic ratio: 3-22), silt fraction and shell fragments in sediments increased (12-93 and 0-65% d.wt respectively). Different types of macrophytic communities could be defined in the shallow zone (1.5-2.5 m) corresponding to four main and successive stages of degradation. A pure eelgrass stand (*Zostera marina* and *Z. noltii*) and an eelgrass community colonized by macroalgae were observed in S-W sites and could be distinguished by their sediments features. In sites (N-E) more affected by eutrophication (fine-textured sediment), available incident light determined two main seaweed communities: an *Ulva rigida* community, outside the shellfishes tables, and a *Gracilaria bursa-pastoris* community among the shellfish tables (lower incident light).

Keywords: Brackishwater aquaculture; Shellfish culture; Culture effects; Aquaculture effluents; Eutrophication; Ecosystem disturbance; Sediment pollution; Pollution effects; Community composition; Sea grass; Seaweeds; Zostera marina; Ulva rigida; Gracilaria bursa-pastoris; MED, France, Languedoc-Roussillon, Thau Lagoon..

Goulletquer, P., R. Robert, and G. Trut. 1999. **Manila clam (*Tapes philippinarum*) culture: Sediment clam interaction.** Aquat. Living Resour./Ressour. Vivantes Aquat. Vol. 12, no. 1, pp. 45-46. IS: ISSN 0990-7440.

Manila clam (*Tapes philippinarum*) culture and sediment interactions were tested by comparing two rearing areas, including an oceanic (Le-Ferret) and a more estuarine (Les-Jacquets) sites in the bay of Arcachon (France). The growth of calibrated clam population (10-mm spat) was monitored in these two areas with a concomitant sediment-water interface survey over a 1.5-year period. Two sites per area, including control and rearing plots, were sampled on a monthly basis. The potential clam farming impacts by bioturbation and interactions were examined at three sediment depths: O-1, 1-2 and 2-10 cm. Moreover, the main hydrobiological parameters were measurement on a weekly basis to establish a relationship between these parameters and sediment-water interface characteristics. The existence of a gradient between the three depths was revealed for most of the parameters examined, with the exception of silt and organic carbon levels, and this regardless of the area examined. Clam growth showed a rate improvement in the oceanic area, which is characterized by a lower silt content. The clam effect was minimal and the activity identified at the 'Ferret' site was in fact due to the presence of a net which acted as a particle trap. No significant relationship was established between water column parameters and those of the sediment-water interface at the two geographical sites examined. These results demonstrate that clam rearing had only a limited effect on the environmental

sediment parameters (i.e. water percentage, and phaeopigments and silt levels) from a spatio-temporal point of view. Therefore, a return to environmental conditions existing before the implementation of clam farming is likely to occur upon cessation of this activity.

Keywords: Clam culture, Sediments, Bioturbation, Sediment, water interface, Rearing, Tapes philippinarum, Francewater column, Bivalvia.

Han, J., Z. Zhang, and Z. Yu. 2001. **Effects of manila clam (*Ruditapes philippinarum*) on the benthic-pelagic particle flux in Xuejiadao intertidal zone.** Journal of Ocean University of Qingdao; Qingdao, Haiyang, Daxue, Xuebao, Qingdao. Vol. 31(no. 5):pp. 723-729.

An annular flux system (AFS) was deployed to measure the biodeposition and the sediment resuspension processes at four stations in the mid-shore and low-shore along both natural and Manila clam (*Ruditapes philippinarum*) farming transects in Xuejiadao intertidal zone. The results showed that there was a significant correlation between the biodeposition rates and the density (r=0.984, P0.05). It was supposed that the lower stability of sediments in the mid-shore level at both transects was probably associated with higher densities of bioturbators and with disturbance by shrimp farming in the high-shore.

Keywords: Bioturbation, Eulittoral zone, Zoobenthos, Resuspension, Suspended particulate matter, Abundance, Biomass, Ruditapes philippinarum, INW, China, People's Rep., Shandong Prov., Jiaozhou Bay.

Han, J., Z. Zhang, Z. Yu, and J. 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. vol. 261(no. 2):pp. 245-261.

An annular flume or flux system (AFS) was deployed to measure the biodeposition and sediment resuspension processes at four stations in the mid -shore and low-shore zones along both natural and Manila clam (*Ruditapes philippinarum*) farming transects in Xuejiadao intertidal area located in Jiaozhou Bay, eastern China. The results showed that there was a significant correlation between biodeposition rates and the density (r = 0.984, P 0.05). Furthermore, it was found that the site differences in sediment erodability were not significantly correlated with measured physical properties of sediments and biota factors such as total macrofauna biomass, total abundance and macrofauna densities, Chl-a and Ph-a (P > 0.05). However, there was a significant correlation between sediment erodability and both median grain size (P < 0.01) and the density of the bioturbator M. incongrua (P < 0.05). There was also evidence of a slight increase in sediment stability after 3 h of air exposure, but the effect was not overcome following the addition of Manila clams. It is hypothesized that the lower stability of sediments at the mid-shore level was probably associated with higher densities of bioturbators and with disturbance by shrimp farming near the high-shore.

Keywords: Sedimentation, Sediment texture, Bioturbation, Grain size, Clam culture, Intertidal environment, Particulate flux, Aquaculture, Particulate matter, Sediment water interface, China Macoma incongrua, Ruditapes philippinarum, INW, China, People's Rep. -Shandong Prov., Jiaozhou Bay.

Jie, H., Z. Zhinan, Y. 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(2):245-261.

An annular flume or flux system (AFS) was deployed to measure the biodeposition and sediment resuspension processes at four stations in the mid-shore and low-shore zones along both natural and Manila clam (*Ruditapes philippinarum*) farming transects in Xuejiadao intertidal area located in Jiaozhou Bay, eastern China. The results showed that there was a significant correlation between biodeposition rates and the density (r=0.984, Pr=0.977, P-1 ind.-1 and the biodeposition rate was calculated to be 0.06+/-0.01 g h-1 ind.-1. The critical erosion velocities of intertidal sediment at Xuejiadao were from 17.4 to 20.4 cm s-1. Relationships describing suspended particulate matter (SPM) vs. current velocity were analyzed by linear regression following log transformation of the SPM. Statistical analysis of the slopes of the regression lines revealed that there were distinct differences between the low-shore and mid-shore (*PPMacoma incongrua* etc.), however, there was no significant difference between the two low-shore stations (P0.05). Furthermore, it was found that the site differences in sediment erodability were not significantly correlated with measured physical properties of sediments and biota factors such as total macrofauna biomass, total abundance and macrofauna densities, Chl-a and Ph-a (P0.05). However, there was a significant correlation between sediment erodability and both median grain size (PM. incongrua (P<0.05). There was also evidence of a slight increase in sediment stability after 3 h of air exposure, but the effect was not overcome following the addition of Manila clams. It is hypothesized that the lower stability of sediments at the mid-shore level was probably associated with higher densities of bioturbators and with disturbance by shrimp farming near the high-shore.

Keywords: manila clam, flume, erosion, ECOP.

Kamimura, R., K. Hiromatsu, Y. Tian, I. Oshima, and S. Tsuzuki. 1999. **Impact assessment of coastal structure installation on the stock of the Japanese surf clam (*Spisula sachalinensis*) using a life cycle model.** Fish Eng Japan; Suisan Kogaku Japan. 36(1):75-85.

The relationship between distribution of juvenile Japanese surf clam *Spisula sachalinensis* and environmental factors in the neighboring area of nuclear power plant was investigated. Then a life cycle model of population dynamics incorporating the environmental factors was developed to evaluate the impact of the coastal structure installation on the stock of the surf clam. And a wave transport model was also developed to evaluate the effect of wave transport on the juvenile clam. Results of surveys show that the density of juvenile clam is higher around the breakwater. The mortality of the surf clam in shallow bottom and deeper offshore areas was affected by waves and the silt content respectively. Therefore a method was developed to estimate the mortality coefficient in terms of the Shields number. The life cycle model focuses on effect of the environmental factors such as current, silt content, Shields number and water temperature on survival and growth of the surf clam at various life stages. Results of the model show that the installation of coastal structures has an effect to reduce the mortality rate of juvenile clam, so that stock abundance of the clam increased accordingly. A wave transport model for the juvenile clam shows that clams tend to accumulate in the depth zone of 8 to 10m under average wave condition. It suggests that optimal habitats of the surf clam result from the

small mortality and effect of wave transport.

Keywords: Stock assessment, Coastal structures, Environmental factors, Juveniles, Mollusc fisheries, Powerplants, Lifecycle, Spisula-sachalinensis, INW, Japan, Honshu, Fukushima, Prefect, mathematical models.

Klumpp, D.W., B.L. Bayne, and A.J.S. Hawkins. 1992. **Nutrition of the giant clam Tridacna gigas (L.). 1. Contribution of filter feeding and photosynthates to respiration and growth.** Journal of Experimental Marine Biology and Ecology. Vol. 155, no. 1, pp. 105-122. IS: ISSN 0022-0981.

The total carbon requirements (growth + respiration) of the host tissues of the giant clam Tridacna gigas from Davies Reef on the Great Barrier Reef were measured, and compared with rates with which nutrients were acquired from the two potential sources, translocated photosynthates and filter feeding. The giant clam is an efficient utilizer of particulate organic matter available in reef waters, retaining on average 75% of particles between 2 and 50 mu m, and absorbing from them 54% of C. The proportion of carbon deposited in tissues relative to that respired is high in giant clams relative to completely heterotrophic bivalves. We conclude that autotrophy is the major source of car bon to this clam, potentially capable of satisfying all respiratory requirements of the host. However, the potential importance of heterotrophy to total energy needs of the host is also significant and changes with the size of clam. The spectacular rates of growth in this clam are such that filter feeding is able to provide 65% of the total carbon needed both for respiration and growth in small clams (100 mg dry tissue wt), whereas large clams (10 g) acquire only 34% of their carbon from this source.

Paterson, K.J., and J.A. Nell. 1997. E**ffect of different growing techniques and substrate types on the growth and survival of the clams *Tapes dorsatus* (Lamarck) and *Katelysia rhytiphora* (Lamy).** Aquacult.Res. 28(9):707-715.

Potential clam farming areas containing clean sandy sediment accessible at low tide are limited in New South Wales, Australia. The availability of farming infrastructure such as oyster racks and floating devices along with the prevalence of sediment other than clean sand prompted the assessment of farming methods for *Tapes dorsatus* (Lamarck) and *Katelysia rhytiphora* (Lamy) and sediment preferences for *T. dorsatus*. This study indicates that both clam species, when contained in baskets, grow (whole weight and shell length increase) significantly faster (P 0.05). *Tapes dorsatus* held in a sandy-shell substrate grew faster than those cultured in substrates of only shell, sand or mud at the same intertidal site. Survival rates over 6 months were high in all these translocated sediments and ranged from 95 to 100%. *Tapes dorsatus* grown in the same sediments in a nearby tidally-exchanged subtidal pond reached market size (approximately 38 mm) after 6 months of grow-out and were over twice as heavy (whole weight 10.0-11.9 g) as those grown inter-tidally (whole weight 3.7-5.7 g).

Keywords: Survival, Growth, Aquaculture techniques, Substrata, Aquaculture development, Clam culture, Marine aquaculture, Katelysia rhytiphora, Tapes dorsatus, PSE, Australia, New South Wales, Australia..

Pranovi, F., S. Libralato, S. Raicevich, A. Granzotto, R. Pastres, and O. Giovanardi. 2003. **Mechanical clam dredging in Venice lagoon: ecosystem effects evaluated with a trophic mass-balance model.** Marine Biology. 143(2):393-403.

Harvesting of the invasive Manila clam, *Tapes philippinarum*, is the main exploitative activity in the Venice lagoon, but the mechanical dredges used in this free-access regime produce a considerable disturbance of the lagoon ecosystem. An ecosystem approach to study the complex effects of clam harvesting was implemented using a trophic mass-balance model. The trophic relations in the ecosystem were quantified with a mixed trophic impact analysis and further evaluated by considering different explanations for the " *Tapes* paradox", which consists of the apparent population enhancement of Manila clams by dredging and the apparent nutritional advantages that this species receives from re-suspended organic matter. The key-role played by this introduced species is highlighted by a network analysis that indicates a "wasp-waist control" of the system by Manila clams. The model constructed to characterize the present state of the Venice lagoon ecosystem is compared with models produced for a reconstructed past lagoon and a projected future lagoon. The future model was obtained by simulating the elimination of clam dredging in 10 years. The three different models were compared using thermodynamic and informational indices. Simulating the elimination of clam dredging produced a 33% increase in artisanal fishery catches, carried out by means of static gears, even with no change in fishing effort. These simulations also forecast an increase in the mean trophic level of the artisanal fishery catches as a positive effect of eliminating mechanical clam harvesting

Keywords: species, culture, mechanical, clam, dredging, Venice Lagoon.

Pranovi, F., and O. Giovanardi. 1994. **The impact of hydraulic dredging for short-necked clams, *Tapes spp*., on an infaunal community in the lagoon of Venice.** Scientia Marina (Barcelona). 58(4):345-353.

No abstract identifying these species for this category.

Sokolowski, A., M. Wolowicz, H. Hummel, and R. Bogaards. 1999. **Physiological responses of *Macoma balthica* to copper pollution in the Baltic.** Oceanol-Acta 1999. 22(4):431-439.

Physiological and behavioral responses to Cu exposure were measured in the Baltic clam *Macoma balthica* from the Gulf of Gdansk, southern Baltic Sea. The burrowing activity, mortality rate, glycogen content, condition index and free amino acid (FAA) composition were analyzed as indicators of stress in a series of field and laboratory studies. M. balthica exposed to Cu showed clear Cu-concentration related differences in burrowing activity and mortality rate, but no consistent differences in the condition index, glycogen content, and free amino acids. The clams from a less polluted area reacted stronger and were more sensitive to additional stress as compared to organisms from a more polluted region. The effect of Cu on the ecophysiology of Baltic clams in the field was probably obscured by reproduction-related changes in the organism. The role of sediment as a potential source of Cu in the Baltic clam was discussed.

Keywords: Biological stress, Copper, Ecophysiology, Glycogen, Amino acids, Pollution effects, Macoma balthica, ANE, Baltic Sea, Gdansk, Gulf burrowing organisms.

Tallqvist, M. 2001. **Burrowing behaviour of the Baltic clam *Macoma balthica*: effects of sediment type, hypoxia and predator presence.** Marine Ecology Progress Series. 212183-191.

Burial in sediment-dwelling clams is affected by morphological features, such as shell shape and size, but also by biotic and abiotic factors, such as predator presence, oxygen deficiency and sediment characteristics. In the Baltic Sea, oxygen deficiency is a severe problem not only in the deep basins, but also in the shallow coastal areas, due to eutrophication. In the species-poor Baltic Sea, the bivalve *Macoma balthica (L.)* is a key species in both shallow and deep bottoms. This paper analyzes the impact of biotic and abiotic factors on the burrowing behaviour of M. balthica. Experiments were conducted to study the importance of sediment type, hypoxia, predator presence and algal mats on the burrowing behaviour (start of burial and burial velocity) of M. balthica. Results show that sediment type and the presence of the predatory isopod Saduria entomon did not affect the burrowing behaviour of M. balthica. In contrast, the burrowing behaviour was negatively influenced by hypoxia and drifting algae. Physical disturbance and oxygen deficiency are important forces that may displace M. balthica in the sediment and make it susceptible to predators at the sediment surface. Burial in the sediment is the only way in which infauna bivalves may escape predators, and this study shows that burrowing capability can be affected by poor environmental conditions.

Keywords: Macoma balthica, Burial, Eutrophication, Hypoxia, Predation, Algal mats.

Whiteley, J.A. 2005. **Macroinvertebrate Community Responses to Clam Aquaculture Practices in British Columbia, Canada.** M.Sc. Thesis, Simon Fraser University. pdf 'JAW.MSc_Thesis_05'; Hardcopy. Paired reference/farm or prefarm sites in Baynes Sound(5), Barkley Sound(3), Desolation Sound(3) sampled May-Aug 2002.

Three paired (netted or not) 5x5m experimental plots in Baynes Snd sampled over 10 months; Found no difference in composition, density, or biomass of macroinvertebrate communities within netted clam farm sites and reference sites; Found no effect/benefit of netting in terms of reduction in predation; mortality rate of non-Manila clam species was the same under netting and at ref sites; Some (multivariate vs. univariate stats?) evidence of increasing homogeneity and dominance of Manila clams in farm plots; Greater differences amongst reference sites; ref sites were not enough like farm sites in terms of sediment type, tidal elevation, slope, wave exposure, salinity;

Keywords: species, culture, macroinvertebrate, response, British Columbia, Canada..

4.2 Geoduck

Cheney, D. 2007. **Summary of Pacific Shellfish Institute 2006 Geoduck Farm Preliminary Sampling and Sorting Studies – Hood Canal and South Puget Sound.** Pacific Shellfish Institute, Olympia, Washington.

No abstract identifying these species for this category.

Pearce, C.M., Y.X. An, J.M. Blackburn, L.J. Keddy, D.L. Paltzat, and S.W. Williams. 2007. **Intertidal culture of juvenile geoduck clams (*Panopea abrupta*): an examination of predator protection technology and potential environmental interactions.** Pacific Biological Station, Department of Fisheries and Oceans, Canada.

No abstract identifying these species for this category.

Short, K.S., and R. Walton. 1992. **The transport and fate of suspended sediment plumes associated with commercial geoduck harvesting.** Final Report. Prepared by Ebasco Environmental (Bellevue, Washington) for the Washington Department of Natural Resources.

Concludes that "based on existing information, field data collected during this project, plume transport modeling results, and results from semi-empirical techniques regarding resuspension and deposition,"...."transport and fate of suspended sediment associated with commercial geoduck harvesting will have minimal impact on the physical environment in the harvest tract and adjacent areas, including intertidal." Alludes to a separate study into the biological impacts associated with geoduck harvesting.

Keywords: geoduck, harves tsediment, plume,harvest

Willner, G. B. 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.** Masters Thesis, Evergreen State College, Olympia, Washington.

No abstract identifying these species for this category.

4.3 Mussels

Anderson, A.S., A.L. Bilodeau, M.R. Gilg, and T.J. Hilbish. 2002. **Routes of introduction of the Mediterranean mussel (*Mytilus galloprovincialis*) to Puget Sound and Hood Canal.** Journal of Shellfish Research. 21(1):75-79.

To test alternative routes of introduction we describe the distribution of *Mytilus galloprovincialis*, *M. trossulus* and their hybrids in Puget Sound and Hood Canal. Native mussels, *Mytilus trossulus*, dominate the blue mussel communities of Puget Sound and Hood Canal; at most sites *M. galloprovincialis* alleles were rare or absent. *M. galloprovincialis alleles* were present but uncommon (similar to 5%) in mussel populations in the southern portion of Puget Sound, and were nearly absent in populations in the northern Puget Sound and the Hood Canal. The only locations where *M. galloprovincialis alleles* are locally common are sites where they are likely to have been repeatedly introduced. These include sites near mussel farming operations and near the Port of Seattle and Bremerton Naval Shipyards. The results indicate that both aquaculture and shipping activities have been responsible for the repeated introduction of *M. galloprovincialis* to Puget Sound. Although hybridization between *M. galloprovincialis* and *M. trossulus* occurs, there was little evidence for advanced introgression between these two species.

Keywords: Introduced species, Shipping, Aquaculture, Allelles, Hybridization, Marine molluscs, Distribution records, Man-induced effects, Marine transportation, Ballast, Shipyards, Marine aquaculture, Culture effects, Mussel culture, Hybrids, Mytilus galloprovincialis, Mytilus trossulus, INE, USA, Washington, Seattle, Port of SeattleINE, USA, Washington, Puget SoundINE, USA, Washington, Puget Sound, Hood Canal species culture

Boyd, A.J., and K.G. Heasman. 1998. **Shellfish mariculture in the Benguela system: Water flow patterns within a mussel farm in Saldanha Bay, South Africa**. Journal of Shellfish Research. 17(1):25-32.

The water flow rates within mussel rafts in Saldanha Bay were measured and related to hydrodynamic forcing (in terms of ambient flow in the farm) and raft specifications. Currents within and in the vicinity of the mussel farm were highly variable in speed and direction and were subject to wind and tidal forcing, as well as bay resonances. The rafts affected the water flow in three ways: most of the flow diverged around a raft; within a raft, the flow tended to align along one of its major axes; and within the raft, the water was retarded. Retardation appeared to depend on ambient flow speed and was statistically related to mussel rope spacing. Velocities of 7.5 cm/s and 1.25 cm/s within the farm and rafts, respectively, are suggested as the most appropriate values for calculating the food supply rates required by associated studies. The effect of a similar farm on downstream advection velocities is modeled considering a uniform flow, and possible future advection limitations on a designated new lease area are discussed.

Keywords: Shellfish culture, Mussel culture, Water currents, Cage culturespecies culture.

Dahlbaeck, B., and L.A.H. Gunnarsson. 1981. **Sedimatation and Sulfate Reduction Under a Mussel Culture.** Marine Biology. 63(3):269-275.

The sedimentation and dissimilarory sulfate reduction under a blue-mussel (Mytilis edulis) culture were quantified in order to gain in formation on the environmental impact of intense mussel farming. The sedimentation rate (3gC multiplied by m super(-2) multiplied by d super(-1)) under a culture is nearly three times higher than at a nearby reference station. A build-up of sediment rich in organic material and sulfide takes place under the mussels. At 15 degree C the sulfate reduction rate was 30.5 mmol SO super(=)@)d4 ;m super(-2) multiplied by d super(-1 in the upper 10 cm of the mussel sediment. The increase in sedimentation under a mussel culture and the consequent effects should be considered when establishing mussel farms.

Keywords: shellfish, culture, sedimentation, fecal, pellets, sulfate reduction, Mytilus edulismussel.

Grant, J., and C. Bacher. 1999. **Modelling resuspension and its effects on bivalve food supplies.** Journal of Shellfish Research. 18(1):308.

Many models of shellfish growth in culture are based on food supplies being a primary determinant of growth. The representation of suspended food in these models is difficult because seston is a mixture of phytoplankton, detritus, and other material with complex temporal dynamics. In shallow coastal systems, resuspension contributes significantly to the particle load, although the material injected into the water column is of variable quality, depending on the abundance of benthic microalgae, macrophyte detritus, etc. Rates of resuspension are regulated by substrate type (sand and mud), shear stress due to waves and currents, and biological processes such as bioturbation. For cohesive muds, a model of resuspension and its effect on water column turbidity is superficially straightforward. However, there are a variety of pitfalls including critical erosion threshold, depth of erosion, deposition, food quality, and groundtruth data all of which complicate model formulation. A model of tidal resuspension is applied to a mussel aquaculture site in a shallow muddy bay (Upper South Cove, Nova Scotia). Previous studies in the cove have examined erosion rate and threshold as well as near-bottom suspended particulate matter, providing an unusually complete data set for model verification.

Considerations of erosion formulation and its assumptions are presented for this model. The implications for applying resuspension to overall models of bivalve culture carrying capacity are then explored.

Keywords: Resuspended sediments, Filter feeders, Aquaculture techniques, Shellfish culture, Detritus feeders, Food availability, Turbidity, Mathematical models.

Grant, J., A. Hatcher, D.B. Scott, P. Pocklington, C.T. Schafer, and G.V. Winters. 1995. **A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities.** Affiliation – Department of. Oceanography Dalhousie Univ., Halifax, NS B3H 4J1, Canada Estuaries. Vol. 18, no. 1A, pp. 124-144. IS: ISSN 0160-8347

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.

Keywords: mussel culture; zoobenthos; environmental impact; ecosystem disturbance; community composition; aquaculture; environmental effects; benthos; effluents; Mytilus; mussels; Mytilus; ANW, Canada, Nova Scotia; Canada, Nova Scotia.

Grant, J., A. Hatcher, D.B. Scott, P. Pocklington, C.T. Schafer, and G.V. Winters. 1996. **A Multidisciplinary Approach to Evaluating Impacts of Shellfish Aquaculture on Benthic Communities.** Estuaries. 18(1A):124-144.

No abstract identifying these species for this category.

Hatcher, A., J. Grant, and B. Schofield. 1994. **Effects of Suspended Mussel Culture (*Mytilus spp.*) on Sediment, Benthic Respiration and Sediment Nutrient Dynamics in a Coastal Bay**. Marine Ecology Progress Series. 275219-235.

Many studies have shown that the primary effect of shellfish culture on nearshore marien systems is enhanced sedimentation. This study was designed to measure the effects of this enhanced sedimentation on the respiration and nutrient fluxes of the benthic community and the coupling between the pelagic and benthic systems at a mussel culture site (*Mytilus edulis* and *M. trossulus*) in Upper South Cove, Nova Scotia, Canada. There was a significant association between chlorophyll in the water column and sedimentation rate in Upper South Cove over the study year, 1990, particularly under the mussel lines, but the majority of the particulate carbon and nitrogen which fell of the bottom was not incorporated into the sediments. Suspended mussel culture had little impact on sediment phosphorus dynamics. The largest response of the sediment community to suspended mussel culture was ammonium release, which was higher under the mussel lines at all times of the year. Over the year, the sediments of the reference site were a net

sink for total dissolved nitrogen, while the sediments under the mussel line were a source.

Keywords: Sediment, Respiration, Nutrient, Flux, Aquaculture, Mussels, ECOP, mussel, rafts.

Hoagland, P., Di Jin, and H.L. Kite Powell. 1998. **Understanding the potential of offshore marine aquaculture: A bioeconomic approach.** Journal-of-Shellfish-Research. 17(1):356.

Social scientists at the Woods Hole Oceanographic Institution's Marine Policy Center are developing a generic model of the project economics of a marine aquaculture operation in offshore waters. The model will be applied to planned or hypothetical offshore ventures in New England. Employing a bioeconomic approach, the model will incorporate information now emerging about construction requirements and biological growth processes in marine settings, the effects of engineering and biological uncertainties, the costs of regulatory compliance, and variability in supply and demand in the relevant product markets. The model will be designed to estimate the economic feasibility of an individual operation at a particular location and to determine the minimum efficient scale of operations. Importantly, because of the risky nature of ocean aquaculture, the model will incorporate riskbased methods. The modelling approach involves two steps. The first step is a two part cost assessment. We will estimate the internal costs of growout systems (cages, moorings, etc.), vessel operations (boat and crew costs), transportation, and other relevant costs. These costs will be incorporated into a project evaluation component. Where appropriate, we will also estimate any external costs associated with nutrient loading and other effluents or the impingement of marine aquaculture operations on other uses of the ocean. (The estimation of external costs is generally outside the scope of a private project evaluation effort, but these estimates will be useful for any social benefit cost analyses.) Second, we will conduct a feasibility study to determine the likelihood that a project can be commercially successful. This step requires linking the project evaluation component to a model of supply and demand (market component) in the relevant product market. We present some early results from the modelling efforts, focusing on the hypothetical ocean aquaculture of the blue mussel, *Mytilus edulis*, as an example.

Keywords: Mussel culture, Aquaculture development, Aquaculture economics, Marine, Edible blue mussel, species culture.

Kaiser, M..J., G. Burnell, and M. Costello. 1998. **The environmental impact of bivalve mariculture: A review.** Aquaculture '98 Book of Abstracts. pp. 81-82.

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 multiuser 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. Bivalve cultivation can be broadly split into three main processes: (1) seed collection, (2) seed nursery and on-growing, and (3) harvesting. In many instances, commercial species are reared as seed in hatcheries prior to seeding, with few effects on the environment. However, some species are collected from the

wild using spat collectors or dredgers. 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. The nursery and ongrowing of bivalves either takes place intertidally (clams and oysters) or subtidally (mussels and scallops). 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 t he 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.

Keywords: Marine aquaculture; Mollusc culture; Clam culture; Mussel culture; Oyster culture; Scallop culture; Culture effects; Off-bottom culture; Seed collection; Harvesting; Anthropogenic factors; Filter feeders; Suspended particulate matter; Excretory products; Anoxic conditions; Degradation; Nursery grounds; Habitat; Environmental impact; Intertidal environment; Ecosystem disturbance; Trophodynamic cycle; Biological stress; Mortality causes; Biota; Marine birds; Bivalvia; British Isles; ANE, British Isles; Eire; ANE, Eire.

Lindahl, O., R. Hart, and B. Hernroth, et al. 2005. **Improving Marine Water Quality by Mussel Farming: A ProfitableSolution for Swedish Society.** Ambio. 34(2):131-138.

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.

Walton, W.C. 2001. **Removal of blue mussels, *Mytilus edulis*, from mudflats: Does it improve softshell clam, *Mya arenaria*, habitat?** Journal-of-Shellfish-Research. vol. 20(no. 1):528.

In response to apparent increasing abundance of the blue mussel, *Mytilus edulis*, on certain productive mudflats, municipal shellfish managers in Downeast Maine have become concerned about the effects of mussels upon clams. In Perry, ME, the shellfish committee enlisted local clam diggers to remove similar to 1 acre of mussels to reduce presumed negative effects upon softshell clams, *Mya arenaria*. To test both the effects of mussels and the efficacy of removal, we conducted a field-based experiment initiated on August 1 super(st), 2000. Sediment-filled, plastic flowerpots (similar to 150 mm deep and similar to 150 mm in diameter) were each seeded with 10 juvenile clams, 14.3 plus or minus 0.17 mm shell length. To test the effect of the presence of a mussel bed, 36 pots were then placed in either a bed of mussels (a patchwork of clumps of mussels) or on an adjacent mudflat in the lower intertidal of a cove in Perry. Within each of these two areas, pots were placed underneath a clump of mussels (>0.5 m in diameter), adjacent to a clump, or in an open area without mussels (>1 m from any mussels). Lastly, half of the pots were meshed to protect them from predation with flexible 6 mm meshing. All pots were collected on September 28 super(th), 2000, and surviving clams were counted and measured. Survival was significantly lower in unprotected pots (P = 0.0001) than protected pots, and was also low underneath mussels. More interestingly, among unprotected clams not under mussels, survival tended to be better in the mussel bed than on the flat (adjacent, P = 0.0801; open, P = 0.0380). In terms of growth, final shell length was lowest underneath clumps of mussels; among clams not underneath mussels (where survival was very low), growth tended to be better on the mudflat than in the mussel bed. This result was greater for unprotected clams (P less than or equal to 0.1437) than for protected clams (P greater than or equal to 0.2803), suggesting a possible interaction with predation. Thus, the presence of mussels has a mixture of effects upon clams, which need to be considered when contemplating removal.

Keywords: Density dependence, Clam culture, Marine molluscs, Competition, Filter feeders, Predation, Mytilus edulis, Mya arenaria, ANW, USA, Maine, Blue mussel, Softshell, clam.

4.4 Oysters

Coen, L.D., and M. Bolton Warberg. 2003. **Evaluating the impacts of [oyster] harvesting practices, boat wakes and associated shoreline erosion on intertidal creek habitats in the southeastern U.S.: Managers and restoration programs take note**. Journal of Shellfish Research. 22(1):325.

In areas where oysters are intertidal and fringe marsh-lined creeks, they can act as shoreline `stabilizers'. Recent work (FL, SC, and NC) suggests that harvesting and boating, in addition to natural phenomena, can significantly impact natural intertidal habitats and restoration/enhancement efforts. We assessed oyster populations prior to applied treatments, evaluating the direct impacts of four common harvesting practices on oyster population recovery at 12 sites, paired with controls. Concurrently, recruitment, survival, and growth were also examined annually and populations reassessed similar to 3 years later to evaluate `recovery'. Simulated boat wake experiments used shell treatments (with and without mesh) to evaluate impacts of wakes on restoration efforts. Results are discussed and current larger-scale study

designs applying our findings are summarized. Four study sites were established in 1999 to measure shoreline erosion. Over 25-38mo, rates ranged from similar to 0-23cm/month; overall bank losses were from 69-154 cm. In 2001, we expanded sampling at nine additional sites using our SCORE program. Erosion rates (4-16mo.) ranged from similar to 2-8cm/month, with overall losses from 13-104cm. These and other results suggest that anthropogenic impacts may be having much greater impacts on critical intertidal habitats than previously perceived.

Keywords: Oyster fisheries, Catching methods, Harvesting, Wakes, Fishing vessels, Ecosystem disturbance, Intertidal environment, Salt marshes, Damage, Mortality causes, Population dynamics, Commercial species, Marine molluscs, Stabilizers, Coasts, Coastal erosion, Environmental monitoring, Man-induced effects, Restoration, Coastal zone management, Crassostrea virginica, USA, South Carolina, ANW, USA, South Carolina..

Crawford, C., I. Mitchell, and C. Macleod. 2001. **Effects of shellfish farming on the environment.** Aquaculture 2001: Book of Abstracts, Louisiana State, University, Baton Rouge, LA 70803 USA World Aquaculture Society. 14321-25. Conference - Aquaculture 2001, Lake Buena Vista, FL (USA), 21-25 Jan 2001.

The production of shellfish, mainly *Crassostrea gigas*, in Tasmania, Australia is approximately 2,500 metric tons per annum, which is small by world standards. Nevertheless, there is considerable community opposition to the expansion of the industry, partly because of concerns about possible detrimental effects on the environment. As a consequence, several projects were instigated to investigate the interactions between shellfish farming and the environment. The effects of shellfish farming on the benthic environment were investigated in detail at three deep water shellfish farms in Tasmania which have had a relatively high level of production. Benthic samples collected from within and outside the farm area were analyzed for physical/chemical variables, and composition and abundance of the invertebrate faunal community. Rates of sediment deposition were measured, and sections of the seabed were recorded using a video camera. 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.

Keywords: Marine aquaculture, Shellfish culture, Oyster culture, Environmental effects, Benthic environment, Ecosystem disturbance, Disease transmission, Eutrophication, Sedimentation, Suspended particulate matter, Particulate organic matter, Particulate flux, Man-induced effects, Aquaculture, Human impact, Population environment relations, Sediments, Risk assessment, Pests,-Pathogens, Coastal zone, Estuaries, Filter feeders, Nutrients, Environmental impact,

Crassostrea gigas, Australia, Tasmania, PSE, Australia, Tasmania, Oyster culture, Pacific giant oyster.

Forrest, B.M., and R.G. Creese. 2006. **Benthic impacts of intertidal oyster culture, with consideration of taxonomic sufficiency.** Environmental Monitoring and Assessment. 112(1-3):159-176.

An investigation of the impacts from elevated intertidal Pacific oyster culture in a New Zealand estuary showed enhanced sedimentation beneath culture racks compared with other sites. Seabed elevation beneath racks was generally lower than between them, suggesting that topographic patterns more likely result from a local effect of rack structures on hydrodynamic processes than from enhanced deposition. Compared with control sites, seabed sediments within the farm had a greater silt/clay and organic content, and a lower redox potential and shear strength. While a marked trend in macrofaunal species richness was not evident, species composition and dominance patterns were consistent with a disturbance gradient, with farm effects not evident 35 m from the perimeter of the racks. Of the environmental variables measured, sediment shear strength was most closely associated with the distribution and density of macrofauna, suggesting that human-induced disturbance from farming operations may have contributed to the biological patterns. To evaluate the taxonomic sufficiency needed to document impacts, aggregation to the family level based on Linnean classification was compared with an aggregation scheme based on ;general groups' identifiable with limited taxonomic expertise. Compared with species-level analyses, spatial patterns of impact were equally discernible at both aggregation levels used, provided density rather than presence/absence data were used. Once baseline conditions are established and the efficacy of taxonomic aggregation demonstrated, a ;general group' scheme provides an appropriate and increasingly relevant tool for routine monitoring.

Keywords: species, culture, oyster, culture impacts.

Luckenbach, M.W., and V. Harry. 2004. **Linking watershed loading and basin-level carrying capacity models to evaluate the effects of land use on primary production and shellfish aquaculture.** Bulletin-Fisheries Research Agency Japan.123-132.

Aquaculture production of hard clams, *Mercenari mercenaria*, in the lower Chesapeake Bay, Virginia, U.S.A., has increased dramatically within the last decade. In recent years concern has been raised that some growing areas may be approaching the exploitation carrying capacity for clam production. Preliminary calculations indicate that large-scale intensive clam aquaculture may be controlling nutrient and phytoplankton dynamics in this system. To date, carrying capacity models have not been applied to this system, but we are in the process of building models for that purpose. Moreover changing land use in the watersheds surrounding the clam-producing areas raises the need for an improved understanding of how these changes will affect water quality, primary production and shellfish production. We describe an ongoing project linking a watershed-based loading model with a physical transport-based water quality model to simulate primary production and predict carrying capacity for clam aquaculture. Extensive calibration and verification of the water quality model has demonstrated its utility for simulating primary production and water quality parameters in the Chesapeake Bay. In our present efforts, watershed loading models have been developed and tested for predicting both surface and groundwater inputs into the coastal waters. We are currently coupling the water quality and

watershed loading models, and developing clam physiology and population-level sub-models. Also, under development is a sediment deposition/resuspension sub-model. Each of these components will be linked to estimate exploitation carrying capacity for clam production in this system. Our goal is to use the coupled models to predict how varying land use scenarios impact water quality, primary production and shellfish carrying capacity of coastal waters.

Keywords: Mercenaria mercenaria, aquaculture, carrying capacity, water quality model.

Luckenbach, M.W., L.D. Coen, P.G. Ross Jr., and J.A. Stephen. 2005. **Oyster Reef Habitat Restoration: Relationships between Oyster; Abundance and Community Development Based on Two Studies in Virginia; and South Carolina.** J. Coast. Res.(40):64-78.

Before the 20th century, the U.S. coastal waters on the Atlantic Ocean and Gulf of Mexico abounded with oysters. Not only were oysters an important commercial fishery, these mollusks also provided an efficient water-filtering system for estuaries. Recent research has shown that oyster reefs are sites of enhanced biodiversity and primary production. However, oyster populations throughout the southern and eastern U.S. were decimated by over harvesting, disease, and environmental degradation. In the past decade, several oyster restoration projects have been undertaken, many of them funded by state and federal agencies. However, as these efforts are in relatively early stages, there is as yet little data on long-term results and no standardized criteria for assessing restoration success. To accurately evaluate restoration efforts, researchers must more fully understand the relationship between oyster population structures and abundance and the ecological services desired through restoration. It has been suggested that oyster reefs do not regain positive ecological function until oysters attain a market size. To assess the results of oyster reef restoration, researchers analyzed the results of two markedly different restoration studies. In one study, oyster reefs were constructed at four sites on the Rappahannock River in Virginia, a tributary of the Chesapeake Bay. The reefs were built from oyster and surf clam shells. The reefs are fairly large and extend several meters above the seabed. In a second project, a series of small reefs were constructed adjacent to natural reefs in Inlet Creek in South Carolina, a tributary of Charleston Bay. These reefs extended just 10-30 centimeters (cm) above the upper sediment. While the Virginia project is 2 years old (in terms of data), the South Carolina project is nearly 7 years old. At both sites, the presence of oyster reefs increased biodiversity and resident species abundance within a relatively short time. No relationship was found between oyster size and positive environmental effects. These results indicate that, even in early stages, oyster reef restoration has a strong positive impact on ecosystem quality.

Keywords: oyster reef restoration, habitat restoration, rappahannok, riverinlet, creek, South Carolina, biodiversity, general aquaculture.

Luckenbach, M.W., J. Harding, R. Mann, J. Nestlerode, F.X.O. Beirn, and J.A. Wesson. 1999. **Oyster reef restoration in Virginia, USA: Rehabilitating habitats and restoring ecological functions.** Journal of Shellfish Research. 18(2):720.

Repletion efforts in response to declines in abundance of the eastern oyster, *Crassostrea virginica*, have historically relied upon transplanting of oyster seed and planting of a suitable settlement substrate. These efforts have generally failed to revitalize the fishery because they (1) failed to rehabilitate degraded reef habitat and (2) placed little emphasis upon reestablishing a population age structure capable of sustaining a self-supporting reef. More recently restoration

efforts in Virginia have focused on reconstructing 3-dimensional reef habitats and establishing brood stock sanctuaries with an emphasis on restoring lost ecological functions of reefs. Manipulative studies of reef placement, construction material and interstitial space have lead to the development of design criteria for maximizing oyster recruitment, growth and survival on constructed reefs. Further, we have characterized the successional development of resident macrofaunal communities on restored reefs and have begun to relate that development to specific habitat characteristics. Utilization of these restored reef habitats by transient species has been characterized through extensive field collections and underwater video observations; gut analyses of finfish are beginning to elucidate trophic linkages between the reefs and adjacent habitats. In addition, these structures appear important to the early developmental stages of juvenile fishes, some of which have considerable recreational and commercial importance. These studies are helping us to (1) clarify the ecological functions supported by oyster reef habitat, (2) define design criteria for reconstructing reefs and (3) establish success criteria for such restoration projects. While destructive fishing of oyster reefs appears inconsistent with meeting these goals, an emerging paradigm is that reef sanctuaries can be used to support desired ecological functions as well as supply recruits to adjacent areas which can be managed from a fisheries perspective.

Keywords: Oyster reefs, Habitat improvement, Benthos, Marine ecology, Environmental-impact, Fishery management, Recruitment, Crassostrea virginica, ANW, USA, Virginia, Eastern oyster.

Mallet, A.L., C.E. Carver, and T. Landry. 2006/5/31. I**mpact of suspended and off-bottom Eastern oyster culture on the benthic environment in eastern Canada.** Aquaculture. 255(1-4):362-373.

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.

Keywords: Shellfish farming, Oyster culture, Environmental impact, Sulfide, Redox, Sedimentation rates, species culture.

Mazouni, N., J.C, Gaertner, J.M. Deslous-Paoli, S. Landrein, and M. Geringer d'Oedenberg. 1996. **Nutrient and oxygen exchanges at the water-sediment interface in a shellfish farming lagoon (Thau, France).** Journal of Experimental Marine Biology and Ecology. Vol. 205, no. 1-2, pp. 91-113. 1 Nov.

The Etang de Thau (France) is a shallow lagoon characterized by the semi-intensive farming of oysters (*Crassostrea gigas*, Thunberg) cultured in suspension on frames. Analysis of the benthic fluxes of inorganic nutrients and oxygen over a period of a year has provided a basis for describing the dynamics of the water-sediment interface in the lagoon. Monthly measurements of fluxes at the water-sediment interface at two stations have been compared. One station (UC) is located under a culture table, and is subject to intensive accumulation of organic matter (biodeposition); the other (OC) is located outside the area directly under the impact of the culture activities. Oxygen consumption ranged from 288.24 to 1026.85 mu mol times m super(-2) times h super(-1) according to the season and the station. Ammonium production was maximal at station UC in Summer (600 mu mol times m super(-2) times h super(-1)) and minimal at station OC in the Autumn (30 mu mol times m super(-2) times h super(-1)). In general, the fluxes recorded at station UC were 1.8-3 times higher than those recorded at station OC for oxygen and 1-5 times higher for ammonium. Nevertheless, the variability between stations was lower than the seasonal variability. Using a Multiple Correspondence Analysis (MCA), it was possible to point out the occurrence of an atypical event that was responsible for the disruption of the seasonal cycle. This event was a state of hypoxia known locally under the generic name of malaiegue. The dystrophic crisis consists of a major perturbation of the ecosystem, responsible for a massive mortality affecting both the benthos and the reared stocks.

Keywords: Oyster culture; Aquaculture effluents; Sediment-water exchanges; Biogeochemistry; Eutrophication; Nitrogen cycle; Zoobenthos; Pollution effects; Hypoxia; Crassostrea gigas; MED, France, Languedoc-Roussillon, Thau Lagoon..

Richardson, N.F. J.L. Ruesink, S. Naeem, S.D. Hacker, H.M. Tallis, B.R. Dumbauld, L.M. Wisehart. 2007. **Bacterial abundance and aerobic microbial activity across natural and oyster aquaculture habitats during summer conditions in a northeastern Pacific estuary.** Hydrobiologia, in press.

Observational study of sediment properties, especially microbes, in six habitat types and along the estuarine gradient of Willapa Bay. Habitat types: eelgrass, unstructured, oyster hummocks (reefs), mechanically-harvested ground, hand-picked ground, and longline oyster aquaculture. Microbial cell density varied most strongly along the estuarine gradient, being positively associated with organic content. Aerobic microbial activity varied less strongly along the estuarine gradient and additionally showed habitat-specificity, being slightly lower in on-bottom oyster aquaculture. Although in this study, sediment properties such as grain size and organic content did not vary by habitat type, other experimental work suggests that biodeposits from oyster hummocks reduce grain size and increase organic content. [Funding: USDA WRAC, UW Bridges, Mellon Foundation].

Rodney, W.S., and K.T. Paynter. 2006/7/25. **Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland.** Journal of Experimental Marine Biology and Ecology. 335(1):39-51. http://www.life.umd.edu/biology/paynterlab/labpub/R_P2006.pdf

Maryland's recently created oyster restored reefs provide us with a unique opportunity to observe the abundance and species composition of macrofauna assemblages on unexploited reefs with high concentrations of mature oysters and undisturbed reef architecture. They might thus be used to better understand the magnitude of losses to reef dwelling macrofauna communities, and the associated loss of ecological functions resulting from reef destruction. We sampled reef macrofaunal assemblages on restored plots at four restored oyster reefs and adjacent non-restored plots located outside restored boundaries. We then compared the effects of study site location, and habitat quality (restored versus non-restored) on macrofaunal density using thirteen response variables. Density of macrofauna was an order of magnitude higher on restored reefs, epifaunal density was more than twice as high on restored reefs and sessile macrofaunal density was two orders of magnitude higher on restored reefs. Three out of the five dominant taxonomic groups were much more abundant on restored plots. Mean amphipod density was 20 times higher on restored plots and densities of xanthid crabs and demersal fish were both four times greater on restored plots. Two out of four functional feeding groups: suspension feeders and carnivore/omnivores, were more abundant on restored plots. Since reef macrofauna include many important fish prey species, oyster reef restoration may have the potential to augment fish production by increasing fish prey densities and fish foraging efficiency.

Keywords: Crassostrea virginica, Functional feeding group, Macrofauna, Oyster reef, Restoration ecology, general aquaculture.

Rumrill, S.S., and V.K. Poulton. 2003. **Ecological role and potential impacts of molluscan shellfish culture in the estuarine environment of Humboldt Bay, CA.** Journal of Shellfish Research. Vol. 22, no. 2, p. 607. Sep. IS: ISSN 0730-8000. Conference - Annual Meeting of the National Shellfisheries Association (Pacific Coast Section) and the Pacific Coast Shellfish Growers Association, Newport, OR (USA), Sep 27-30 2002.

The intertidal mudflats of Humboldt Bay, CA, provide habitat for eelgrass (*Zostera marina*), invertebrates, shellfish, finfish, and birds. Humboldt Bay is also the leading producer of Pacific oysters (*Crassostrea gigas*) in California. We have completed the first year of a 3-year project to identify and quantify the effects of commercial oyster mariculture in tideflat habitats, eelgrass beds, and invertebrate communities. Experimental oyster long-line spacing plots were established for comparison to a ground culture site and 6 reference sites (no oysters). We sampled study plots quarterly between Aug 2001-Aug 2002 for presence of eelgrass, oysters, and other cover types. We collected infaunal cores, deployed fish traps, and measured water quality, sedimentation, light intensity, and oyster growth characteristics. Eelgrass shoot density and percent cover were consistently highest in an eelgrass bed control site, lowest at the 1.5-ft. long-line spacing plot, and most variable at the ground culture site. Eelgrass metrics in the other long-line spacing plots were generally lower but within the range of variation exhibited by the reference sites. Preliminary analysis of invertebrate cores has produced a species list of over 70 taxa, many of which are known prey items for estuarine fish. Sedimentation measurements showed no consistent patterns among experimental long-line plots. Oyster growth measurements did not differ substantially between long-line plots; oysters grew 20-35 mm in length and 16-22 mm in width between May and Aug 2002. Light intensity was lower beneath oyster long-lines, but did not differ substantially between the 1.5 and 5 ft. spacing plots.

Soletchnik, P., P. Goulletquer, and N. Faury, et al. **Global change impacts on the Shellfish secondary production along the French Southwest Atlantic Coastline: evidence for a relationship with Pacific cupped oyster *Crassostrea gigas* (Thunberg) summer mortality.**

The Marennes Oleron bay located along the French Atlantic coastline, is the first European oyster rearing area with a 100,000 metric tons of stocking biomass and an yearly production reaching 40,000 metric tons. This estuarine ecosystem has shown significant environmental changes along decades. Temperature, insolation and rainfall are critical factors controlling this estuarine ecosystem. These three parameters are largely contributing to seasonal seawater temperature and salinity values, control nutrients inputs, and therefore primary and secondary productivity in the coastal area. Air temperature trend analysis showed a stabilized figure around 12.5*C between 1950 and 1980, to a significantly increase of more than 1*C over the last 20 years. Over the same half century, insolation trend has significantly decreased from 198 hours to 176 hours a month, corresponding to a 11% insolation loss. The yearly rainfall distribution showed that spring rainfall increased of almost 30% between the 1950's and the two last decades. These mid-term environmental changes have significantly increased over the last decades, therefore affecting the estuarine ecosystem. This study demonstrated how phytoplankton blooms, the main food resource for oyster stock, gradually shifted from May to June over the last 3 decades. Since temperature and trophic resource are representing the two forcing variables in oyster biology, a relationship was developed with the occurrence of summer abnormal oyster mortalities. Thus, a specific study carried out in 2000 compared four oyster batched and two types of culture (on- and off- bottom cultures). The study confirmed the higher mortality rate of on-bottom cultured oysters compared to off-bottom oysters. In 6 months, mortality rates reached 25-48% for on-bottom culture against 12-15% for the off-bottom cultures. The study pointed out the relationship between mortality rates and oyster maturation, through observed biochemical cycles disorders. The four on-bottom oyster batches on only one off-bottom batch were characterized by a significant lipogenesis discontinuity in June. Biochemical cycles presented alternative cycles in spring carbohydrates' synthesis and catabolism, thus demonstrating various energetic pathways. The significant temperature increase and the insolation decline showed opposite effects on oyster metabolism: the first factor accelerates the sexual products' development and the second delay the vitellogenesis process by decreasing food availability for the maturation process. Increasing the vitellogenesis duration as well as the delay of seasonal spawnings from decade to decade, and the phytoplanktonic peak spring delay can be considered as biological answers which reflect the effects of climatic changes at the primary and secondary productivity level in the Marennes-Oleron estuarine ecosystem.

Keywords: shellfish, global warming, france, pacific oyster, crassostrea gigas, summer, mortality, oyster production, climatic change, estuarin, ecosystem, marennesoleron bay, mortality rate.

Sornin, J.M. 1981. **Influence of Shell-Fish Culture Plants on the Hydrology and the Bottom Morphology.** Rev.-Trav.-Inst.-Peches-Marit.,-Nantes. 45(2):127-139.

Elevated shell-fish culture plants disturb hydrological conditions: bottom current is reduced by a factor of 2 between the rack of oysters farm and by a factor of 3 between the pales of mussels farm. The amplitude of wave is also reduced. These modifications influence the sedimentary process: the fine particles are most easily deposited and could be locally thickened.

The deposits are undisturbed by the minor waters agitation, but their particular relief modifies the flow of the shallow stream.

Keywords: oyster culture, mussel culture, environmental impact, hydrography, bottom, topography, France, suspended culturerack.

Sornin, J.M. 1981. **Sedimentary Processes and Biodeposition Linked to Different Shellfish Culture Methods.** Baie de Cancale, Anse de l'Aiguillon et Bassin de Marennes-Oleron.188.

The sedimentation and biodeposition processes are influenced by oyster and other invertebrate filter feeders in the shellfish culture zones. The accumulation and transformation of organic substance in marine sediments depend on the organisms activity. To study the environmental impact of these cultures on the transport and deposition mechanisms three areas are investigated on the French Atlantic littoral. In the Baie de Cancale, the oyster parks receive mud transfer; in the Anse de l'Aiguillon, new surface are devoted to oyster culture near a mussel culture area. In the Marennes-Oleron Basin, the artificial substrata are moved and the sediments evolution changes. After studying these processes this thesis analyzes two aspects of the marine culture: - a physical one: the impact of the structures on hydrology and sedimentation - a biological one: the effects of the biological outfalls on sedimentation.

Keywords: sedimentation, sediment deposition, suspended matter, shellfish, culture, environmental impact, France, littoral zone.

Visel, T.C. 1988. **Mitigation of dredging impacts to oyster populations. Coastal Resource Management and Shellfishing: A Global Perspective**. Selected Papers from an International Conference held at Hofstra University, Hempstead, New York, August 1987. Siddall, S.E.;Taylor, L.J. eds. 7(2):267-270.

Maintenance and extensive navigational dredging in coastal areas along the Northeast and Mid-Atlantic coasts have altered the population dynamics of oysters, *Crassostrea virginica*. In most instances, oyster production has been reduced by removing shell bases and reefs upon which spat could set. One type of mitigation of dredging impacts may be made through a variety of reshelling programs. In July 1986, 8,000 bushels of clam shell were planted over the shell base which obtained at set of 0-year oysters. A harvest of several thousand bushels of seed oysters was anticipated in 1987. Mitigation agreements, which are small in scale and do not interfere with other coastal activities, can be expanded to improve oyster resources.

Keywords: dredging, environmental impact, oyster, fisheries, Crassostrea virginica, ANW, USA, cultch, habitat, improvement, stocking, organisms, spat, ecosystem, resilience, oyster, reefs.

Waddell, J.E. 1964. **The effect of oyster culture on eelgrass (Zoostera marina L.) growth**.

No abstract identifying these species for this category.

Walne, P.R., and G. Davies. 1977. **The effect of mesh covers on the survival and growth of *Crassostrea gigas* Thunberg grown on the sea bed.** Aquaculture. 11(4):313-321.

Growth and mortality were measured in samples of C.gigas planted in trays on the beach at 4-.-5, 7-.-5 and 20% exposure. The oysters were graded by live weight into < 1, 1-2, 3-4, 5-6 and 8-10 groups at planting. Three levels of protection were provided: none, 36-mm and 12-.-5-

mm mesh. Five separate trials of 41-108 days covered about a year. Mortality decreased with increasing size of oyster at planting and with increasing degree of cover. On average, oysters of < 1 g and without cover showed 50% survival over 30 days, while oysters of 3-4 g protected with a 12-.-5-mm mesh showed a 97% survival. Neither seasonal variation in survival nor variation related to exposure was detected. Unprotected oysters grew to a smaller size than protected oysters and those at 20% exposure grew less than those at 7-.-5 or 4-.-5% exposure. It is probable that the two sizes of mesh provided protection against interference and predation by the shore crab *Carcinus maenas*. The combined results of the trials indicated that the standing stock at the end of about 6 months, which included the summer, obtained from laying 100, 0-.-6 g oysters at 4-.-5% exposure would be 564 g and 99 g with 12-.-5-mm mesh and no protection, respectively.

Keywords: habitat improvement, physical, cage, culture, survival, oyster culture, Crassostrea gigas, British Isles, Conwy, growth, marine aquaculture, pacific, oyster, mortality.

4.5 Scallops

Wildish, D.J., and D.D. Kristmanson. 1988. **Estimating bivalve carrying capacity and potential production.** Journal of Shellfish Research. 7(1):181.

State-of-the-art methods for estimating carrying capacity and production of bivalves are considered. Hydrodynamic conditions involved include natural bottom or open channel flow, suspension culture and pipe flow. A modified Wildish and Kristmanson (1979) model is used which treats populations rather than individual bivalves. Biological phenomena of interest in the model include the "seston depletion effect," bivalve density and pumping capacity and the spatial extent of the bivalve bed. The utility of the model is demonstrated with practical examples involving potential giant scallop, *Placopecten magellanicus* , culture in the Bay of Fundy, Canada.

Keywords: aquaculture, systems, potential yield, scallop culture, Placopecten magellanicus, mathematical models, ANW, Fundy, Bay, mussel culture, mussel(s), scallop.

4.6 Other Shellfish Aquaculture Effects References

Bach, H. K., K. Jensen, and J. E. Lyngby. 1997. **Management of marine construction works using ecological modelling.** Science for Management in Coastal and Estuarine Waters: Proceedings Of The 25th Annual Symposium of the Ecsa. Part 3 held in Dublin 11-16 September 1995. Costello, M.J.;Wilson, J.G.; Emblow, C.S.; Kelly,-K.S. eds. 44(SUPPL A):3-14.

A system of bridges and tunnels between Denmark and Sweden is being constructed. The environmental management of the dredging and reclamation work includes planning using a mathematical model which can forecast the effect of different spill scenarios in order to minimize adverse effects on eelgrass (*Zostera marina*) beds. To develop the model, plots of eelgrass beds (4 m super(2)) were covered with nets excluding 30, 60 and 90% of the light. Shoot density, leaf and root/rhizome biomass, and soluble carbohydrates in roots and rhizomes were observed in order to determine the response of the plants to shading. In selected plots, all aboveground biomass was harvested to assess the re-growth potential. The minimum level of soluble carbohydrates necessary for securing re-growth was 60-90 mg g super(-1). The inclusion of the subsediment parts of the eelgrass permits model runs beyond one growth season, and the

prediction of re-growth after subsequent shading and winter dormancy. The model has been satisfyingly calibrated and validated. A feedback monitoring system has been developed based on field studies of eelgrass variables, a set of pre-fixed environmental criteria and forecasting of the effects of the construction works. The system facilitates planning and management of the dredging and reclamation operations, and mitigating actions during the progression of the work.

Keywords: coastal, zone,management, coastal, engineering, dredging, dredge, spoil, bridges, tunnels, offshore engineering, seagrass, environmental impact, man-induced effects, biomass, Zostera marinaland, reclamation, ANE, Denmark, Store, Baelt, ANE, Baltic Sea, Oeresund, Denmark, Sweden, construction, planning,, seagrasses, light penetration, ecological effects shading, effects.

Boyd, C.E. 1996. **Source water, soil, and water quality impacts on sustainability in aquaculture.** Proceedings of the Pacon Conference on Sustainable Aquaculture '95.24-33.

Site selection is a critical factor in pond aquaculture. A water source of adequate quality and quantity, and soils with suitable characteristics are essential for successful and sustainable aquaculture projects. Site soil must be adequate for constructing water-tight ponds with stable levees. Acidic soils and highly organic soils result in deterioration of water quality in production ponds. Soil treatments should be applied to improve impaired soil characteristics. Water volume requirements per hectare of pond can be estimated from climatic data, predictions of seepage, and pond management plans. Estimates of water availability under worst case conditions should be used for determining the maximum pond area at a given site. Key water quality variables in source water are salinity, suspended solids, pH, nutrients, total alkalinity, total hardness, and organic matter. Sedimentation may be used to remove suspended solids from inflowing water, but few other techniques for treating source water have proved useful. Once water is transferred to ponds, water quality can be improved by physical, chemical, and mechanical treatments. Management inputs to enhance aquatic animal production cause deterioration of both water and soil quality in ponds. Use of good quality feed, conservative feeding practices, and moderate stocking rates can prevent excessive phytoplankton blooms. Water exchange rates should be as low as possible. Excessive aeration causes a large internal sediment load in ponds and is detrimental to pond bottom soils. Ponds should be dried for 2-3 weeks between crops when possible. Periodic reshaping of pond bottoms between crops is a better way of preventing sediment accumulation than sediment removal.

Keywords: water, quality, soils, freshwater, aquaculture, fish, culture, shellfish, culture, pond, culture, sedimentation, water treatment.

Ji, R., X. Mao, and M. Zhu. 1998. **Impacts of coastal shellfish aquaculture on bay ecosystem.** J-Oceanogr-Huanghai-Bohai-Seas; Huangbohai-Haiyang. 16(1):21-27.

The major ecological characteristics of high-density cultured shellfish including biodeposition and filter feeding control on phytoplankton and impacts on population of zooplankton and their ecological effect are described. The subsequent impacts on bay ecosystem is analyzed according to the recent literature in this field and our in situ investigation. The importance of this study on sustainable shellfish aquaculture development protection was pointed out and some techniques used in this field were proposed for further study.

Keywords: Eutrophication, Effluents, Shellfish culture, Ecosystems, Environmental impact, phytoplankton, zooplankton, chlorophylls, biomass, bays.

Keen, D.M., D.R. Maynard, and Department of Fisheries and Oceans Canada, Charlottetown, PEI (Canada) Oceans Habitat Divis. 2005. **Prince Edward Island shellfish aquaculture: the NWPA-CEAA assessment process.** Can. Manuscr. Rep. Fish. Aquat. Sci./Rapp. Manuscr. Can. Sci. Halieut. Aquat. 272865.

In 1999, the Department of Fisheries and Oceans determined that the existing 426 surface and/or off bottom aquaculture sites in Prince Edward Island required formal review and approval for compliance with the Navigable Waters Protection Act. This document details the cooperative process developed between the Government of Prince Edward Island, the Prince Edward Island Aquaculture Alliance, the Canadian Environmental Assessment Agency, and DFO's Regional Sections of Fish Habitat, Navigable Waters protection, and Aquaculture Leasing to bring those aquaculture sites into compliance with the Navigable Waters Protection Act. This resulted in Approval Documents being issued for all 426 sites in February of 2002. Ancillary benefits included the development of a unique "bay by bay" environmental assessment and review process and a monitoring program through an Adaptive Management process.

Keywords: Environmental, monitoring, Shellfish, culture, Aquaculture, Environmental assessment, ANW, Canada, Prince Edward Island, Marine.

Kingzett, B.C. 2005. **Stakeholder involvement in shellfish growing, water monitoring, and management in British Columbia, Canada.** Journal of Shellfish Research. 24(1):325.

In British Columbia, shellfish aquaculture offers sustainable economic opportunities for depressed coastal communities. Additionally wild shellfish resources are important commercial and recreational fisheries and as traditional foods for aboriginal communities. Despite BC's well-earned pristine reputation, there has been an increase in sanitary contamination harvest closures, due to increasing upland development, first flush effects in remote forestry areas and lack of resources by regulators to adequately provide monitoring and management services. Faced with increasing "contamination crises" in the late 1990s, the BC shellfish culture industry has become increasingly involved in addressing water quality issues in a number of areas through an approach of scientific data analysis, government liaison, research investigations, education and development of stakeholder monitoring programs, and remediation efforts. In each case, the common theme has involved engaging those affected by harvest closures to understand the basis of the closures, take action to find other management tools or remediation options, and negotiate these with government regulators. This has led to an increased participation by stakeholder groups in regulatory monitoring programs, increased "ownership" of local water quality, and a desire to take larger roles in shellfish sanitary monitoring programs. Regulatory agencies struggle to find new ways to deliver more services with limited budgets which sets the stage for increased partnerships and local co-management of shellfish growing waters.

MacFarlane, S.L. 1996. **Shellfish as the impetus for embayment management.** Marine and Estuarine Shallow Water Science and Management. Spagnolo,-R.J.;Ambrogio,-E.;Rielly,-F.J.,-Jr.-eds. 19(2A):311-319.

Concern about declining stocks of municipally managed shellfish species (*Mya arenaria, Mercenaria mercenaria, Mytilus edulis, Argopecten irradians irradians*) in Orleans,

Massachusetts, led to several shellfish enhancement programs. Projects included bottom and raft culture of hatchery-raised seed, hatchery and upweller techniques, transplants of seed and adult shellfish, and other management options. However, deterioration of water quality and habitat prompted the town to initiate a multifaceted program to address the issues causing environmental degradation. A water-quality task force, appointed to determine solutions to the problems, recommended changes in land-use practices. A drainage remediation program was undertaken at five sites, resulting in the reopening of a viable shellfish area for the first time in 12 yr. Issues concerning nutrient enrichment, groundwater flow and depth, flushing characteristics of the embayments, proliferation of private docks and piers in the public tidelands, effects of barrier beach dynamics including erosion control measures, and the number of users and diversity of their activities employed on the waters themselves will be addressed in current municipal planning initiatives.

Keywords: shellfish, fisheries, shellfish, culture, fishery, management, hatcheries, stock assessment, raft, culture, ecosystem, disturbance, water pollution, land-use, Mya arenaria, Mercenaria mercenaria, Mytilus edulis, Argopecten irradians irradians, ANW, USA, Massachusetts, Cape Cod fisheries, water quality, estuaries, USA, Massachusetts, Orleans, Mollusca, shellfish, management.

Mallin, M.A., K.E. Williams, E.C. Esham, and R.P. Lowe. 2000. **Effect of human development on bacteriological water quality in coastal watersheds**. Ecol. Appl. 10(4):1047-1056.

No abstract identifying these species for this category.

Short, F.T., and S. Wyllie-Echeverria. 1996. **Natural and human-induced disturbance of seagrasses.** Environ.-Conserv. 23(1):17-27.

Many natural and human-induced events create disturbances in seagrasses throughout the world, but quantifying losses of habitat is only beginning. Over the last decade, 90 000 ha of seagrass loss have been documented although the actual area lost is certainly greater. Seagrasses, an assemblage of marine flowering plant species, are valuable structural and functional components of coastal ecosystems and are currently experiencing worldwide decline. This group of plants is known to support a complex trophic food web and a detritus-based food chain, as well as to provide sediment and nutrient filtration, sediment stabilization, and breeding and nursery areas for finfish and shellfish. We define disturbance, natural or human-induced, as any event that measurably alters resources available to seagrasses so that a plant response is induced that results in degradation or loss. Applying this definition, we find a common thread in many seemingly unrelated seagrass investigations. We review reports of seagrass loss from both published and `grey' literature and evaluate the types of disturbances that have caused seagrass decline and disappearance. Almost certainly more seagrass has been lost globally than has been documented or even observed, but the lack of comprehensive monitoring and seagrass mapping makes an assessment of true loss of this resource impossible to determine. Natural disturbances that are most commonly responsible for seagrass loss include hurricanes, earthquakes, disease, and grazing by herbivores. Human activities most affecting seagrasses are those which alter water quality or clarity: nutrient and sediment loading from runoff and sewage disposal, dredging and filling, pollution, upland development, and certain fishing practices. Seagrasses depend on an adequate degree of water clarity to sustain productivity in their submerged environment.

Although natural events have been responsible for both large-scale and local losses of seagrass habitat, our evaluation suggests that human population expansion is now the most serious cause of seagrass habitat loss, and specifically that increasing anthropogenic inputs to the coastal oceans are primarily responsible for the world-wide decline in seagrasses.

Keywords: seagrasses, disturbance, human impact, marine, environment, Human factors, Ecosystem disturbance, Environmental impact, Seagrass, Pollution effects, Sea Grasses, Environmental, Effects, Water, Pollution, Macrophytes, Eutrophication, Aquatic communities, Habitat community studies, Environmental quality, Mechanical and natural changes.

Shumway, S.E.; C. Davis, R. Downey, R. Karney, J. Kraeuter, J. Parsons, R. Rheault, and G. Wikfors. 2003. **Shellfish aquaculture — In praise of sustainable economies and environments.** World Aquaculture (34:4)15-17

No abstract identifying these species for this category.

Silva, L. 1997. **An overview of the Endangered Species Act and its implications for aquaculture in New England.** Journal-of-Shellfish-Research. 16(1):290-291.

The National Marine Fisheries Service (NMFS) has jurisdiction over most marine species listed under the Endangered Species Act of 1973, as amended (ESA), which includes marine mammals, sea turtles, and shortnose sturgeon. These species seasonally occupy a coastal and offshore habitat that stretches from the Gulf of Mexico to the Gulf of Maine. They live in an often hazardous environment with a variety of human-induced impacts. Certain habitats, such as concentration areas, migratory routes, and areas for breeding, reproduction, and foraging are more critical to the survival of these species than others. Potential impacts from aquaculture operations range from direct injury and mortality from lines and cables to more subtle impacts on the food chain. The species, location and critical components of habitats and the potential impacts from culture operations will be identified. The development of aquaculture represents a change in marine resource harvesting methods from a system of hunting/gathering to farming/culturing. Historical methods of harvesting resources from the sea are not without conflicts with endangered and threatened species of marine life, and the new methods and requirements of farming in the oceans come with a whole new variety of gear types and methods. The ESA requires federal agencies to enter into consultation with NMFS on any activities in the marine environment that may interact with protected species and determine what reasonable and prudent measures or alternatives can be implemented to allow the activity to continue without undue harm to the species. In addition to giving an overview of the species, this discussion will review the requirements under the Act as it relates to the Aquaculture permit process. Understanding how to identify the potential impacts and the requirements of the law in the early planning stages of new aquaculture ventures will help reduce the burden of the ESA portion of the federal review process.

Keywords: National Marine Fisheries Service (NMFS), Regulation, Environmental, Impact, Community, Composition, Habitat, Disturbance, Interactions, Harvesting, Methods, Farming Methods, Environmental, Management.

Stewart, J.E. 1997. **Environmental impacts of aquaculture.** World Aquacult. 28(1):47-52.

Aquaculture, as a commercial venture, is now being pursued in areas where it did not exist previously and has become a significant competitor for space in the coastal zone and freshwater areas. A wide variety of species, both plants and animals, are cultured world-wide. The latest available statistics show the total production for 1993 as 22 540 451 tonnes or between 20 and 25% of the food harvested from the sea and freshwater areas. The quantity for inland culture was 10 725 832 tonnes of which carp, barbels and other cyprinids comprised the greatest volume (7 638 001 tonnes); marine culture of fish and shellfish equaled 5 559 303 tonnes to which must be added 6 255 316 tonnes for aquatic plants and 84 674 tonnes of others for a total of 11 899 293 tonnes produced by marine culture. Species grown in quantity in marine areas, in addition to seaweeds, include the pearl oyster, edible oysters, abalone, mussels, scallops, prawns, milkfish, Atlantic salmon, yellowtail, rainbow trout and sea bream. Other species, such as halibut and Arctic char, are in the commercial development phase. For aquaculture to be accepted it must demonstrate convincingly that aquaculture activities will not jeopardize other legitimate uses of the coastal, brackish and freshwater areas by causing unacceptable changes in environmental quality. To be able to offer such assurances, methodology must be developed that will permit authorities to assess the consequences of various loadings. Unfortunately, we do not have a model that will allow us to estimate the limits to the assimilative capacity of the various culture locations or the full consequences of exceeding these limits. Studies undertaken over the past decade to fill this gap have resulted in a variety of hydrographic and other numerical models. They do not, however, possess a biological component to illustrate the consequences for the ecosystem in general or the organisms being cultured.

Keywords: Aquaculture, Ecosystem disturbance, Pollution effects, Man-induced effects, Environmental protection, Air Pollution Effects, Reviews, Human factors, general aquaculture.

Thorgaard, G.H., and S.K. Jr. Allen. 1988. **Environmental impacts of inbred, hybrid, and polyploid aquatic species.** Journal of Shellfish Reseasrch. 7(3):556.

The recent application of techniques for producing inbred and polyploid fish and shellfish and the use of hybrids in aquaculture and fishery management programs has led to increased concern about the environmental impacts of such forms. Genetically altered organisms may harm natural populations of species by competing with, interbreeding with, or replacing them. Sterile organisms are least likely to have negative impacts on natural populations. Sterile hybrids or triploids thus seem least likely to have harmful effects when introduced because their genetic impact on natural stocks should be minimal or minimized. However, sterile hybrids or triploids might in some cases interfere with reproduction of natural stocks in non-genetic ways. Fertile hybrids have sometimes had very negative impacts on natural populations and should not be used outside closed systems, however they provide an opportunity for introducing beneficial genes or chromosome segments into domesticated stocks.

Keywords: selective breeding, polyploids, aquaculture, development, environmental impact, genetic engineering, Pisces, Bivalvia, environmental, release, aquaculture, hybrid, culture.

Thuringer, P.L. 2004. **Documenting Pacific sand lance (Ammodytes hexapterus) spawning habitat in Baynes Sound, east coast Vancouver Island, and the potential interactions with intertidal shellfish aquaculture.** Masters Abstracts International. Vol. 42, no. 6, p. 2098. Dec.

Intertidal beach spawning finfish, such as the Pacific sand lance (Ammodytes hexapterus), are vulnerable to potential impacts to upper intertidal habitats from various foreshore activities, including intertidal shellfish aquaculture. This short-lived species is an important forage fish in the Pacific Northwest that rely on ecologically functioning beaches to sustain their populations. This research documented characteristics of some of the beach spawning habitat in Baynes Sound and interactions between clam tenure operations and beach spawning activity, and evaluated potential approaches to managing these interactions. Pooled data (n = 5) indicates that A. hexapterus tend to spawn on medium (50%, 0.25-0.5mm grain size) to coarse sand (30%, 0.5-2mm) substrate with <3% finer material (silt/fine sand <0.25mm). The greatest potential for interactions between predator netting and sand lance beach spawning activity is in the lower limit of spawning range and the upper limit of net placement (tidal elevation +2.7m to +3.0m CD).

5.0 GENETICS AND SHELLFISH CULTURE

5.1 Clams

Arnold, W.S., S.L. Walters, J.S. Fajan, S.C. Peters, and T.M. Bert. 2004. **Influence of congeneric aquaculture on hard clam (*Mercenaria* spp.) population genetic structure**. Aquaculture International 12: 139–160.

Throughout their range, hard clams of the genus *Mercenaria* support important commercial fisheries, and hard clam aquaculture is rapidly developing in several regions, including Florida, USA. Commercial hard clam aquaculture in Florida waters originated in the Indian River Lagoon during the late 1970s, but by the early 1990s the focus of the industry had shifted to Cedar Key on the west coast of the state. There, the species *Mercenaria campechiensis* predominates the natural hard clam population, whereas *Mercenaria mercenaria* is predominant in the local aquaculture industry. The two species hybridize extensively. The present study was conducted to estimate the genetic implications of *M. mercenaria* aquaculture on the natural population of *M. campechiensis* that occupies Cedar Key waters. We sampled a variety of marine and estuarine habitats surrounding Cedar Key and collected 257 hard clams for analysis of species-specific diagnostic allozyme loci, age, and the presence and stage of gonadal neoplasia. Results indicate that the composition of the hard clam population has changed since the advent of aquaculture (i.e., post-aquaculture). Members of the species *M. mercenaria* were practically nonexistent prior to the 1993 initiation of aquaculture in the area but increased significantly in abundance post-aquaculture, as did hybrid hard clams. There was no significant difference in the abundance of *M. campechiensis* pre- versus postaquaculture. All genotype classes had a high incidence (>80%) of gonadal neoplasia, although it is not clear if this high incidence is a reflection of the introduction of aquaculture into the area or if neoplasia was a common feature of the population prior to 1993. Regardless, this finding is not consistent with previous reports that neoplasia is more common in hybrid hard clams. Overall, the results of this study provide clear evidence that culture of *M. mercenaria* can influence the genotype composition of naturally occurring congeneric populations in the vicinity of the culture operation. The long-term implications of that influence remain to be seen.

Key words: Aquaculture, Disease, Hard clam, Hybrid, Introgression, Mercenaria, Population Genetics.

Morgan II, R.P., S.B. Block, N.I. Ulanowicz, and C. Buys. 1978. **Genetic variation in the soft-shelled clam, *Mya arenaria.*** Estuaries 1: 255-258.

Genetic variability for two populations, Maine and Maryland, of the soft-shelled clam, *Mya arenaria,* was estimated from electrophoretic analyses of whole clams. Polymorphism (12.5% in Maine and 16.7% in Maryland clams) and heterozygosity per individual (4.6% in Maine and 6.6% in Maryland) were low for the two populations based on 40 loci in Maine and 42 loci in Maryland *Mya.*

5.2 Geoduck

Vadopalas, B. A., and J. P. Davis. 1998. **Induction of triploidy in the geoduck clam, *Panope abrupta*.** Journal of Shellfish Research 17: 1285.

The development of geoduck culture techniques coupled with increased market demand led to cultured intertidal geoduck beds. Concerns then arose regarding the potential genetic risk posed by the reproductive contribution of hatchery outplants to wild stocks that may be genetically different. Although an ongoing study to determine the genetic stock structure of Puget Sound geoducks has yet to yield definitive results, the development of techniques to produce sterile triploids would enable geoduck culture to proceed irrespective of any genetic differences found. Moreover, triploid geoducks may exhibit an increased growth rate. Geoduck eggs were fertilized and distributed among three temperature and three salinity 128 treatments to test the effects of these factors on the timing and synchrony of meiotic events. Samples were taken at 5 minute intervals to measure proportions of eggs at each meiotic stage. These data indicated a temperature and salinity combination for optimal triploidy induction of 15 degree C and 30 ppt., with the meiotic period between expulsion of the first and the second polar body lasting 20 minutes, beginning at 50 minutes post fertilization. We also investigated two chemical treatments, cytochalasin B (CB) and 6-dimethylaminopurine (6-DMAP), to evaluate their suitability for triploid induction in geoducks. We found optimal triploid induction (>95%) resulted from a 600 M 6-DMAP treatment using our optima. Preliminary data indicates survivorship to straight hinge was about 20%. Survivorship to metamorphosis was highly variable among groups, which could not be attributed to a single factor. Surviving triploid geoducks have been outplanted to evaluate growth and survivorship.

Vadopalas, B., and P. Bentzen. 2000. **Isolation and characterization of di- and tetranucleotide microsatellite loci in geoduck clams, *Panopea abrupta*.** Molecular Ecology 9: 1435–1436.

No abstract identifying these species for this category.

Vadopalas, B., and J. Davis. 2004. **Optimal chemical triploid induction in geoduck clams, Panopea abrupta (Conrad, 1849), by 6-dimethylaminopurine.** Aquaculture 230: 29-40.

No abstract identifying these species for this category.

Vadopalas, B., L. L. LeClair, and P. Bentzen. 2004. **Microsatellite and allozyme analysis reveal few genetic differences among spatially distinct aggregations of geoduck clams (*Panopea abrupta*, Conrad 1849).** Journal of Shellfish Research 23: 693-706.

No abstract identifying these species for this category.

5.3 Mussels

Beaumont, A., T. Gjedrem, and P. Moran. 2006. **Blue Mussel – *M. edulis* and Mediterranean mussel – *M. galloprovincialis*. In: "Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations."** D. Crosetti, S. Lapègue, I. Olesen, T. Svaasand (eds). GENIMPACT project: Evaluation of genetic impact of aquaculture activities on native populations. A European network. WP1 workshop "Genetics of domestication, breeding and enhancement of performance of fish and shellfish", Viterbo, Italy, 12-17th June, 2006, 6 pp.

In Europe there are three species of mussel, all in the genus *Mytilus*: *Mytilus edulis* (blue mussel), *M. galloprovincialis* (Mediterranean mussel) and *M. trossulus* (Baltic mussel) (1, 2). *M. trossulus* is generally thought to be confined to the Baltic (3) and there is no significant fishery

or aquaculture involving this species. Because of this, the genetic impact of human activity is negligible and the Baltic mussel will not be considered further in this leaflet. On the other hand there is very extensive mariculture of *M. edulis* and *M. galloprovincialis* almost throughout their distribution. There remains debate about the true taxonomic status of these two "species" because wherever their distributions overlap they can hybridise and their hybrids are fertile. Identification of *M. edulis* and *M. galloprovincialis* (and any hybrids) based on shell shape is usually uncertain because of the extreme plasticity of shape exhibited by mussels under environmental variation. Since 1995 a DNA-based genetic method that seems truly diagnostic for European populations of these two species (4, 5) has become available, but no large scale studies have yet been carried out to characterise the mosaic of populations of *M. edulis*, *M. galloprovincialis* and their hybrids that extend from the French Atlantic coast up to northern Scotland. The knowledge of the distribution of mussel species around Europe, as it was assessed in 1992, is given in Fig. 1 (1). Hybrids occur in regions where the species meet or overlap. Recent anecdotal evidence suggests that *M. galloprovincialis* could be present in the Netherlands, and that *M. edulis* has been introduced into culture on the Mediterranean coast of France.

5.4 Oysters

Camara, M.D. 2006. **Genetic considerations for hatchery-based enhancement of native oyster populations. Are good intentions enough?** Proceedings of the NOAA Restoration Center-West Coast Native Oyster Restoration: 2006 Workshop, September 6-8, 2006, San Rafael, CA.

Native oyster populations have, through a combination of over-fishing, habitat degradation, and introductions of non-native competitors, predators, and diseases, been either locally extirpated or drastically reduced in numbers in many U.S. estuaries. The realization that these filter-feeding bivalves provide a variety of ecological services ranging from water filtration to reef-building has generated a great deal of interest in restoring oyster populations; and, given that it's possible to grow millions of juveniles in hatcheries, population supplementation is an attractive strategy for re-building decimated oyster populations. Ecologically, this approach seems straightforward, and it is difficult to see how enhancing local populations could be anything but beneficial. From a genetic perspective, however, things are more complicated. In this presentation, I will briefly outline the ways in which hatchery-based population supplementation may affect the genetics of remnant oyster populations. My purpose is not to criticize current restoration efforts, but to emphasize the importance of understanding current patterns of genetic diversity, the evolutionary forces that may have generated these patterns, and the ways in which hatchery-based restoration might change them for better or worse. I argue that despite the obvious good intentions behind hatchery-based population supplementation efforts, unless we better understand the genetic context in which they occur, hatcherybased population enhancement could have negative genetic impacts on the populations they seek to benefit.

As a matter of necessity, hatchery-based population supplementation of native oyster populations is, in most instances, proceeding with very little, and in some cases no genetic information. Even the best case scenario is one in which local populations have been sampled and genetically characterized using presumably neutral genetic markers such as allozymes, RAPDs, AFLPs, or microsatellite DNA, providing a description of the current distribution of molecular genetic diversity within and among populations. The most crucial decision in any program of hatchery-based restoration is which parents should be used in the hatchery, and the typical default approach is to use

parents from local stocks. However, this strategy is based on at least three untested assumptions: 1) molecular genetic variation is a reasonable proxy for quantitative genetic variation, 2) population differentiation at neutral markers is indicative of local adaptation, and 3) larger populations are always better than small populations. I'll address each of these in turn:

Li, Q., H. Yu, and R. Yu. 2006. **Genetic variability assessed by microsatellites in cultured populations of the Pacific oyster (*Crassostrea gigas*) in China.** Aquaculture 259: 95-102.

Five cultured populations of Pacific oyster, *Crassostrea gigas*, were examined at seven polymorphic microsatellite loci to assess the levels of allelic diversity and heterozygosity within and differentiation among the populations. The genetic variability of the seven loci was high for all the populations. The average numbers of alleles per locus ranged from 19.1 to 26.0, while the average observed and expected heterozygosity ranged from 0.474 to 0.616, and from 0.916 to 0.949, respectively. F_{st} and R_{st} values showed significant genetic differentiation among the five cultured populations. Genetic differences between the populations were also detected by pairwise comparison based on allelic distribution. The Neighbor-joining tree topology constructed on the basis of genetic distances between populations showed a clear separation of the northern three populations and southern two populations, suggesting that geographically separated cultured populations of *C. gigas* could be genetically differentiated unless seeds are transplanted among them. The useful information on the genetic variation and differentiation in cultured populations obtained in this study can be applied for future genetic improvement by selective breeding, and to design suitable management guidelines for the Pacific oyster.

Keywords: Genetic variation; Cultured populations; Microsatellites; Crassostrea gigas

Grosholz, E.D. 2006. **The life and times of the Olympia oyster.** Proceedings of the NOAA Restoration Center - West Coast Native Oyster Restoration: 2006 Workshop, September 6-8, 2006, San Rafael, CA

The Olympia oyster, *Ostreola conchaphila,* is the only oyster native to western North America. Based on museum specimens and recent systematic distinctions, the historical distribution of Olympia oysters extended from Sitka, AK (57° N) to Panama (9° N) with fossil representation extending back to the Pliocene. The current distribution is made up of a disjunct series of reproductive populations between southeastern Alaska and Baha California. Smaller than most other oysters (up to 80 mm), the external shell coloration ranges from purple to gray and white, with internal shell coloration ranging from green to white. The native oyster can be distinguished from the introduced *Crassostrea* species by the ridge of crenulations or chromata on the shell near the hinge. Olympia oysters will experience significant mortality with exposure to salinities >15 ppt over periods of months and requires water temperatures of greater than 12° C to reproduce. This species is a protandrous hermaphrodite that broods its larvae for up to twelve days after which the larvae swim for 3-4 weeks before they settle. They are reproductive within six months and will reach maximum size in four years. Olympia oysters are commonly preyed on by a wide range of predators including crabs, snails, flatworms, ducks, stars, and rays. However, they have comparatively few parasites and pathogens relative to other oysters. Olympia oysters are generally found attached to rocks and cobbles from lower intertidal areas to waters up to several meters deep. Although they don't form extensive reefs, they can form dense aggregations that can support other invertebrate and fish species. This species is believed to have been very abundant prior to the extensive exploitation that began in the mid-19th century.

Stick, D.A., M.D. Camara and C. Langdon. 2006. **Genetic structure of native Olympia oyster (*Ostrea conchaphila*) from four sites in Coos Bay, Oregon.** Proceedings of the NOAA Restoration Center-West Coast Native Oyster Restoration: 2006 Workshop, September 6-8, 2006, San Rafael, CA

The Olympia oyster, *Ostrea conchaphila*, is the only oyster species native to the Pacific Northwest. Historically, the species ranged from southeastern Alaska to Baja, California and supported both tribal subsistence fisheries and large commercial harvests. Overexploitation, habitat degradation, and competition and predation from non-native species have drastically depleted densities and extirpated many local populations, but a few remnant populations persist. This is perhaps most pronounced in Oregon where there are only two extant populations, one in the Yaquina Bay and another in Coos Bay. Archaeological evidence such as shell middens indicate that large populations of the Olympia oyster existed in both of these bays prior to historical documentation, but surveys performed in the 1980s found no Olympia oysters in the Coos Bay watershed. It is unclear, therefore, whether the current population of Olympia oysters in Coos Bay is a recent re-expansion of a surviving remnant population missed by the 1980s surveys or a e-introduction from some other source population.

Due to the species' historical significance and the ecological services provided by oyster reef habitats, restoration efforts are underway in both bays, but these efforts are proceeding without a full understanding of either the existing or historical population structure, largely due to the lack of appropriate molecular markers. We have recently developed a number of microsatellite DNA markers in *O. conchaphila* and have used eight of these to conduct preliminary analyses for genetic structure on samples collected from four sites in Coos Bay, all of which are located in a 12 km section of the Eastern Arm of the bay's watershed. At the phenotypic level, oysters from the southernmost collection site (Shinglehouse Slough) are significantly larger than all other sample locations, including the most probable site for re-introduction as a hitchhiker on *Crassostrea gigas*, which is raised commercially in production beds near the North Bend California Avenue public boat ramp. These size differences are a suggestive, but far from a definitive indication, that the extant populations of Olympia oysters in Coos Bay may be truly native, since one might expect that a re-introduction would result in older, larger animals closest to the site of the primary introduction and smaller, younger oysters at sites colonized secondarily from the source. We will present an analysis of the degree of differentiation among the Coos Bay sample populations and a comparison of these populations with Willapa Bay, WA, the most likely source population for a reintroduction because it is the main source of *C. gigas* seed for commercial culture in Coos Bay.

Vadopalas, B. J.E. Suzuki, N.A. Wight, and C.S. Friedman. 2006. **Using quantitative PCR to understand Olympia oyster larval dispersal.** Proceedings of the NOAA Restoration Center-West Coast Native Oyster Restoration: 2006 Workshop, September 6-8, 2006, San Rafael, CA

Our understanding of the relationship between behavior and dispersion in marine invertebrate larvae has been hampered by the lack of suitably rapid techniques for identification and quantification from field samples. The need to understand larval dispersal dynamics of Olympia oysters *(Ostrea conchaphila)* to a) site productive restoration projects, and b) increase our knowledge of this critical life history stage, motivated the development of a high-throughput method for identification and quantification of Olympia oyster larvae in seawater samples. Our assay essentially counts mitochondrial genomes and correlates this information to numbers of larvae using standard curves

constructed from different size classes of Olympia oyster larvae.

We size-fractionated seawater samples through a series of filters (105, 150, 200, and 250 ~m), extracted DNA from all organisms present in retentate, and used primers and a duallabeled hydrolysis probe specific to Olympia oyster Cytochrome Oxidase I (COI) mitochondrial DNA sequence to conduct quantitative PCRs (qPCR). Using light microscopy, we enumerated spiked samples of each size class of larvae to verify quantity estimates derived from qPCR standard curves. Partial or full PCR inhibition can give spurious results, so to avoid bias from either underestimation of quantity or false negatives, we multiplexed Olympia oyster-specific reactions with primers, probe and exogenous template as an internal positive control (IPC).

We estimate that 70 samples can be processed from DNA extraction through qPCR in about four hours at a cost of approximately $3/sample for reagents. Our results demonstrate that qPCR can have utility for high-throughput identification and quantification of pelagic marine invertebrate larvae in seawater samples. By shedding some light on Olympia oyster larval dispersal, we may increase the likelihood of success by restoring source, rather than sink, aggregations.

5.5 Scallops

5.6 Other Shellfish Aquaculture Effects References

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