Fisheries and Oceans Canada, Pacific Region
Shellfish Aquaculture Operational Statements
Review Document

Appendix 1. Annotated Bibliography

March 2006

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Table of Contents

Assessment Guides

1. Environment Canada, Environmental Protection Branch, Atlantic Region. 2001. Environmental assessment of shellfish aquaculture projects: guidelines for consideration of Environment Canada expertise (June 2001).
   - **Source:** http://www.atl.ec.gc.ca/assessment/guidelines/fw_shellfish_e.pdf
   - Good overview, particularly of legislation, but lacking in particulars.

2. GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2001. Planning and management for sustainable coastal aquaculture development. Rep. Stud. GESAMP, (68): 90 p.
   - **Source:** ftp://ftp.fao.org/docrep/fao/007/y1818e/y1818e01.pdf

3. Goldburg, R.J., M.S. Elliot, and R.L. Naylor. 2001. Marine Aquaculture in the United States – Environmental Impacts and Policy Options. Pew Oceans Commission, Arlington, Virginia. 33p.
   - Hardcopy. Source of references

4. Hambrey, J., M. Phillips, M.A.K. Chowdhury, and R.B. Shivappa. 1999. Composite Guidelines for the Environmental Assessment of Coastal Aquaculture Development, Vol. 1: Guidelines. Prepared for SEACAM (Secretariat for Eastern Africa Coastal Area Management. pp.
   - **Source:** http://www.nautilus-consultants.co.uk/pdfs/seacam1.pdf
   - Lots of detail on the whole 'screening' and 'scoping' process. Has environmental assessment bibliography.

5. Hambrey, J. and T. Southall (Nautilus Consultants). 2002. Environmental risk assessment and communication in coastal aquaculture. A background paper and discussion document for GESAMP WG31. 70 p.
   - Hardcopy

6. Ministry of Fisheries (New Zealand). 2002. A Guide to Preparing a Fisheries Resource Impact Assessment – Marine Farming and Spat Catching Permit Applications. 28p.
   - **Source:** www.fish.govt.nz/commercial/aquaculture/fria/summary.html

7. New Zealand Seafood Industry Training Organization, SITO. 2004. Explain the Procedures to Gain legal Authorization for an Aquaculture Associated Activity. Learning Resource for Unit Standard 19217v2.
   - pdf
   - Includes requirements for environmental effects assessment.

Assessment/Monitoring Methods

8. Carleton, J.H. and T.J. Done. 1995. Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14(1):35-46.
   - **Abstract.** The feasibility of reliably estimating percent cover of coral reef benthos by video techniques is examined. Video belt transects were recorded within study areas on Davies and John Brewer Reefs in the central Great Barrier Reef during September 1988. Two years later in September 1990, the study area at Davies Reef was resampled concurrently by video and line intercept transects. Percent cover data of major coral growth forms and

non-biotic physionomic attributes were extracted from video footage by scoring the identity of items located at even or random spaced points along the transect. A cost-benefit analysis which compared increases in precision with increases in sampling effort suggested that the optimum regime for analyzing 200 m long video transects was five subsamples of 110 random points or one sample of 550. This regime resolved both spatial variability at large and smaller spatial scales (between study areas and among transects) and temporal change (within a single study area over a two year period) for total live coral and individual growth forms. The strengths of the technique lie in its cost-savings in filed expenses, and in the production of a permanent visual record. The limitations of the technique lie in reduced taxonomic resolution when compared hands on field techniques. The results suggest that for broad taxonomic categories of coral reef benthos reliable estimates of relative abundance can be obtained by video techniques.

9. Carswell, B., S. Cheesman, and J. Anderson. In Press. The use of spatial analysis for environmental assessment of shellfish aquaculture in Baynes Sound, Vancouver Island, British Columbia, Canada. Aquaculture: Article in Press.

- pdf
- **Abstract.** 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.

10. Crawford, C.M., I.M. Mitchell and C.K.A. Macleod. 2001. Video assessment of environmental impacts of salmon farms. ICES Journal of Marine Science 58(2):445-452.

- **Abstract.** Video recordings have become a common method for monitoring the benthic environment around salmon farms, but generally they are only assessed qualitatively. We made a quantitative assessment of video recordings and compared the results with benthic invertebrate faunal data from the same sites. Transects around two Atlantic salmon (*Salmo salar* L.) farms were videoed, with environmental variables that clearly showed change with levels of organic enrichment ranked according to their degree of occurrence. These variables included *Beggiatoa* cover, pellets and faeces, sediment colour, and abundance of flora and fauna. Analysis of the data by multivariate statistics indicated that quantitative data from video recordings can clearly detect major organic enrichment, but that they are not as sensitive as benthic infaunal data to lower levels of disturbance. This assessment technique will need to be tailored to different environmental conditions, but shows promise for long-term monitoring programs.

11. Engel, J. and R. Kvitek. 1998. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conservation Biology 12:1204-.

- **Abstract.** Bottom trawling is one of the most disruptive and widespread human-induced physical disturbances to seabed communities and has become a global environmental concern. We used a comparative approach to test the hypothesis that persistent otter trawling decreases bottom habitat complexity and biodiversity, increases the abundance of opportunistic species, and benefits prey important in the diet of some commercially valuable fish. We compared two similar and adjacent fishing areas at 180 m off central California in Monterey Bay National Marine Sanctuary: one inside the three-mile coastal zone of restricted fishing with light levels of trawling and one beyond the three-mile limit with high levels of trawling. Differences in fishing effort between the two areas were confirmed and quantified by means of data and tow number statistics from Pacific Fishery Management Council (PFMC) Trawl Logbook records. We used still photography, video footage, bottom grab samples, and experimental trawling to compare the physical and biological parameters of the two areas. The area with high levels of trawling had significantly more trawl tracks, exposed sediment, and shell fragments and significantly fewer rocks and mounds and less flocculent material than the lightly trawled area. Most invertebrate epifauna counted were significantly more abundant in the lightly trawled area. The density of the amphinomid polychaete, *Chloeia pinnata*, as well as that of oligochaetes, ophiuroids, and nematodes, were higher every year in the highly trawled area, and there were significantly fewer polychaete species every year in the highly trawled area. Content analysis of fish guts showed that *C. pinnata* was a dominant prey item for some of the commercially important flatfishes in both lightly and heavily trawled areas. Our study provides evidence that high levels of trawling can decrease bottom habitat complexity and biodiversity and enhance the abundance of opportunistic species and certain prey important in the diet of some commercially important fishes. Our work also illustrates how constraints currently imposed on fisheries research by the near universal absence of true unfished control sites severely limit our ability to determine appropriate levels of harvest pressure for maintaining sustainable fisheries and marine biodiversity. Valid research in these areas will require marine reserves in which fishing effort and methods can be manipulated in collaborative studies involving fishers, researchers, and resource agencies.

12. Gavine, F.M. and L.J. McKinnon. 2002. Environmental monitoring of marine aquaculture in Victorian coastal waters: a review of appropriate methods. Technical Report No. 46. Marine and Freshwater Institute, Victoria. 50 p.

- www.dpi.vic.gov.au/fishing (Follow the links) Managing Fisheries, Management Plans and Strategies, Flinders Aquaculture Fisheries Reserve Management Plan

13. Gavine, F.M. and L.J. McKinnon. 2002. Environmental monitoring of marine aquaculture in Victorian coastal waters: a review of appropriate methods. Technical Report No. 46. Marine and Freshwater Institute, Victoria. 50 p.

- **Source:** www.dpi.vic.gov.au/fishing Follow the links Managing Fisheries, Management Plans and Strategies, Flinders Aquaculture Fisheries Reserve Management Plan
- Good synopsis of environmental issues and impacts of bivalve shellfish culture, monitoring techniques and recommendations for licensing requirements, regulatory mechanisms (local and international), and hazard assessment.

14. Maldonado, M., M. Carmen-Carmona, Y. Echeverria, A. Riesgo. 2005. The environmental impact of Mediterranean cage fish farms at semi-exposed locations: does it need a reassessment? Helgoland Marine Research 59(2):121-135.

- **Abstract.** During spring and summer 2003, we measured a variety of chemical and biological parameters in five medium-sized, Mediterranean cage farms that exploit semi-offshore conditions, and controlled the supply of fodder. The objective was to assess whether modern cage farms proliferating at semi-offshore sites exert environmental impact levels equivalent to the levels described from more traditional cage farms located in shallow, sheltered sites. In the water column, we examined the concentration of dissolved inorganic nutrients and

heterotrophic bacteria in both surface and near-bottom water. At the bottom, we examined the concentrations of benthic chlorophyll *a*, phaeophytin and organic matter in sediments, the granulometric structure of the sediment, and the taxonomic (at the family level) abundance of benthic macroinvertebrates. For most parameters, we found no substantial differences between farm and control sites. Rather, most variation was explained as a function of depth (surface versus bottom water) or season (spring versus summer conditions). Deviations of farm values from control values, when they occurred, were small and did not indicate any significant impact on either bacterioplankton or benthic chlorophyll. Only one of the five farms studied exerted a detectable impact on the benthic macroinvertebrate community immediately under the cages. These results suggest that medium-sized fish farms located on semi-exposed western Mediterranean coasts have fewer environmental impacts than traditional fish farms located in shallow, sheltered sites. Impact characterization in these new farms may require refinement of the standard approach to deal with rapid dispersal of effluents and sub-lethal levels of environmental disturbance.

- **Keywords:** Aquaculture pollution, Bacterioplankton, Cage fish farms, Dissolved nutrients, Macroinvertebrates

15. Joint Nature Conservation Committee. 2001. Marine Monitoring Handbook. J. Davies (Senior editor) prepared for the UK Marine SACs Project.
    - pdf

16. Puget Sound Ambient Monitoring Program (PSAMP) Management Committee. 2005 Review of the Puget Sound Ambient Monitoring Program – Final Report.
    - **Source:** www.psat.wa.gov/Publications/PSAMP_2005_review.pdf

17. Sutherland, T. 2004. Framework for a benthic aquaculture monitoring program in the Pacific region. Canadian Science Advisory Secretariat (CSAS) Research Document – 2004/56.
    - **Source:** http://www/dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocsRech/2004/2004-056-e.htm

18. Wildish D.J., G.W. Pohle, B.T. Hargrave, T.F. Sutherland, and M.R. Anderson. 2005. Benthic monitoring methods for habitat management of finfish maricultuture in Canada. Canadian Science Advisory Secretariat (CSAS) Research Document – 2005/039.
    - **Source:** http://www/dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocsRech/2005/2005-039-e.htm

Carrying Capacity

19. Alpine, A.E. and J.E. Cloern. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol. Oceanogr. 37(5):946-955.
    - **Source:** http://www.aslo.org/lo/toc/vol_37/issue_5/0946.pdf
    - Interesting results of the invasion of San Francisco Bay by a suspension-feeding clam that resulted in primary productivity falling from an average of 106 g C m-2 yr-1, when bivalves were absent or present in low numbers, to an average of 39 g C m-2 yr-1 from 1977 to 1990 when bivalve suspension feeder abundance exceeded 2000 m-2.

20. Dowd, M. 1997. On predicting the growth of cultured bivalves. Ecological Modelling 104(2-3): 113-131.
    - **Abstract** A simple, limited ecosystem model focused on bivalve growth in a coastal aquaculture site is presented. The model is based on a system of coupled, nonlinear ordinary differential equations which predict the temporal evolution of the following state variables: individual bivalve weight, bivalve numbers, zooplankton biomass, phytoplankton biomass and non-plankton seston. A limiting nutrient is also included to constrain the overall system. The equations are based on population mass budgets and allow for particle exchange with adjacent regions. The model structure is general and designed to be applicable to a variety of bivalve species or sites. In order to test the feasibility of the model for predicting growth, it is applied to a blue mussel *Mytilus edulis* culture site in a coastal inlet near Lunenburg, Nova Scotia, Canada. Idealized forcing functions for the annual cycles of light,

temperature and the far-field concentrations of the state variables are used. It is shown that the model is able to reproduce the general features of observed mussel growth in the different regions of the inlet at the relatively low stocking densities found there. Numerical experiments with high stocking densities are carried out in order to estimate carrying capacity for the inlet. Sensitivity analysis shows that predicted mussel growth is highly influenced by small changes in the physiological parameters which describe the mussel energy budget. It is suggested that this feature may prove to be an important limitation in using such models as predictive tools for managing the development of shellfish aquaculture.

- **Author Keywords:** Shellfish; Bivalves; Model; Aquaculture

21. 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(1-2):109-143.

- **Abstract** In the context of aquaculture, carrying capacity is generally understood as the standing stock of a particular species at which production is maximised 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 analysing 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.
- **Author Keywords:** Ecological modelling; Carrying capacity; Multi-species culture

22. Hay & Company Consultants Inc. 2001. Productive Capacity Study of Gorge Harbour. British Columbia Science Council.

- Hardcopy. Preliminary report to Richardson and Newell 2002.

23. ICES. 2005. Report of the Working Group on Environmental Interactions of Mariculture (WGEIM), 11-15 April 2005, Ottawa, Canada. ICES 2005/F:04 Ref. I, ACME

- **Source:** http://www.ices.dk/reports/MCC/2005/WGEIM05.pdf"
- European focus; good analysis of carrying capacity in the context of physical, production, ecological and social.
- See previous years also. Some useful info in the Country sections.

24. Hily, C. (1991). "Is the activity of benthic suspension feeders a factor controlling water quality in the Bay of Brest?" Mar. Ecol. Prog. Ser. 69: 179-188.

25. Jiang, W. and M.T. Gibbs. 2005. Predicting the carrying capacity of bivalve shellfish culture using a steady, linear food web model. Aquaculture 244(1-4):171-185.

- **Abstract** An investigation into the potential carrying capacity of suspended bivalve culture was undertaken using a linear food web model. The investigation involved configuring the model for the present state using all available

information, and then perturbing the food web by introducing the bivalve culture until pre-determined carrying capacity limits were achieved. These carrying capacity trigger levels were defined by the production carrying capacity and the ecological carrying capacity. The production carrying capacity represents the theoretical maximum bivalve culture that could be supported in the embayment. This is defined as when the ecosystem collapses down to a nutrient–phytoplankton–culture–detritus dominated system. This level of culture was found to be a yield of bivalve culture of 310 t km-2 year-1 averaged across the bays in question. By contrast, the ecological carrying capacity was defined as the level of culture that could be introduced without significantly changing the major energy fluxes or structure of the food web. This limit was found to correspond to a bivalve culture yield of 65 t km-2 year-1 averaged across the bays. Introducing the large-scale bivalve culture resulted in a decrease in the mean trophic level of the ecosystem, an increase in the total yield, throughput and efficiency, and the bivalves replaced zooplankton as the major grazers in the modelled system.

- **Keywords:** Tasman and Golden Bays; Food web model; Bivalve culture; Carrying capacity; Aquaculture sustainability

26. Nunes, J.P., J.G. Ferreira, F. Gazeau, J. Lencart-Silva, X.L. Zhang, M.Y. Zhu, and J.G. Fang. 2003. A model for sustainable management of shellfish polyculture in coastal bays. Aquaculture 219(1-4):257-277.

- **Abstract** 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 longline 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, but at 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 multiannual 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.
- **Author Keywords:** Polyculture; Scallop; Oyster; Model; Aquaculture management; China

27. Richardson, J. and C. Newell. 2002. Building a model for sustainable west coast shellfish aquaculture production – Productive capacity study of Gorge Harbour, Cortes Island, BC. Prepared for: British Columbia Shellfish Growers Association.

- pdf
- See also Hay 2001.

28. Smaal, A., M. van Stralen, E. Schuilling. 2001. The interaction between shellfish culture and ecosystem processes. CJFAS 58: 991-1002.

- Abstract: 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 changed 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 (*i*) feedbacks of the mussels in the Oosterschelde ecosystem—through their large filtration and nitrogen-regeneration capacity, increased phytoplankton turnover was induced; and (*ii*) adaptation to the new conditions by the shellfish farmers in their management of the mussel stocks. It was concluded that feedbacks by filter feeders and farmers have to be addressed in estimating the exploitation capacity of ecosystems.

Clam culture

29. Badino, G., F. Bona, A. Maffiotti, O. Giovanardi, F. Pranovi. 2004. Impact of mechanical clam harvesting on benthic habitat: evaluation by means of sediment profile imaging. Aquatic Conservation: Marine and Freshwater Ecosystems 14(S1): S59-S67.

- 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.

30. 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(1-3):203-212.

- **Abstract** 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–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 O2 demand and CO2 production were stimulated by a factor of, respectively, 1.8 and 3.3, whilst nutrient release was 6.5 times higher for NH4 + and 4.6 times higher for PO4 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 mol NH4 + m–2 h–1 and 150 mol PO4 3- m–2 h–1) stimulated by the high biodegradability of clam faeces and pseudofaeces could in turn favour macroalgal growth.

- **Keywords**: clam culture - surficial sediments - benthic fluxes - anoxia - nutrient budget

31. Goulletquer, P., R. Robert, and G. Trut. 1999. Manila clam *Tapes philippinarum* culture: sediment-clam interactions. Aquatic Living Resources 12(1):45-56.
    - **Abstract.** 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 a 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: 0–1, 1–2 and 2–10 cm. Moreover, the main hydrobiological parameters were measured 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 fanning is likely to occur upon cessation of this activity.
    - Keywords: trestles, vehicles, macrobenthic community chances.

32. Kaiser, M.J., G. Broad and S.J. Hall. 2001. Disturbance of intertidal soft-sediment benthic communities by cockle hand raking. Journal of Sea Research 45(2):119-130.
    - **Abstract**. Recent awareness of the ecosystem effects of fishing activities on the marine environment means that there is a pressing need to evaluate the direct and indirect effects of those activities that may have negative effects on non-target species and habitats. The cockle, *Cerastoderma edule* (L.) is the target of a commercial and artisanal fishery that occurs in intertidal and estuarine habitats across Northern Europe. Cockles are harvested either mechanically using tractor dredges or suction dredges or by large numbers of individual fishers using hand rakes. This study examined the effects of hand raking on the non-target species and under-sized cockles associated with intertidal cockle beds and the effects of size of the patch of sediment disturbed on subsequent recolonisation. Hand raking led to an initial three-fold increase in the damage rate of under-sized cockles compared with control plots. The communities in both small and large raked plots showed community changes relative to control plots 14 days after the initial disturbance. The small raked plots had recovered 56 days after the initial disturbance whereas the large raked plots remained in an altered state. Samples collected over a year later indicated that small-scale variations in habitat heterogeneity had been altered and suggest that while effects of hand raking may be significant within a year, they are unlikely to persist beyond this time-scale unless there are larger long-lived species present within the community.
    - Author Keywords: Fishing disturbance; Cockle; Intertidal; Benthic community; Recovery rate

33. Kaiser, M.J., D.B. Edwards and B.E. Spencer. 1996. Infaunal community changes as a result of commercial clam cultivation and harvesting. Aquatic Living Resources 9(1):57-63.
    - Hardcopy.

34. Mojica, Jr. R., 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.
    - **Abstract.** The impact of the growout of cultured hard clams 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**: hard clam, growout bags, benthic macrofauna, water quality parameters, sediment

35. Pranovi, F., S. Librato, S. Raicevich, A. Granzotto, R. Pastres, O. Giovanardi. 2003. Mechanical clam dredging in Venice lagoon: ecosystem effects evaluated with a trophic mass-balance model. Marine Biology 143(1):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 characterise 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.

36. Spencer, B.E., M.J. Kaiser, and D.B. Edwards. 1998. Intertidal clam harvesting: Benthic community change and recovery. Aquaculture ecological effects of intertidal Manila clam cultivation: Observations at the end of the cultivation phase. Aquaculture Research 29:429-437.

- **Abstract**. 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 longterm 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 shortterm 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**. Manila clam cultivation, invertebrate infaunal community, benthic habitat, impacts,

37. Thom, R.M., T.L. Parkwell, and D.K. Shreffler. 1994. Effects of gravelling on the primary productivity, respiration and nutrient flux of two estuarine tidal flats. Marine Biology 118(2):329-341.

- **Abstract** This study was conducted in Puget Sound, USA, and investigated the effect of graveling intertidal mud and sandflats to enhance clam production on the benthic assemblage structure, primary productivity, respiration, and nutrient flux. The study was conducted between spring and autumn (1991), the period of greatest productivity and plant standing stock in Puget Sound. Graveled and control plots were established in the low intertidal zone on a mud flat in a protected embayment (Chapman Cove) and an exposed sandflat (Semiahmoo Bay). Gravel altered benthic assemblage structure, respiration, and nutrient flux rates. Graveled plots contained more surface coverage of sessile animals and seaweeds. Net productivity (NP), which differed relatively little between graveled and control plots, was negative for all but one sampling at the protected embayment plots. In contrast, NP was always positive at the exposed sandflat plots. The respiration rate was 13 to 57% greater in the graveled plot at Chapman Cove than in the adjacent control plot, and 7 to 54% greater in the gravel plot than the control plots at Semiahmoo Bay. Heterotrophy was greater in the graveled plots, as reflected by a lower net productivity to respiration ratio. Effects of graveling on water quality parameters such as dissolved oxygen and inorganic nitrogen concentrations were not detected. Graveling sandy and mud beaches increases secondary productivity, which is associated with increased rates of remineralization and release of dissolved nutrients to the water column.

38. Thuringer, P. (Archipelago Marine Research Ltd.). 2003. See FISH; sand lance and clam culture.

39. Whiteley, J.A. 2005. Macroinvertebrate Community Responses to Clam Aquaculture Practices in British Columbia. M.Sc. Thesis, Simon Fraser University. 134 pp. (SFU, Centre for Coastal Studies, Sustainable Shellfish Aquaculture Institute).

- 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;

Critical Habitats /SARA

40. Jamieson, G.S., E.J. Gregr, and C. Robinson. 2004. Northern abalone case study for the determination of SARA critical habitat. Canadian Science Advisory Secretariat, CSAS, Research Document – 2004/117.

- http://www.dfo-mpo.gc.ca/csas/Csas/Publications/ResDocs-DocRech/2004/2004_131_e.htm

DFO National Advisory Process Documents 2006

41. DFO, 2006. Assessing habitat risks associated with bivalve aquaculture in the marine environment. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/xxx (IN PRESS).

- Open-water, marine bivalve aquaculture is conducted in British Columbia and in all five provinces of Atlantic Canada, including Quebec. The term bivalve is preferred to shellfish because in Canada most shellfish species used in aquaculture are bivalves. On the Pacific coast almost all of these species are non-indigenous. The opposite is true on the Atlantic coast, where, with the exception of the flat oyster and bay scallop, bivalve culture is conducted with native species. This industry is important in coastal communities and is growing rapidly. In contrast to finfish aquaculture, bivalves are sustained on food that occurs naturally in the ecosystem. A wide range of practices and habitats are used in the culture of bivalves.
- A national workshop was held in Moncton NB, February 28 – March 3, 2006, to consider methods available to assess potential environmental risks of bivalve aquaculture in the marine environment. The workshop was based on the peer review of five working papers. Referees included scientists from around North America and Europe. Five teams, formed in August 2005, wrote the papers. Each paper was focused on a particular theme and each theme was divided into a suite of questions. The themes were to identify:
    1. positive and negative impacts of marine bivalve aquaculture on fish habitat;
    2. chemical, biological or physical indicators to measure these effects;
    3. modeling methodologies available to predict any impacts of bivalve aquaculture;
    4. cumulative and far-field effects; and,
    5. sensitive habitats that may be affected by bivalve aquaculture.

42. McKindsey, C.W., Anderson, M.R., Barnes, P., Courtenay, S., Landry, T and Skinner, M. Feb. 28-Mar. 3, 2006. Effects of Shellfish Aquaculture on Fish Habitat. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Moncton, NB p. 1-88 *DRAFT*.

43. Dowd, K. 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. Feb. 28-Mar. 3 2006. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. *DRAFT*.

44. Chamberlain, J., Weise, A., Dowd, M. and Grant, J. Modeling approaches to assess the potential effects of shellfish aquaculture on the marine environment Feb. 28-Mar. 3, 2006. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Moncton, NB p. 1-126 *DRAFT*.

45. Cranford, P.J., Anderson, R., Archambault, P., Balch, T., Bates, S.S., Bugden, G., Callier, M.D., Carver, C., Comeau, L., Hargrave, B., Harrison, W.G., Horne, E., Kepkay, P.E., Li, W.K.W., Mallet, A. Ouellette, M. and Strain, P. Indicators and Thresholds for Use in Assessing Shellfish Aquaculture Impacts on fish Habitat. Feb. 28-Mar. 3, 2006 Effects of Shellfish Aquaculture on Fish Habitat. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Moncton, NB p. 1-126 *DRAFT*.

46. Anderson, M.R.,Cranford, P.J., McKindsey, C.W., Strain, P., Hargrave, B.T., Li, W.K.W. and Harrison, W.G. Feb. 28-Mar. 3, 2006 Cumulative and Far-Field Fish Habitat Effects. Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. Moncton, NB *DRAFT*.

47. Brooks, K.M. Supplemental study of dissolved nutrients and particulate organic matter in the waters near the proposed mussel farm in North Totten Intet. Feb. 28-Mar. 3, 2006 Fisheries and Oceans Canada. National Advisory process on Environmental Effects of Shellfish Aquaculture. 45 pages Moncton, NB *DRAFT*.

Eelgrass/Seagrasses

48. Alexandre, A., R. Santos, and E. Serrão. 2005. Effects of clam harvesting on sexual reproduction of the seagrass Zostera noltii. Marine Ecology Progress Series 289:115-122.

- Abstract available at www.int-res.com/abstracts/meps/v298/p123-129/
- Results suggest that *Z. noltii* responds to clam harvesting disturbance by both increasing its reproductive effort and extending its fertile season. Significantly lower vegetative shoot density after experimental harvest during fertile season.

49. Backman, T.W. and D.C. Barilotti. 1976. Irradiance reduction: effects on standing crops of the eelgrass Zostera marina in a coastal lagoon. Marine Biology 34:33-40.

- Hardcopy

50. 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.

- **Abstract**. The effect of recreational clam harvesting on eelgrass (*Zostera marina* L.) was experimentally tested by raking or digging for clams in experimental 1 m^2 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.

51. Bologna, P., and K. Heck. 2002. Impact of habitat edges on density and secondary production of seagrass-associated fauna. Estuaries 25(5): 1033-1044.

- **Keywords**: edges, patches, invertebrate faunal densities, eelgrass.
- **Abstract** Species richness and abundance of seagrass-associated fauna are often positively correlated with seagrass biomass and structural complexity of the habitat. We found that while shoot density and plant biomass were greater in interior portions of turtle grass (*Thalassia testudinum*) beds than at edges, mean faunal density was significantly greater at edges than interior sites during 1994. This pattern was also observed in 1995, although differences were not significant. The four numerically dominant taxonomic groups showed varying degrees of elevated densities at edges of *T. testudinum* beds. Peracarids and polychaetes had significantly greater densities at edges of *T. testudinum* beds, while both decapods and gastropods showed dramatic temporal variability in density, with reversals in density between edge and interior occurring during the course of the study. This within-habitat variability in abundance may reflect both active accumulation of fauna at edges and settlement shadows for species with pelagic larvae. Active accumulation of highly mobile taxa seeking refuge in seagrass beds may explain the differences in density between edge and interior of *T. testudinum* patches for peracarids in 1994 and in 1995. Active accumulation at edges may also explain differences in density for some decapod taxa. Changes in gastropod densities between habitats may reflect larval settlement patterns. Results showed a distinct settlement shadow for the gastropod *Caecum nitidum* whose densities (primarily second stage protoconch) increased by more than an order of magnitude in 1994. Settlement shadows and post-settlement processes may also explain density

differences of polychaetes between the edge and interior of *T. testudinum* patches. The differences in faunal densities between edge and interior habitat resulted in habitat specific differences in secondary production among the major taxonomic groups. On four of five dates in 1994 and in 1995, secondary production was greater at edge than interior locations. These unexpected results suggest that differences in faunal densities and secondary production between edges and interiors of seagrass patches represent a potentially vital link in seagrass trophic dynamics. If this elevated secondary production leads to increases in trophic transfer, then edges may serve as a significant trophic conduit to higher-level consumers in this system.

52. BC Coastal Eelgrass Stewardship Project. 2002. Eelgrass conservation for the BC coast - A discussion paper. Prepared by N. Wright, Sea Change Marine Conservation Society.

- pdf

53. Cabaço, S., A. Alexandre, R. Santos. 2005. Population-level effects of clam harvesting on the seagrass Zostera noltii. Marine Ecology Progress Series 298:123-129.

- Abstract available at www.int-res.com/abstracts/meps/v298/p123-129/
- Intertidal eelgrass meadows in Ria Formosa lagoon in southern Portugal are highly disturbed by clam harvesters who dig and till the sediment with a modified knife with a long blade. Present some evidence that clam harvesting activities change species population structure by significantly reducing shoot density and total biomass, but impact on shoot density was short-term in experimental harvests. Rhizome fragmentation experiments showed that plant survival is reduced only if rhizomes are left with only one intact internode, although growth and production were lower when only 2 internodes were left.

54. Cancemi, G., G. De Falco, G. Pergent. 2003. Effects of organic matter input from a fish farming facility on a *Posidonia oceanica* meadow. Estuarine, Coastal and Shelf Science 56(5-6):961-968.

- **Abstract.** In the Mediterranean, the development of aquaculture along the coasts appears as a source of disturbance to the littoral ecosystems, and in particular to *Posidonia oceanica* seagrass meadows. Although the impact of fish farms in Northern Europe has been studied over the last few years, the data are more scarce in the Mediterranean. Thus, a number of physico-chemical and biological parameters have been examined here in order to evaluate the impact of a fish farm in a littoral bay of Corsica. The following values that were recorded in the vicinity of the fish farm are much higher than those at the reference station: organic content of the sediment (24–21 versus 2%), nitrogen concentrations (ammonium: 19.5–8.4 versus 1.8 μM) and phosphorous levels in the pore water (orthophosphates: 5.2–1.3 versus 1.7 μM). The seagrass meadow vitality also seems to be affected in the vicinity of cages, with densities that drop from 466 (reference station) to 108 shoots m^{-2} (20 m from cages). Total primary production also varies from 1070.6 to 87.9 g m^{-2} $year^{-1}$. The main impact factors seem to be the input of organic matter originating from the cages and the high epiphyte biomass caused by the nutrient enrichment. The high level of organic matter and the presence of mud seem to alter the physico-chemical characteristics of the bottom sediment; moreover, the plant/epiphyte competition seems to lead to a leaf fragility and, more importantly, to a decrease in available light.

55. Castel, J., P.-J. Labourg, V. Escaravage, I. Auby, and M.E. Garcia. 1989. Influence of seagrass beds and oyster parks on the abundance and biomass patterns of meio- and macrobenthos in tidal flats. Estuarine, Coastal and Shelf Science 28(1):71-85.

- In Arcachon Bay, on the south-west coast of France, the intertidal area is mainly occupied by sandbanks, oyster parks (*Crassostrea gigas*) and mud flats covered with seagrass beds (*Zostera noltii*). In order to estimate the relative contribution of meio- and macrofauna to the benthic ecology of these tidal flats, seven stations were studied seasonally for a year. Relationships between faunal density and biomass, and external factors such as sediment structure, benthic chlorophyll and seagrass debris were investigated. A comparison was made between bare sands, oyster beds and vegetated sediment in semi-exposed conditions and in sheltered areas.

- Using a stepwise method of multiple linear regression it was shown that high densities of macrobenthos are mostly explained by high quantities of plant debris. For meiofauna, together with plant debris, other effective variables are involved: silt content, organic carbon, chlorophyll pigments. On an average, a correlation between macro- and meiofaunal abundances could be found. However, this general pattern is modified by the biogenic structure created by the oysters and seagrass. When compared to the adjacent sandbanks, oysters clearly enhanced meiofaunal abundance (from 1130–4170 individuals 10 cm^{-2}) but depressed macrofaunal densities (from 640-370 individuals 400 cm^{-2}). The organic-rich oyster biodeposits probably favour meiofauna by an increase of the trophic resources but do not favour macroinfauna by inducing low oxygen concentrations. Moreover, it is likely that macrofauna is more sensitive to predation than meiofauna both in sandbanks and in oyster parks. For both meio- and macrofauna the highest incidences (7200 individuals 10 cm^{-2} and 2470 individuals 400 cm^{-2}, respectively) are recorded in seagrass bed sediments. *Zostera* induces an enhancement of organic detritus and provides a refuge against predation. In terms of biomass, the macrofauna/meiofauna ratio is 25·1 in sandbanks, 1·5 in oyster parks and 4·2 in seagrass bed sediments. Macrofaunal biomass is more variable both spatially and temporally than meiofauna biomass. It is likely that the macrofauna is more sensitive to external factors such as predation, anoxia, exposure, than the meiofauna. Meiofauna abundance and biomass are more usually a function of food abundance and physical properties of the sediment.
- **Author Keywords:** Meiobenthos; macrobenthos; biomass; *Zostera* beds; oyster parks; tidal flats; Arcachon Bay

56. Conservation Council of New Brunswick. 2004. Estimating human-derived nitrogen loading to New Brunswick estuaries: a simple export model – Including source backgrounders.

- **Source:** http://www.conservationcouncil.ca/marine/files/
- Good section on shellfish impact on nutrient flux and references
- Comparison table of oyster and mussel fecal/pseudofaeces production rates

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

- pdf
- **Abstract** 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.
- **Author Keywords:** Shellfish farming; Environmental impact; Benthic environment
- Tasmania. No significant difference found between sediment deposition, redox values, sediment sulphide concentrations, organic carbon content and water turbidity levels near the bottom inside, outside and on the boundary of three established (>10 years) subtidal shellfish farms (all grew oysters and mussels) and no evidence for organic enrichment of benthic infauna. Some evidence for lack of impact on seagrass.

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

- **Abstract** 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-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% 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).

59. De Casabianca, M.-L., T. Laugier, and E. Marinho-Soriano. 1997b. Seasonal changes of nutrients in water and sediment in a Mediterranean lagoon with shellfish farming activity (Thau Lagoon, France). ICES J. Mar. Sci., 54(5): 905-916

- **Abstract** The French Mediterranean lagoon of Thau is characterized by an important eutrophication dominated by shellfish farming (ca. 15 times the terrestrial inputs). On the basis of increasing eutrophication, three areas were identified and monitored for one year (overlying and sediment pore water nutrients, macrophytic biomass and water column chlorophyll*a*). Though some parameters show similar changes in the three areas (salinity, temperature), others are elevated in eutrophicated sites, e.g. organic content and siltation of the sediments, dissolved inorganic nitrogen (136.1 μmol lμ-1overlying water, and 1185 μmol lμ-1pore water), dissolved reactive phosphorus (DRP) (20.9 μmol 1μ-1 overlying water), the summer oxygen depletion (1.1 mg lμ-1), the peak of macrophytic biomass (8 kg w · wt mμ-2) and phytoplanktonic bloom (14 μg lμ-1). Differences in DRP levels arise from sediment release during the summer anoxia; DRP appeared to play a key role as a limiting factor, and regulates competition between macrophytes and phytoplankton in spring. The macrophytes (seagrass*Zostera*and seaweeds*Gracilaria*and*Ulva*) may sustain the environment they are living in, acting as additional eutrophication sources.
- **Author Keywords:** lagoon; shellfish; farming; eutrophication; nutrients; sediments; macrophytes

60. De Casabianca, M.-T., M. Rabotin, and R. Rigault. 2003. Preliminary results on eelgrass regression and red seaweed dominance under increasing eutrophication (Thau Lagoon, France). Acta Adriatica 44(1):33-40.

- This study measures biomass, composition and specific diversity of marine macrophyte communities in three sites situated along eutrophic gradient, in the Mediterranean Thau Lagoon, subject to intensive shellfish farming activity (increase of siltation and shell fragments percentage in sediments to the detriment of sand). The study was conducted for one year at three different periods, at 1.50m water depth. Along the increasing eutrophic gradient, the dominant communities were: (I) mixed eelgrass (Zostera noltii); (II) mixed eelgrass (Z. marina) invaded by seaweed (Rhodophyceae and Chlorophyceae); and (III) a red seaweed community dominated by three Gracilaria species. The algae diversity degree of the community was maximum in the second site, because the shell debris increase the settlement of algae. In the third site, due to the large quantity of mud, the sea-grass disappeared and the red algae were dominant in relation with the light intensity decrease. This increasing eutrophication gradient squares with the steps of the long-term historic eelgrass degradation. So, these results are important for the management of marine eutrophicated areas.

61. Dumbauld, B., J. Ruesink, H. Macrellis, F., Oyarzun, 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', Sept. 14-18, 2003, Seattle, Washington.
    - Abstracts available at: www.erf.org/erf2003/abstracts?
    - **Abstract**. 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.
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62. Dumbauld, B., J. Ruesink, H. Macrellis, D. Armstrong. 2003. Interactions between oyster aquaculture and seagrass (*Zostera marina*) in Willapa Bay. Pacific Estuarine Research Society. Presentations at "Applying Science and Information to Sustainability to Pacific Coast Estuaries. Meeting April 3-4, 2003, Vancouver BC.
    - **Source:** Abstracts only ;www.pers-erf.org/PERS_03_Program.pdf
    - Surveys suggest direct negative effects of harvest dredge operations while handpicking and longline operations appear compatible with high seagrass cover.

63. Durrance, C., M. Pepin. 2004. Eelgrass mapping in the Frazer River Estuary. Presentation at the Pacific Estuarine Research Society 2004 Annual Meeting, May 17-18, 2004, Port Townsend, Washington.
    - **Source:** http://www.pers-erf.org/PERS04Program.pdf
    - Report increases in eelgrass (Z. marina) coverage of 92% (280 ha in 1959 to 500 ha in 2004) and 647% (30 ha in 1959 to 224 ha in 2004) in two areas of the Fraser River Estuary that have been highly modified by the construction of two causeways.

64. Durance, C. 2006. Wildlife impacts on eelgrass beds. T'aanuu Telegram Pg. 8.
    - **Source:** www.stewardshipcentre.bc.ca/eelgrass/newsletterjan06.pdf
    - Green urchins decimating eelgrass beds in Campbell River and Sechelt Inlet
    - Canada geese and green crabs diminishing eelgrass beds on Atlantic coast and NS
    - Grey whales foraging at Rathtrevor and Clayoquot Sound, and sea otters on West Coast Van Isle

65. Environment Canada, Canadian Wildlife Service. 2002. Methods for mapping and monitoring eelgrass habitat in British Columbia. Draft 4. Precision Identification Biological Consultants.
    - **Source:** www.stewardshipcentre.bc.ca/eelgrass/methods.pdf

66. Estuarine Research Federation. 2003. 17th Biennial conference of the Estuarine Research Federation. Meeting held September 14-18, 2003. Seattle Washington.
    - Abstracts only, available at http://www.erf.org/meetings.html

67. Everett, F., G. Ruiz, and J.T. Carlton. 1995. Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. Marine Ecology Progress Series 125: 205-217.
    - Hardcopy

68. Healey, D. and K.A. Hovel. 2004. Seagrass bed patchiness: effects on epifaunal communities in San Diego Bay, USA. JEMBE 313(1): 155-174.

- **Abstract** Seagrass habitat structure influences epifaunal density, diversity, community composition and survival, but covariation of structural elements at multiple scales (e.g., shoot density or biomass per unit area, patch size, and patch configuration) can confound studies attempting to correlate habitat structure with ecological patterns and processes. In this study, we standardized simulated seagrass shoot density and bed area among artificial seagrass beds in San Diego Bay, California, USA to evaluate the singular effect of seagrass bed configuration ("patchiness") on the density and diversity of seagrass epifauna. Artificial seagrass beds all were 1 m2, but were composed of a single large patch ("continuous" treatment), four smaller patches ("patchy" treatment), or 16 very small patches ("very patchy" treatment). We allowed epifauna to colonize beds for 1 month, and then sampled beds monthly over the next 3 months. Effects of seagrass bed patchiness on total epifaunal density and species-specific densities were highly variable among sampling dates, and there was no general trend for the effects of fragmentation on epifaunal densities to be positive or negative. Epifaunal diversity (measured as Simpson's index of diversity) was highest in very patchy or patchy beds on two out of the three sampling dates. Very patchy beds exhibited the highest dissimilarity in community composition in the first two sampling periods (August and September), but patchy beds exhibited the highest dissimilarity in the third sampling period (October). Our results indicate that seagrass patch configuration affects patterns of epifaunal density, diversity, and community composition in the absence of covarying bed area or structural complexity, and that patchy seagrass beds may be no less valuable as a habitat than are continuous seagrass beds. The spatial pattern employed when harvesting or planting seagrass may influence epifaunal habitat use and should be a key consideration in restoration plans.
- **Keywords:** Abundance; Diversity; Epifauna; Habitat structure; Patchiness

69. Hessing-Lewis, M. 2005. Assessing the potential for eelgrass restoration in the Squamish estuary, British Columbia. MSc. Thesis. Queens University, Kingston, Ontario, Canada.

- **Source:** http://www.stewardshipcentre.bc.ca/eelgrass/research.html
- Recommendations on transplanting procedure, plant donor selection, plant monitoring, water column monitoring, substrate analysis.

70. Holmer, M., M. Pérez, C.M. Duarte. 2003. Benthic primary producers – a neglected environmental problem in Mediterranean maricultures? Marine Pollution Bulletin 46(11):1372-1376.

- **Abstract.** Marine fish farming is increasing rapidly in the Mediterranean and in contrast to the Atlantic the coastal zone in the Mediterranean is characterized by clear waters with high transparency. This allows benthic primary producers such as the slow-growing seagrass *Posidonia oceanica* to grow at large depths at locations suitable for fish farming and generating a conflict between the conservation of these meadows and the growth of aquaculture operations in the Mediterranean. In this paper we review the current knowledge on environmental interactions between fish farming and benthic primary producers with particular focus on *P. oceanica*, as this seagrass is a key component along Mediterranean coasts. The recovery times of *P. oceanica* are very long, in the order of centuries, and losses of this species are thus considered to be irreversible at managerial time scales.

71. Hosack, G.R., D.A. Armstrong, B.R. Dumbauld, B. Semmens, J. Ruesink. 2003. Relationships between habitat and community structures in the low intertidal zone of a large Pacific Northwest estuary. Presentation at '17th Biennial Conference of the Estuarine Research Federation Conference', Sept. 14-18, 2003, Seattle, Washington.

- **Source** (Abstracts only): www.erf.org/erf2003/abstracts?
- **Abstract.** The effect of habitat structure on species assemblages and abundances in estuarine systems is well documented. Seagrass presence, for instance, has been shown to be associated with increased nekton diversity and abundance. We compared community structure between the three main habitat types found in the low intertidal zone of Willapa Bay, Washington: seagrass meadow (Zostera marina), open tideflat, and ground culture oyster. Because commercial oyster beds occupy the same tidal elevation zone as state-protected seagrass meadows,

information on community differences between these two habitat types are especially critical to management. In 2001 and 2002, we used a variety of passive and active gears to sample nekton macrofauna and epibenthic meiofauna, and obtain juvenile salmon for diet analyses. Canonical correspondence analyses and univariate tests show that habitat structure influences nekton species composition but not total abundance. However, both meiofaunal composition and density vary distinctly among habitat types. Differences in nekton and epibenthic species composition are greatest between unstructured and structured habitats. Our results suggest that while overall community structure differs between habitats, the occurrence of some common or economically important nekton species may not differ significantly between habitats.

72. Hosack, G.R., D.A. Armstrong, B.R. Dumbauld, B. Semmens, J. Ruesink. 2003. Does habitat structure influence low intertidal communities in Willapa Bay, Washington? Pacific Estuarine Research Society. Presentations at "Applying Science and Information to Sustainability to Pacific Coast Estuaries, April 3-4, 2003, Vancouver BC.

- **Source** (Abstracts only): www.pers-erf.org/PERS_03_Program.pdf
- Much the same content as talk given at the ERF meeting above. Compared nekton use in three main habitat types found within the low intertidal zone: seagrass meadow (*Z. marina*), unvegetated tideflat, and commercial oyster ground culture. Observed differences in the composition of the nekton and epibenthic communities were greatest between unvegetated and structured habitats. Active sampling of juvenile chinook salmon did not reveal a habitat preference within the low intertidal.

73. Johnson, S.W., M.L. Murphy, D.J. Csepp, P.M. Harris, and J.F. Thedinga. 2003. A survey of fish assemblages in eelgrass and kelp habitats of southeastern Alaska. NOAA Technical Memeorandum NMFS-AFSC-139.

- **Source** (pdf available): www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-139.pdf
- Good discussion of eelgrass-fish ecology

74. Lee, K.-S., F.T. Short, and D.M. Burdick. 2004. Development of a nutrient pollution indicator using the seagrass, *Zostera marina*, along nutrient gradients in three New England estuaries. Aquatic Botany 78(3): 197-216.

- **Abstract** Worldwide, seagrasses provide important habitats in coastal ecosystems, but seagrass meadows are often degraded or destroyed by cultural eutrophication. Presently, there are no available tools for early assessment of nutrient over-enrichment; direct measurements of water column nutrients are ineffective since the nutrients typical of early enrichment are rapidly taken up by plants within the ecosystem. We investigated whether, in a gradient of nutrient availability but prior to actual habitat loss, eelgrass (*Zostera marina* L.) plant morphology and tissue nutrients might reflect environmental nutrient availability. Eelgrass responses to nitrogen along estuarine gradients were assessed; two of these plant responses were combined to create an early indicator of nutrient over-enrichment. Eelgrass plant morphology and leaf tissue nitrogen (N) were measured along nutrient gradients in three New England estuaries: Great Bay Estuary (NH), Narragansett Bay (RI) and Waquoit Bay (MA). Eelgrass leaf N was significantly higher in up-estuary sampling stations than stations down-estuary, reflecting environmental nitrogen gradients. Leaf N content showed high variance, however, limiting its ability to discriminate the early stages of eutrophication. To find a stronger indicator, plant morphological characteristics such as number of leaves per shoot, blade width, and leaf and sheath length were examined, but they only weakly correlated with leaf tissue N. Area normalized leaf mass (mg dry weight cm-2), however, exhibited a strong and consistently negative relationship with leaf tissue N and a significant response to the estuarine nutrient gradients. We found the ratio of leaf N to leaf mass to be a more sensitive and consistent indicator of early eutrophication than either characteristic alone. We suggest the use of this ratio as a nutrient pollution indicator (NPI).
- **Author Keywords:** Author Keywords: Seagrass; *Zostera marina*; Eelgrass; Nutrients; Nitrogen; Eutrophication; Indicator; Estuary; New England

75. Levings, D.C. 1991. Strategies for restoring and developing fish habitats in the Strait of Georgia – Puget Sound inland Sea, northeast Pacific Ocean. Marine Pollution Bulletin 23:417-422.

- **Abstract.** Rehabilitation and development of fish habitats are potential techniques for achieving sustainable development in coastal seas. Recent projects in the Strait of Georgia and Puget Sound to examine this possibility have conducted trials or experiments with sedge marshes (*Carex lyngbyei*) (26 sites) and eelgrass beds (*Zostera marina*) (14 sites). Some studies have been appropriate for examining the potential compensation of wetland losses from industrial developments, but many were experimental and small scale. Larger scale projects and longer term monitoring are needed to confirm that the policy goals of no net loss or net gain in fish habitat can be met using these techniques.

76. Madigan, S., J. Higham, and S. Clarke. 1999. Oyster Environmental Monitoring Program ()EMP): Broad-scale Seagrass Changes Associated with Intertidal Oyster Farming. South Australian Research and Development Institute.

- Report no effect visible using digital image analysis.

77. Madigan, S., S. Venema, K. Haskard, and S. Clarke. 2000. Oyster Environmental Monitoring Program (EMP): Small-scale seagrass health study. South Australian Research and Development Institute.

- Looks at oyster racks and longlines. Record no effect from longlines and effect of racks only within 1 metre of racks. Observed some other farms that had seagrass where previously there hadn't been any.

78. Mumford, T.F., S. Wyllie-Echeverria, R.R. Thom, D.E. Penttila. 2003. Loss of eelgrass (Zostera marina L.) in small embayments, Puget Sound, Washington: similarity to worldwide early signs of collapse. Presentation at '17th Biennial Conference of the Estuarine Research Federation Conference', Sept. 14-18, 2003, Seattle, Washington.

- **Source** (abstracts only): www.erf.org/erf2003/abstracts?
- While overall populations of eelgrass (Zostera marina L.) in the Puget Sound Basin and Salish Sea area of Washington State appear to be stable, we document substantial loss in both subtidal and intertidal regions for several small embayments and nearshore areas adjacent to urban freshwater inputs such as Westcott Bay; Quartermaster Harbor, Eagle Harbor, Fauntleroy and Dumas Bay. Techniques used to quantify this loss include: historical diver surveys and mapping, herring spawn rake data from the 1970's to the present, aerial photography, side-scan sonar and underwater videography. Our analysis suggests losses are linked to degraded water quality rather than overwater structures or competition from introduced species (e.g., Zostera japonica; Sargassum muticum). We present a model that describes the relationship between watershed alterations such as increased housing starts and additional septic systems and changes in situ eelgrass polygons. Landscape patterns depicting patch fragmentation and/or extinction compare to those documented by similar describing losses on the East coast of the US, Texas, and Australia suggesting loss in Puget Sound could become more widespread unless water quality is improved.

79. North, E.W., S. Chen, R.R. Hood, F. Shi, L.P. Sanford, J.T. Kirby, E.W. Koch, and R.I. Newell. 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.

80. Oleson, B. 1996. Regulation of light attenuation and eelgrass *Zostera marina* depth distribution in a Danish embayment. Marine Ecology Progress Series 134: 187-194.

- Have abstract hardcopy only.
- Suspended inorganic matter (mineral particles) vs phytoplankton biomass (ch *a*) as components of Secchi disc reading

81. Pacific Estuarine Research Society. 2003. Presentations at "Applying Science and Information to Sustainability to Pacific Coast Estuaries. Meeting April 3-4, 2003, Vancouver BC. On CD.

- **Source** (Abstracts only); www.pers-erf.org/PERS_03_Program.pdf
- Interactions between oyster aquaculture and seagrass (Zostera marina) in Willapa Bay, Washington. Dumbauld et al.
- Ecological impacts of commercial oyster long-line culture in Humboldt Bay, CA. Rumrill and Poulton.
- Does habitat structure influence low intertidal communities in Willapa Bay, Washington. Hosack et al.

82. Pacific Estuarine Society. 2004. Meeting may 17-18, 2005. Port Townsend, Washington.

Abstracts only, available at http://www.pers-erf.org/PERS04Program.pdf

83. Pacific Estuarine Society. 2005. Meeting March 18-20, 2005. Coos Bay Oregon.

Abstracts only, available at www.pers-erf.org/PERSProgram.doc

84. Pentilla, D. and D. Doty. 1990. Progress Report. Results of 1989 eelgrass shading studies in Puget Sound. Washington Department of Fisheries, Marine Fish Habitat Investigations Division.

- **Source:** http://depts.washington.edu/newwsdot/pentdot.html

85. Peterson, B.J. and K.L. Heck. 1999. The potential for suspension feeding bivalves to increase seagrass productivity. JEMBE 240:37-52.

- **Source:** http://www.pcsga.org/Research/

86. Peterson, B.J. and K.L. Heck. 2001. Positive interactions between suspension-feeding bivalves and seagrass – a facultative mutualism. Marine Ecology Progress Series – Mar. Eco.l Prog. Ser. Vol. 213:143-155.

- **Source:** http://www.pcsga.org/Research/

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

- **Source:** http://www.pcsga.org/Research/

88. Plus, M., J.-M. Deslous-Paoli, and F. Dagault. 2003. Seagrass (Zostera marina L.) bed recolonisation after anoxia-induced full mortality. Aquatic Botany 77(2):121-134.

- Recolonisation of *Zostera marina*, following complete destruction caused by an anoxic crisis, was studied in the Thau lagoon (French Mediterranean Sea) from February 1998 to September 1999. The recolonisation took place surprisingly rapidly as biomasses similar to those from untouched areas were reached only nine months after seed germination. The recolonisation success was partly due to a high seedling survival rate as well as a rapid vegetative recruitment (ranging from 0.012 to 0.042 per day). Two phases of recovery could be observed: a rapid multiplication of shoots during the first 3 months was followed by an increase in biomass due to elongation of leaves. During the first year of recolonisation no flowering shoot was observed whilst reproductive effort was considerable during the second year. In case of two consecutive anoxic crises at the same site, the recovery would have probably been much slower, since the annual seedbank would have been depleted.
- **Author Keywords:** Seagrass recolonisation; Anoxic crises; *Zostera marina*; Thau lagoon

89. Pulich, Jr.,W.M., R.W. Virnstein, S. Wyllie-Echeverria, R.S. Fletcher, H.D. Berry. 2003. Deriving landscape indicators of stress for the seagrass biome. Presentation at '17th Biennial Conference of the Estuarine Research Federation Conference', Sept. 14-18, 2003, Seattle, Washington.

- **Source** (Abstract only): www.erf.org/erf2003/abstracts?
- Seagrass landscape analysis has routinely focused on mapping seagrass distribution using aerial photography and ground surveys. However critical, but neglected, aspects are spatial analysis of features and patterns within the seagrass biome, and derivation of spatial/landscape indicators of habitat condition or ecosystem stress. Defining landscape indicators or criteria constitutes a new challenge for seagrass research. We propose herein a conceptual model built on insights derived from terrestrial ecosystem analysis, to evaluate landscape patterns observed within the seagrass biome that may indicate reduced fitness or altered community structure, based on the assumption that landscape patterns reflect the cumulative response of the seagrass biome to environmental processes. Three distinct categories of landscape features are identified: 1) Bed morphology patterns including shape, size and the symmetry of edge boundaries; 2) Temporal dynamics of species composition and spatial distribution; and 3) Non-seagrass features located within the biome. By integrating these landscape patterns with intensive ground survey data for subareas of seagrass coverage, landscape indices (analogous to bioindicators) for assessing ecosystem health can be developed using geospatial analysis or image processing software. Applications of this conceptual model will be described for three geographic areas (viz.Texas, Florida, and Washington).

90. Pulich, Jr., W.M., T. Mutchler, B. Hardegree, K. Dunton, S. Wyllie-Echeverria. 2005. Development of a landscape-based approach for predicting disturbances of seagrass beds. Presentation at 'Estuarine interactions: biological-physical feedbacks and adaptations', Estuarine Research Federation Conference 2005, Oct. 16-20, 2005, Norfolk, Virginia.

- **Source** (Abstract only): www.erf.org/erf2005/abstracts/authors00.html
- **Abstract**. Time series analysis of landscape patterning in terrestrial biomes can signify variation in bistability which can, in turn, predict ecosystem collapse (Rietkerk et al. 2001). Whereas the loss of seagrass flora can often provide an early warning of system wide degradation, methods to estimate the rate and trajectory of decline are needed to (a) catalyze efforts to determine cause; (b) arrest any human activities responsible and (c) advance proactive restoration planning as disturbed sites become habitable. Recently, while describing the historical antecedents of the sudden and complete loss of the seagrass, Zostera marina, from small embayments in Northern Puget Sound, Washington, we have detected a times series variation in patch structure that could potentially signal the local extinction event that followed population decline. Fundamental to our approach is an a priori assumption that the size and shape of seagrass patches and the unvegetated bottom separating these patches should be evaluated in the change analysis matrix. Using a set of landscape analysis tools, we have investigated the relative contribution of disturbance events, including hydrodynamic influence, on seagrass persistence or loss. We discuss the application of our findings for the analysis of landscape scale changes observed in other seagrass species.

91. Rowell et al. 2005. See GEODUCK

92. Ruesink, J. and S. Hacker. *In Progress*. Scale-dependent and indirect effects of filter feeders on eelgrass: Understanding complex ecological interactions to improve environmental impacts of aquaculture.

- **Source** (Annual Progress Report) http://www.fish.washington.edu/wrac/pdfs/Filter%20Feeders%20and%20Eelgrass.pdf#search='Ruesink%20eelgrass'
- Potential negative effects from disturbance; potential positive effects through fertilization and improved water clarity. Willapa Bay and Puget Sound.
- **Keywords**: oyster culture, geoduck culture,

93. Ruiz, J.-M., M. Pérez, J. Romero. 2001. Effects of fish farm loadings on seagrass (*Posidonia oceanica*) distribution, growth and photosynthesis. Marine Pollution Bulletin 42(9):749-760.

- **Abstract**. The spatial extent and timing of the impact of fish farms on the distribution and performance of a *Posidonia oceanica* meadow were examined in an embayment of the south-eastern coast of Spain (Hornillo Bay, Murcia). Changes in seagrass distribution were determined using available seagrass mapping (from 1988, i.e., before the onset of aquaculture activities and 1998) and by successive sampling in 1994 and 1998. Environmental variables (light attenuation coefficient, water-column dissolved nutrients and organic content of sediments) together with plant performance (shoot biomass, leaf growth rate, photosynthetic activity, carbohydrate reserves, the number of leaves per shoot, epiphyte loads and herbivore pressure) were measured in plants affected by organic discharges, and were compared with those found in reference healthy plants over an annual growth cycle. Since the onset of fish farm activity, 11.29 ha of *P. oceanica* meadow has been completely lost and 9.86 ha significantly degraded, thus resulting in a total affected area which accounts for about 53% of the former meadow, or 7-fold the fish farming area. Unequal propagation of seagrass die-off or degradation reflects the relevance of local factors such as depth and hydrodynamism on the true extent of fish farm impact. Water transparency decreases and dissolved nutrient and organic content of sediments increases in the vicinity of cages compared to distant reference stations, thus supporting the notion of environmental gradients caused by the organic release from cages, which spreads outwards. Shoot size, leaf growth rate and the number of leaves per shoot in plants close to the fish farm decreased. Moreover, low leaf growth and low rhizome carbohydrate concentration (always relative to that found in an undisturbed area) indicated carbon budget imbalances. Since light reduction in the affected area was only modest (31% of light reaching the sea surface, while at the same depth this figure was 39% at the reference site), and light availability was well above the minimum requirement estimated for this species, neither this factor nor epiphyte overgrowth (epiphyte load was lower in the affected area) seem to explain such carbon imbalances or the observed meadow regression. Alternatively, the high herbivore pressure found in the affected zone suggests that overgrazing is one of the main causes of decreasing shoot sizes and hence of carbon imbalance, reduced growth and shoot mortality. The impact of fish farms on seagrasses, therefore, seems to be highly variable and depends on complex interactions between a large number of processes.

94. Rumrill, S.S., and V.K. Poulton. 2003. Ecological role and potential impacts of oyster culture in the estuarine environment of Humboldt Bay, CA. Presentation at '17th Biennial Conference of the Estuarine Research Federation Conference', Sept. 14-18, 2003, Seattle, Washington.

- **Source** (Abstracts only): www.erf.org/erf2003/abstracts?
- **Abstract**. Humboldt Bay, CA, is the leading producer of Pacific oysters (Crassostrea gigas) in California, but the effects of commercial oyster mariculture on tideflat habitats, eelgrass (Zostera marina) beds, and invertebrate communities are poorly studied. We established experimental oyster plots and eelgrass reference areas to evaluate alternate best management practices for long-line spacing. We sampled study plots quarterly between 2001-2003 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. One year into the study, eelgrass shoot density and percent cover were consistently highest in a 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 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 100 taxa, including known prey items for estuarine fish. Sedimentation and oyster growth measurements showed no consistent differences between experimental long-line plots. Light intensity was lower beneath oyster long-lines, but did not differ substantially between the 1.5 and 5 ft. spacing plots.

95. Rumrill, S.S., and V.K. Poulton. 2003. Ecological impacts of commercial oyster long-line culture in Humboldt Bay, CA. Pacific Estuarine Research Society. Presentations at "Applying Science and Information to Sustainability to Pacific Coast Estuaries. Meeting April 3-4, 2003, Vancouver BC. Abstracts only.

- **Source:** www.pers-erf.org/PERS_03_Program.pdf
- 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.

96. Rumrill, S.S., and V.K. Poulton. 2004. Ecological role and potential impacts of oyster culture in the estuarine environment of Humboldt Bay, California. Presentation at the Pacific Estuarine Research Society 2004 Annual Meeting, May 17-18, 2004, Port Townsend, Washington.

- **Source** (Abstracts only): http://www.pers-erf.org/PERS04Program.pdf
- Sedimentation generally increased under long-lines when oysters became large. Light intensity was highly variable beneath long-lines, but did not differ substantially between oyster plots and control sites.

97. Tallis, H. and J. Ruesink. 2004. The effects of oyster aquaculture on eelgrass (Zostera marina L.) biomass, density and growth rates in Willapa Bay, Washington. Presentation at the Pacific Estuarine Research Society 2004 Annual Meeting, May 17-18, 2004, Port Townsend, Washington.

- **Source** (Abstracts): http://www.pers-erf.org/PERS04Program.pdf
- Investigated eelgrass conditions (measured growth rate, percent cover, density of vegetative and flowering shoots) in three areas that used different methods of growing oysters (off-bottom long-line culture, dredged ground culture, handpicked ground culture) and an eelgrass control area. Found significant interaction between site and aquaculture type suggesting that site-specific conditions may be more influential than culture technique.

98. Thom, R., A.B. Borde, S. Rumrill, D.L. Woodruff, G.D. Williams, J.A. Southard, S.L. Sargeant. 2003. Factors influencing spatial and annual variability in eelgrass (*Zostera marina* L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries. Estuaries 26(4B):1117-1129.

- **Abstract --** Environmental factors that influence annual variability and spatial differences (within and between estuaries) in eelgrass meadows (*Zostera marina* L.) were examined within Willapa Bay, Washington and Coos Bay, Oregon over a period of 4 years (1998-2001). A suite of eelgrass metrics were recorded annually at field sites that spanned the estuarine gradient from the marine-dominated to mesohaline region of each estuary. Plant density (shoots m^{-2}) of *Z. marina* was positively correlated with summer estuarine salinity and inversely correlated with water temperature gradients in the estuaries. Eelgrass density, biomass and the incidence of flowering plants all increased substantially in Willapa Bay, and less so in Coos Bay, over the duration of the study. Warmer winters and cooler summers associated with the transition from El Niño to La Niña ocean conditions during the study period corresponded with this increase in eelgrass abundance and flowering. Our findings indicate that large-scale changes in climate and nearshore ocean conditions may exert a strong regional influence on eelgrass abundance which can vary annually by as much as 700% in Willapa Bay. Lower levels of annual variability observed in Coos Bay may be due to the stronger and more direct influence of the nearshore Pacific Ocean on the Coos Bay study sites. The results suggest profound effects of climate variation on the abundance and flowering of eelgrass in Pacific Northwest coastal estuaries.

99. Touchette, B.W., J.M.Burkholder, and H.B. Glascow. 2003. Variations in eelgrass (*Zostera marina* L.) morphology and internal nutrient composition as influenced by increased temperature and water column nitrate. Estuaries 26(1): 142-155.

- **Abstract** In an experimental mesocosm system, we evaluated changes in morphology and tissue nutrient content (carbon [C], nitrogen [N], phosphorus [P]) of eelgrass (*Zostera marina* L.) as influenced by increased temperature and nitrate. During the late summer-fall growing season (14 weeks, August through mid-November), control plants were compared to plants grown at elevated temperatures (3oC to4oC above ambient, based on 20-yr weekly means) and elevated water column nitrate enrichment (8 mM NO_3-, pulsed daily). Both increased temperature and increased nitrate led to declines in shoot density (by 40% and 48% for nitrate and temperature treatments, respectively), as well as decreased leaf and root production. High temperature promoted increased total C content of leaf tissues, whereas high nitrate increased the percentage of N in belowground tissues and depressed the C:N ratio in aboveground tissues. The data indicated that increases in nitrate or temperature can significantly reduce the size of *Z. marina* shoots and can also alter the internal C and N content. This reduction was not associated with significant increases in light-attenuating algae as we controlled epiphytic growth, so we suggest that a direct physiological mechanism or other mechanism was involved.

100. Ward, D.H., A. Morton, R. L. Tibbits, D.C. Douglas, and E. Carrera-González. 2003. Long-term change in eelgrass distribution at Bahia San Quintin, Baha California, Mexico, using Satellite Imagery. Estuaries 26(6):1529-1539.

- **Abstract** 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 Bahía San Quintín, Baja California, Mexico, using a map to map comparison of data interpreted from a 1987 Satellite Pour l' 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 14% less (-323 ha) in 2000 than in 1987 with most losses occurring in subtidal areas. Over the 13-year study period, there there was a 34% loss of submerged eelgrass (-457 ha) and a 13% (+134 ha) gain of intertidal eelgrass. Within the 2 types of intertidal eelgrass, the patchy cover class (<85% cover) expanded (+250 ha) and continuous cover class (>85% cover) declined (-116 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
- 34% loss of submerged eelgrass and 13% increase in intertidal eelgrass possibly due to sediment loading and turbidity from combination of much flooding in 1992-1993 and increase in upland agriculture, not thought to be due to increase in number of oyster racks from 57 to 484 during study period (1987, 2000) although maybe resolution not high enough to detect. Suggest that the concern of other authors regarding shading by culture materials maybe offset by the ability of oysters to improve water clarity by filtering sediments from the water column.
- **Keywords**: oyster racks, intertidal/submerged eelgrass, satellite image, Landsat Thematic Mapping image

101. Vandermeulen, H. 2005. Assessing marine habitat sensitivity: a case study with eelgrass (*Zostera marina* L) and kelps (*Laminaria* and *Macrocystis*). Canadian Science Advisory Secretariat, CSAS Research Document 2005/032.

- **Source:** www.dfo-mpo.gc.ca/csas/Csas/DocREC/2005/RES2005_032_e.pdf
- Hardcopy
- Primarily concerned with fish culture impacts but many references to shellfish. Will follow next year with paper focused on shellfish impacts.
- Not to be cited without permission of author.

102. Wisehart, L. and S. Hacker. 2004. A description of eelgrass (Zostera marina L.) seed production and recruitment patterns inside and outside of oyster aquaculture areas in Willapa Bay, Washington. Presentation at the Pacific Estuarine Research Society 2004 Annual Meeting, May 17-18, 2004, Port Townsend, Washington.

- **Source** (Abstracts): http://www.pers-erf.org/PERS04Program.pdf
- Seed production and seedling densities were observed in dredged and handpicked oyster ground–culture beds, long-line oyster culture areas and eelgrass control at three sites. Preliminary data suggest a positive relationship between oyster cover and eelgrass seed production and seedling density in ground cultured oyster beds.

103. Wisehart, L.M., S.D. Hacker, B.R. Dumbauld, J.L. Ruesink. 2005. Does oyster aquaculture influence eelgrass recruitment. Presentation at 'Estuarine interactions: biological-physical feedbacks and adaptations', Estuarine Research Federation Conference 2005, Oct. 16-20, 2005, Norfolk, Virginia.

- **Source** (Abstracts): www.erf.org/erf2005/abstracts/authors00.html
- Shellfish aquaculture may directly or indirectly affect eelgrass vegetative and reproductive life history stages. To better understand the influence of oyster aquaculture on eelgrass (*Zostera marina* L.), we observed seedling densities in dredged and long-line aquaculture areas as well as eelgrass control sites in Willapa Bay, Washington. We recorded the density of mature vegetative shoots, reproductive shoots, and seedlings in addition to percent cover of eelgrass and oysters. Shoot density was high in long-line aquaculture areas but seedling densities in this culture type were significantly lower than all other habitats. Beds dredged and seeded with oysters immediately preceding surveys had low shoot and seedling densities while beds one year post-harvest had the highest seedling densities. Two years post-harvest, density of mature vegetative shoots was comparable to eelgrass controls. Although eelgrass biomass in dredged beds is generally reduced immediately following harvest, these data suggest that recovery is relatively rapid, occurring within two years after disturbance.
- See also www.pers-erf.org/PERSProgram.doc for PERS 2005 annual meeting, presentation by same title and authors, but no abstracts available online.

104. Wright, N. 2005. Communities connecting to place: a strategy for eelgrass restoration in British Columbia. Prepared for Seagrass Conservation Working Group.

- **Source:** http://www.stewardshipcentre.bc.ca/eelgrass/communities_connecting_2.pdf
- Includes history of eelgrass transplants with discussion of causes of failures and criteria for success.

105. Zhang, Z. and A. Campbell. 2000. Evaluation of horse clam stock dynamics for a directed subtidal horse clam (Tresus capax and Tresus nuttallii) fishery in British Columbia. Canadian Stock Assessment Secretariat, CSAS Research Document 2000/167. 54 p.

- **Source:** www.dfo-mpo.gc.ca/csas/Csas/DocREC/2000/PDF/2000_167e.pdf
- Discussion of eelgrass depth distributions
- Not to be cited without permission of author.

106. Zimmerman, R.C., J.L. Reguzzoni, and R.S. Alberte. 1995. Eelgrass (*Zostera marina* L.) transplants in San Francisco Bay: role of light availability on metabolism, growth and survival. Aquatic Botany 51:67-86.

- Hardcopy
- Survival, metabolism and growth of *Zostera marina* L. transplants were examined along depth gradients in Keil Cove and Paradise Cove in the extremely turbid San Francisco Bay estuary. Water transparency was unusually high throughout 1989–1990 for San Francisco Bay. Transplant survival was strongly depth-dependent at Paradise Cove but not at Keil Cove. All transplants were lost below − 1.0 m depth within 1 year at Paradise Cove, but survived to depths of − 1.5 m at Keil Cove. Half the transplants growing in shallow water survived the first year at both sites. Shoot photosynthesis, respiration, growth, and sugar content did not differ between sites. Daily periods of

irradiance-saturated photosynthesis (H_{sat}) were over 6 h all year. Seasonal photosynthetic acclimation to light availability maintained long H_{sat} periods and high ratios of daily whole-plant production to respiration through the winter, indicating a potential for net carbon gain throughout the year. Winter growth was 50% of the summer rate. Despite high initial losses, surviving transplants have persisted at both sites through 1994. Although eelgrass transplants can succeed in San Francisco Bay given sufficient light availability, the role of carbon reserves and transplant timing may influence transplant survival.

- **Author Keywords:** Seagrass; Transplant; Photosynthesis; Carbon budget; *Zostera marina*

FinFish

107. Brehmer, P., Gerlotto, F., Guillard, J., Sanguinède, F., Guénnegan, Y. and Buestel, D. 2003. New applications of hydroacoustic methods for monitoring shallow water aquatic ecosystems: the case of mussel culture grounds. Éditions scientifiques et médicales Elsevier SAS and Ifremer/IRD/Inra/Cemagref.

- The development of acoustics tools and methods for monitoring anthropized ecosystems represents a new field for the application of acoustics. Monitoring such an environment was not possible with single vertical echo sounders, due to the fact that the artificial structures and the natural targets were not distinguishable. Monitoring data were collected along the French Mediterranean coastline, during five short surveys of mussel culture longline areas. Both the *Reson Seabat 6012* multibeam sonar (455 kHz) and the *Simrad SR 240* omnidirectional sonar (23.75 kHz) were used for target detection. The former tools allow accurate allocation of the different types of echoes to artefacts, fish schools and scattered fish. The school characteristics collected included morphological, geographical (GPS, school location), and behavioural (connections with the longlines). An acoustic survey undertaken with the same hardware near the study area allowed the comparison of fish schools and the TS distribution of individual fish in the open sea and in the mussel area. These data permitted us to evaluate the ecological impact of a mussel culture on the ecosystem, in a context of predation behaviour of fish on these longlines. Finally, the acoustic data revealed the configuration of each concession and the level of charge of each line.We discuss the applicability of this technology for in situ real time monitoring for joint management of such ecosystems. The information can allow littoral cooperative management or incorporating it into an

ecosystem approach.

- *Keywords:* Multibeam sonar; Monitoring; Fish school; Mussel longline; Artificial reef; Ecosystem
- hardcopy

108. Coen, et al.,1999. See OYSTER.

109. Cole, R. 2002. Impacts of marine farming on wild fish populations. Final Research Report for Ministry of Fisheries Research Project ENV2000/08 Objective one. Prepared for National Institute of Water and Atmospheric Research.

- Pdf A review of the literature. Lots of documentation for New Zealand studies as well as international ones.

110. Hosack, G., D. Armstrong, B. Semens, B. Dumbauld, S. Rumrill. 2001 . Oyster aquaculture as fish habitat in Pacific Northwest coastal estuaries. School of Aquatic and Fishery Sciences, Seattle, WA. Presented at the 55th Annual Conference of the Pacific Coast Shellfish Growers Association and the National Shellfisheries Association – Pacific Coast Section. Sept 20-21, 2001. (CI - Emmett, 2002)

- See also Hosack *et al* 2003 in EELGRASS: Pacific Estuarine Society

111. Thuringer, P. (Archipelago Marine Research Ltd.). 2003. Documenting Pacific sand lance *(Ammodytes hexapterus)* spawning habitat in Baynes Sound and the potential interactions with intertidal shellfish aquaculture. Draft prepared for J. Truscott, Coast and Marine Planning Office, BC Ministry of Sustainable Resource Management. 32 p + app.

Source: http://srmwww.gov.bc.ca/rmd/coastal/south_island/baynes/docs/sandlance/Baynes_sandlance_%20draftreport. pdf

- Hardcopy, pdf
- Minimal effects due to clam netting;
- No overlap between clam netting and potential sand lance spawning habitat because occupy different elevations; Farmed clams below +2.5 m and sand lance spawn above +2.6 m;
- Report sediment grain size info for designating potential sand lance spawning grounds;
- Timing of sand lance spawning in Bayne Sound Nov 14 to Feb 16;
- Possible conflict between vehicle use on beach and sand lance spawning habitat;
- Sediment at aquaculture sites (except south Metcalf Bay) studied had grains size too fine for sand lance spawning.

Geoducks

112. Entrix, Inc. 2004. Programmatic Biological Evaluation of Potential Impacts of Intertidal Geoduck Culture Facilities to Endangered Species and Essential Fish Habitat. Taylor Shellfish, Seattle Shellfish, and Chelsea Farms Culture Facilities (DRAFT)

- hardcopy

113. Feldman K, Vadopalas B, Armstrong D, Friedman C, Hilborn R, Naish K, Orensanz J, Valero J, Ruesinck J, Suhrbier A, Christy A, Cheney D, Davis JP (2004) Comprehensive literature review and synopsis of issues relating to geoduck (*Panopea abrupta*) ecology and aquaculture production. Washington State Department of Natural Resources, Olympia. [note from C. Pearce, DFO]

114. Fleece C, Waller D, Fisher J, Vaderpham J, Reub G (2004) Programmatic biological evaluation of potential impacts of intertidal geoduck culture facilities to endangered species and essential fish habitat. Report Prepared for Taylor Shellfish, Seattle Shellfish and Chelsea Farms by Entrix Inc. [note from C. Pearce, DFO]

115. 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 , CSAS, Research Document – 2004/131.

Source: http://www.dfo-mpo.gc.ca/csas/Csas/Publications/ResDocs-DocRech/2004/2004_131_e.htm

- Hardcopy
- Impact discussion mostly confined to impact of aquaculture on wild fishery, with note on limited impacts via to sediment changes during harvesting but encourage monitoring.

116. Christopher M. Pearce Research Scientist / Chercheur Scientifique Fisheries and Oceans Canada / Pêches et Océans Canada PBS

- Pers. Comm. We have an intertidal geoduck project in Nanoose Bay which is currently underway. Part of the project is examining potential effects on a nearby eelgrass bed. We are looking at eelgrass shoot density, shoot length, shoot mass, and bed area. Our experimental plot is quite small though and I would be surprised if there were any negative effects on the eelgrass. I don't think that we will have any results ready until early/mid 2007.

117. Rowell, K., J. White, and J. Ruesink. 2005. Influences of geoduck aquaculture on eelgrass. University of Washington. Abstract in Proceedings of the 2005 Puget Sound Georgia Basin Research Conference.

- pdf.

118. Ruesink, et al., *In Progress*. See EELGRASS

119. State of Washington, Department of Natural Resources. 1992. The Transport and Fate of Suspended Sediment Plumes Associated with Commercial Geoduck Harvesting. Final Report.
    - Hard copy.
    - 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. Not found.

Hard bottom/Rocky Reef

120. Glasby, T.M. 1998. Estimating spatial variability in developing assemblages of epibiota on subtidal hard substrata. Marine and Freshwater Research 49:429-437.
    - **Abstract.** A nested hierarchical sampling design was used to estimate the scales of natural variability in developing assemblages of subtidal epibiota on rocky reefs. The appropriate spatial scales were needed for sampling to test for environmental impact in this habitat. Sandstone settlement plates were used to mimic the natural substratum. They were designed and deployed in such a way that the effects of any supporting structures were minimized. Differences in recruitment of epibiota were found at all of the spatial scales examined (10s, 100s and 1000s of metres). When differences were found at the smallest spatial scale, they were generally still detected at the two larger scales. The results highlighted the need for adequate small- and large-scale spatial replication for studies of environmental impact.
    - **Keywords:** spatial scale, sessile organisms, fouling, environmental impact assessment, Australia

121. Glasby, T.M. 1999. Effects of shading on subtidal epibiotic assemblages. Journal of Experimental Marine Biology and Ecology 234:275-290.
    - **Abstract.** Mensurative and manipulative experiments were done to test hypotheses about the effects of shading on subtidal assemblages of epibiota. Previous studies found large differences in the composition of epibiotic assemblages on pier pilings (shaded by boats and wharves) and adjacent rocky reefs at marinas in Sydney, Australia. Different degrees of shading were proposed to explain the differences between assemblages on these two substrata. Assemblages of epibiota on free-standing, unshaded pilings were sampled and, as predicted, found to be different from those on shaded pilings and similar to those previously described on rocky reefs. Unshaded pilings were covered primarily by filamentous and foliose algae and spirorbid polychaetes. Patches on these unshaded pilings were then experimentally shaded to test the hypothesis that increased shading would result in the assemblages changing to become like those on permanently shaded pilings. After shading patches for 9 months, the composition of assemblages changed compared to controls and taxa such as bryozoans (*Fenestrulina mutabilis*), serpulid polychaetes, solitary ascidians (*Styela plicata*) and sponges became common. Results suggested that different degrees of shading could explain differences in the cover of many epibiota growing on pier pilings and adjacent rocky reefs at marinas. Other factors that may be important in structuring subtidal epibiotic assemblages are also discussed.
    - **Author Keywords:** Artificial habitats; Environmental impact; Fouling; Light; Marinas; Shade

122. McConnell, M.L., P. Dinnel, I. Dolph, J. Robinette, D. Semrau. 2001. Rocky reef bottom fish recovery in Skagit County. Skagit County Marine Resources Committee.
    - Source: http://www.nwstraits.org/annualreport01/O_Skagit_AG_Report.pdf

123. Reefkeepers http://www.keepersweb.org/Reefkeepers/

124. Fox, D., A. Merems, M. Amend, H. Weeks, C. Romos, M. Appy. 2004. Comaprative characterization of two nearshore rocky reef areas: a high-use recreational fishing reef vs. an unfinished reef. Oregon Department of Fish and Wildlife, Marine Program, Marine Habitat Project. Final report prepared for U.S. Fish and Wildlife Service.
    - Source: http://hmsc.oregonstate.edu/odfw/reports/

Mussels

125. Baudinet, D., E. Alliot, B. Berland, C. Grenz, M.-R. Plante-Cuny, C. Salen-Picard. 1990. Incidence of mussel culture on biogeochemical fluxes at the sediment-water interface. Hydrobiologia 207(1):187-196.
    - **Abstract** Upward nutrient fluxes at the sediment-water interface were studied in a mussel farming zone (Carteau, Gulf of Fos, France) in order to estimate the impact of organic matter input from biodeposition. Nitrate, nitrite, ammonia, silicate, phosphate and oxygen were measured. Fluxes were estimated by means of polyacrylate benthic chambers placed at sites located under (UM) and outside (OM) the rope hanging structures. Transformation of biodeposited organic matter increases phosphate, silicate and ammonia fluxes. No variation in nitrite fluxes could be detected and only minor differences were observed in nitrate and the oxygen production/consumption equilibrium at the two stations. Phosphate and silicate fluxes, which were always higher at the UM than at the OM site, decreased from spring to winter. Ammonia fluxes were very high under mussel cultures in May and September and lower in November. The fact that ammonia flux was always higher at the UM than at the OM sites might be explained by degradation of mussel biodeposit, as well as by benthic macrafauna excretion. Discrepancies between fluxes of the nutrients studied at the UM and OM sites increased as organic particulate matter in the water column decreased. Variations of oxygen flux followed a different pattern, since they were correlated with presence and abundance of photosynthetic microphytes on the bottom and in the water. Bottom respiration exceeded production of oxygen only in May 1988 at the UM station.
    - As it now stands, biodeposit input into the sediment under mussel ropes does not affect the ecosystem, although the flow of nutrients towards the water column is higher than in other areas.

126. Butler, D.J. 2003. Possible impacts of marine farming of mussels (*Perna canaliculus*) on king shags (Leucocarbo carunculatus). DOC Science Internal Series 111. Department of Conservation, Wellington. 29 p.
    - **Source:** http://www.doc.govt.nz/Publications/004~Science-and-Research/DOC-Science-Internal-Series/PDF/DSIS111.pdf
    - Although this is primarily concerned with birds, it has an excellent review of the literature (much of it unpublished) on various aspects of environmental impacts of mussel culture. New Zealand.

127. Chamberlain, J., T.F. Fernandes, P. Read, T.D. Nickell, I.M. Davies. 2001. Impacts of biodeposits from suspended mussel (*Mytilus edulis* L) culture on the surrounding surficial sediments. ICES Journal of Marine Science 58:411-416.
    - Hardcopy
    - Ireland; greater effects seen at older farm explained possibly due to current patterns, although Crawford (2003?) suggests it's due to age of farm.
    - **Abstract**. The effects of increased sedimentation on the macrobenthic community, physical structure, and biogeochemistry of the surficial sediment around two farms in southwest Ireland were examined in conjunction with current characteristics. Both farms had been in production for over eight years, were of reasonably large size (>100 MT) and located in low-energy environments. At one site, the benthic community was subjected to bulk sedimentation and organic enrichment and reduced macrobenthic infaunal diversity and elevated levels of organic carbon were recorded close to the farm. In general, effects were restricted to a radius of 40 m around the farm. Conversely, at the second site, there were no observed effects of mussel biodeposits on the benthos and a diverse

macrobenthic community persisted. We propose that variations in the dispersion of biodeposits caused by local current patterns had a significant influence on the impact observed, and that this could also account for differences reported in other studies.

- Author Keywords: benthic impacts, biodeposition, mussel culture

128. Christensen, P. B., Glud, R.N., Dalsgaard, T., Gillespie, P. (2003). "Impacts of longline mussel farming on oxygen and nitrogen dynamics and biological communities of coastal sediments." Aquaculture 218: 567-588.

129. Dahlbäck, B. and L.Å.H. Gunnarsson. 1981. Sedimentation and sulfate reduction under a mussel culture. Marine Biology 63(3):269-275.

- **Abstract** The sedimentation and dissimilatory sulfate reduction under a blue-mussel culture were quantified in order to gain information on the environmental impact of intense mussel farming. The sedimentation rate (3 g C ·m-2 ·d-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°C the sulfate reduction rate was 30.5 mmol SO = 4 ·m-2 ·-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.

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

- Identified not obtained

131. Danovaro, R., C. Gambi, G.M. Luna, and S. Mirto. 2004. Sustainable impact of mussel farming in the Adriatic Sea (Mediterranean Sea): evidence from biochemical microbial and meiofaunal indicators. Marine Pollution Bull., 49(4): 325-333.

- **Abstract**. We have investigated the impact of a large mussel farm on the benthic environment using a battery of benthic indicators of environmental quality (including biochemical, microbial and meiofaunal parameters). These were analysed through a multi-control sampling strategy over one year. The differences across the seasons are typically higher than those between the impacted and the control stations. No effects are seen in terms of the sediment oxygen penetration and the downward fluxes (as the total mass, organic and phytopigment fluxes). The indicators based on the biochemical compositions of the sediment organic matter and the microbial parameters also show no evidence of the eutrophication process, except as a slight increase in the bacterial density in the sediments beneath the long-lines of the farm during the period of highest mussel stocks. Finally, no effects are observed in terms of the benthic faunal indicators, as the meiofaunal abundance, the community structure and the taxa richness are all indistinguishable between the farm sediments and the controls. These results show that mussel farming in the investigated system is eco-sustainable and does not significantly alter the coastal marine ecosystem, both in terms of the functioning and the trophic state. The battery of indicators selected in this study represents a useful tool for the monitoring of the potential ecological impact of mussel farms, towards guaranteeing the sustainable development of aquacultures in shallow coastal environments.
- **Keywords:** Bio-indicators; Aquaculture; Mussel farms; Sediment organic matter; Microbial indicators; Meiofaunal indicators
- Found no effects on a variety of benthic parameters including benthic faunal indicators, except slight increase in bacterial density in sediments during highest mussel stocking of longlines. Conclude that the system studied was eco-sustainable. Have abstract only.

132. Freire, J., and E. González-Gurriarán. 1995. Feeding ecology of the velvet swimming crab *Necora puber* in mussel raft areas of the Ría de Arousa (Galicia, NW Spain). Marine Ecology Progress Series 119:139-154.

- Abstract available at http://www.int-res.com/abstracts/meps/v119/p139-154/

133. Gibbs, M. 2004. Sustainability performance indicators for mussel farms. Cawthron Report No. 892. 18 p.

- Hardcopy.
- Executive Summary. Investigations into ecological interactions between suspended bivalve farms and the marine environment generally focus on effects to the seafloor beneath farms. By contrast, there has been increasing emphasis over the last decade for farmers and regulators to quantify interactions occurring in the water-column. For example, feedback from the industry and regulatory stakeholders in New Zealand, a significant bivalve producer, demonstrates a general lack of understanding about these interactions, and how to measure and assess them. Hence it is appropriate to attempt to define a common methodoloty for assessing these interactions. An appropriate way to achieve this is through the development of environmental performance indicators. This work firstly describes the ecological role of bivalve farms and the possible ecological costs of having suspended bivalve culture, before defining a set of ecological sustainability performance indicators (clearance efficiency, filtration pressure, regulation ratio, depletion footprint).

134. 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. Estuaries 18(1A): 124-144.

- **Source:** http://estuaries.olemiss.edu/cdrom/ESTU1995_18_1A_124_144.pdf
- Nova Scotia mussels; cited in Crawford et al, 2003
- **Abstract --** 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. Due to deposition of mussel feces and pseudofeces, sedimentation rate was higher under the mussel culture lines than at an adjacent reference site of similar sediment texture. Porewater profiles of sediment sulfate and sulfide indicated greater anaerobic metabolism at the mussel site than at the reference site, but sulfide was absent from the upper centimeters of sediments under the mussels. Seasonal measures of sediment oxygen demand showed little change between sites, but maximum rates of ammonium release at the mussel site were twice the highest rates measured at the reference site. Abundance of benthic macrofauna was higher at the reference site, but biomass was generally lower. Biomass at the mussel site was dominated by molluscs (*Ilyanassa* spp. and Nucula tenuisulcata), that were attracted to mussels fallen from the culture and/or enriched organic matter due to biodeposition. Species diversity was lower at the reference site due to the dominance of the polychaete *Nephtys* neotena. Abundance-biomass comparisons (ABC method) of faunal analysis did not indicate any impact of biodeposition at this site; however, disturbance did not result in a typical assemblage of small opportunistic species anticipated with this method. Cluster analysis of macrofauna usually provided a clear separation between the 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.

135. Gillespie, P. 1989: The impact of long-line mussel culture on benthic habitat. Unpublished Cawthron Client Report 1638 for Coastal and Marine Resources Directorate, Department of Conservation, Wellington.

- Identified paper but unable to obtain as of current

136. Harstein, N.D. and A.A. Rowden. 2004. Effect of biodeposits from mussel culture o macroinvertebrate assemblages at sites of different hydrodynamic regime. Marine Environmental Research 57(5):339-357.

- **Abstract.** The present study examined for differences in macroinvertebrate assemblage composition inside and outside of mussel farm sites experiencing different hydrodynamic regimes. Multivariate analysis revealed that there were significant differences in macroinvertebrate assemblage composition (averaged across seasons) between

samples taken inside and outside of the two relatively low energy sites, whilst no such difference was observed for the relatively high energy site. Taxa that best disciminated between the dissimilarities observed in macroinvertebrate assemblage composition inside and outside farms were principally polychaetes (more abundant inside) and ophiuroids (more abundant outside). Sediment total organic matter and number of mussel shells were the parameters that best explained the difference in macroinvertebrate assemblage observed at the two relatively sheltered farm study sites. No taxa or environmental variables were particularly good at discriminating or explaining differences observed inside and outside the relatively high energy farm site. The present study indicates there is a relationship between the hydrodynamic regime of a farm site, organic enrichment of seabed sediments by mussel biodeposits, and a subsequent modification of the macroinverebrate assemblages. This finding has implications for the siting of mussel farms in coastal environments.

- **Author Keywords:** Biodeposits; Mussel farms; Macroinvertebrate assemblage; Organic enrichment

137. Harstein, N.D. and C.L. Stevens. 2005. Deposition beneath long-line mussel farms. Aquacultural Engineering 33(3):192-213.

- Current meter data, biodeposit settling velocity, turbulent diffusivity and water depth were combined to model the initial depositional distribution of faecal and pseudofaecal pellets at three aquaculture farm sites in sheltered to exposed environments in the Marlborough Sounds. Model results were compared with seabed sediment samples collected at each site. At the sheltered sites, comparison of the modelled dispersal pattern and seabed identification of mussel biodeposits using sedimentological data indicated a very close association. Both were found to reduce to natural levels approximately 30–50 m from the farm site. Such similarity between the model and observed distribution of the mussel biodeposits suggested that, once deposited on the seabed, the biodeposits remain immobile due to the low hydrodynamic energy of the two sites. In contrast, the exposed site had only a poor correlation between the dispersal model and identification of mussel biodeposits on the seabed. The dispersal model indicates that the majority of mussel biodeposits initially accumulate within 50 m of the farm. However, observations found no sign of any mussel biodeposits in sediment beneath or up to 200 m from the farm boundary. This lack of biodeposits indicates that there is at times sufficient energy to re-suspend mussel biodeposits and to disperse these deposits over a wide enough area thereby leaving little impact on the natural sediment.
- **Keywords:** Mussel farms; Biodeposits; Modelling; Diffusion

138. Hatcher, A., J. Grant, and B. Schofield. 1994. Effects of suspended mussel culture (*Mytilus* spp.) on sedimentation, benthic respiration and sediment nutrient dynamics in a coastal bay. Mar. Ecol. Prog. Ser. 115: 219-235

139. 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 Kenepura Sound, Marlborough Sounds, New Zealand. Marine Biology 85: 127-136.

- Hardcopy
- **Abstract** Nitrogen pools and transformations and benthic communities at a *Perna canaliculus* farm and a nearby reference site without direct influence of marine farming in Kenepuru Sound, New Zealand, were compared on four dates between September 1982 and May 1983. The organic nitrogen pool in the top 12 cm sediment was 7.4 to 10.8 mol m-2 at the mussel farm and 6.1 to 8.9 mol m-2 at the reference site. The nitrate and nitrite pools were similar in both sediments, but the ammonium pool in the mussel farm sediment was about twice as high as in the reference sediment. In January, the sediment ammonium concentrations ranged from 418 nmol cm-3 (surface) to 149 nmol cm-3 (12 cm depth) at the mussel farm and from 86 to 112 nmol cm-3 at the reference site. The molar C:N ratio of the sediment organic matter was 6.2 to 7.2 at the mussel farm and 7.9 to 10.0 at the reference site. The molar N:P ratio of the sediment organic matter was 4.3 to 7.2 and 3.3 to 6.1 at mussel farm and reference site, respectively. The total nitrogen mineralisation rate in the top 12 cm sediment ranged from 21.7 to 37.1 mmol m-2 d-1 at the mussel farm and from 8.5 to 25.0 mmol m-2 d-1 at the reference site. Ammonium excretion by mussels was about 4.7% (January) and 7.4% (May) of the combined nitrogen mineralisation by mussels

and sediment. The sediment-denitrification rate was 0.7 to 6.1 mmol m-2 d-1 at the mussel farm and 0.1 to 0.9 mmol m-2 d-1 at the reference site. In January, 76 and 93% of the nitrate reduced in the sediments were denitrified at the mussel farm and reference site, respectively. The denitrification rate on the mussel lines (determined on detritus-covered mussels) was twice the mussel farm sediment-denitrification rate and 10 times the reference sediment-denitrification rate. Total denitrification at the mussel farm was 21% higher than at the reference site. The loss of nitrogen through mussel harvest and denitrification was 68% higher at the mussel farm. The surface layers of both sediments contained about 75 mg m-2 chlorophyll *a*. Sediment phaeophytin levels were 52 mg m-2 at the reference site and 137 mg m-2 at the mussel farm. While the benthic infauna of the mussel-farm sediment consisted only of polychaete worms, the reference sediment contained also bivalve molluscs, brittle stars and crustaceans.

140. Lawrence, J.E., J. Grant, M.A. Quilliam, A.G. Bauder, A.D. Cembella. 2000. Colonization and growth of the toxic dinoflagellate *Prorocentrum lima* and associated fouling maroalgae on mussels in suspended culture. Marine Ecology Progress Series 201:147-154.

- Abstract available at http://www.int-res.com/abstracts/meps/v201/p147-154/

141. Lindahl, O. R. Hart, B. Hernroth, S. Kollberg, L-O. Loo, L. Olrog, A-S. Rehnstam-Holm, J. Svensson, S. Svensson and U. Syversen. 2005. Improving marine water quality by mussel farming: A profitable solution for Swedish society. Ambio 34(2):131-138.

- pdf in Os/
- **Abstract** 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.
- The effect of mussel farming on nitrogen cycling in a Swedish fjord was a 20% reduction in the net transport of nitrogen at the fjord mouth. Hypothesize use of mussel farming in controlling coastal eutrophication.

142. Lloyd, B.D. 2003. Potential effects of mussel farming on New Zealand's marine mammals and seabirds: a discussion paper. Department of Consevation. Wellington. vii + 34 p.

- pdf
- Defines needs for research into phytoplankton dynamics, benthic interactions, hydrodynamics, and cummulative effects

143. McKinnon, L.J., G.D. Parry, S.C. Leporati, S. Heislers, G.F. Werner, A.S.H. Gason, G. Fabris, and N. O'Mahony. 2003. The environmental effects of blue mussel (*Mytilus edulis*) aquaculture in Port Phillip Bay. Fisheries Victoria Research Report Series No.1. 37 p.

- **Source:** www.dpi.vic.gov.au/fishing Follow the links Managing Fisheries, Management plans and Strategies, Eastern Port Phillip Bay Aquaculture Fisheries Reserves Management Plans. Hardcopy.
- Assessed impact on benthos sediments and fauna beneath and at 5, 25, and 50 m distance from a 3 ha mussel farm: sediment particle size, redox potential values, % total organic carbon, spacial analysis of infaunal communities,

species diversity and richness. Conclude low impact probably due to relatively low production level (15-30 t/ha/year).

144. Miron, G., T. Landry, P. Archambault, and B. Frenette. 2005. Effects of mussel culture husbandry practices on various benthic characteristics. Aquaculture 250(1-2):138-154.

- **Abstract** Sediments and macroinvertebrate diversity underneath suspended mussel lines were examined in a shallow water system in Prince Edward Island, Canada. The objectives of the study were to describe the benthic environment in a typical mussel farm from eastern Canada and to underline various relationships between benthic parameters and husbandry practices. Benthic parameters included granulometry of the sediments, organic matter and sulfide contents as well as redox potential and common macroinvertebrate diversity indices. Husbandry operation parameters investigated were the number of years of operation and mussel culture density for a given lease. The results did not show any particular spatial patterns. The sediments' mud content varied between 96 and 100%. Redox potential varied between □150 and 250 mV while sulfide concentration ranged between 100 and 9500 □M. Organic matter content varied between 1 and 16%. A total of 31 species were identified. Diversity indices were small throughout the study site. The number of years of operation for a given site varied between 0 (control sites) and 16 years while mussel culture densities ranged between 0 (control sites) and 0.70 kg/m2. Overall, no strong relationship was underlined between benthic parameters and studied husbandry practices. BIOENV analyses showed that culture density explained a small proportion of the benthic assemblages variability underneath mussel lines when using the macroinvertebrate abundance data set (r = 0.137). Similar analyses showed that water depth better explained the variability observed under mussel lines when using the macroinvertebrate presence/absence data set (r = 0.263). The absence of a strong relationship between husbandry practices and the studied benthic parameters might be related to the oceanographic characteristics and land-based activities associated with the water system rather than direct and cumulative effects of mussel culture.
- **Keywords:** Mussel culture; Blue mussel; *Mytilus edulis*; Biodeposition; Benthic impact; Sediment characteristics; Diversity; Benthic assemblages
- PEI. Suspended mussel longlines. Sediment parameters (granulometry, organic matter, suphide content) and macroinvertebrate diversity in benthos. Husbandry operation parameters were number of years (0-16) in operation and mussel culture density. No strong relationships between husbandry practices and benthic parameters; small proportion of benthic assemblage variability (macroinvertebrate abundance) explained by culture density. Water depth better explained macroinvertebrate presence/absence. Note that absence of strong relationship between husbandry practices and the studied benthic parameters may be more related to (confounded by?) oceanographic characteristics and land-based activities associated with the water system rather than the direct and cumulative effects of mussel culture. Have abstract only.

145. Mirto, S., T. La rosa, R. Danovaro, and A. Massola. 2000. Microbial and meiofaunal response to intensive mussel-farm biodeposition in coastal sediments of the western Mediterranean. Marine Pollution Bulletin 40(3):244-252.

- **Abstract.** We studied the impact of organic loads due to the biodeposition of a mussel farm in a coastal area of the Tyrrhenian Sea (Western Mediterranean). Sediment chemistry, microbial and meiofaunal assemblages were investigated from March 1997 to February 1998 on monthly basis at two stations: the first was located under the mussel farm, while the second was at about 1-km distance and served as control. Benthic response to changes in the biodepositional regime was investigated in terms of biochemical composition of the sedimentary organic matter, phytopigment content, bacterial abundance and composition and meiofaunal community structure. A large accumulation of chloroplastic pigments, proteins and lipids was observed under the mussel farm. Such changes in the sedimentary conditions reflected the accumulation of faeces and pseudo-faeces and led to the creation of reducing conditions. Microbial assemblages beneath the mussel cultures increased their densities and displayed, when compared to the control, a larger cyanobacterial importance associated to a strong decrease of the picoeukaryotic cell density. Farm sediments displayed significant changes in meiofaunal density: turbellarian, ostracod and kinorhynch densities decreased significantly, while copepods remained constant or increased possibly profiting of the enrichment in microphytobenthic biomass associated to mussel biodeposits. The comparative

analysis of the mussel biodeposition and fish-farm impact on sediments beneath the cultures revealed that mussel farms induced a considerably lower disturbance on benthic community structure.

- **Author Keywords**: mussel farm; bacteria; cyanobacteria; picoeukaryotes; meiofauna; Mediterranean Sea

146. 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.

- **Abstract** 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 O2 m−2 h−1; 1.59 ± 0.47 mmol NH4+ m−2 h−1 and 94 ± 42 μmol PO43− 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 m2 h−1 and to regenerate inorganic nitrogen and phosphorus at rates of 8.5 and 0.3 mmol m2 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.

147. Rensel, M., J. Elliott, and P. Wimberger. 2005. Will the introduced mussel *Mytilus galloprovincialis* outcompete the native mussel *M. trossulus* in Puget Sound? A study of relative survival and growth rates among different habitats. *In* Proceedings of the 2005 Puget Sound Georgia Basin Research Conference. On CD

- Mg and Mg-Mt hybrids abundant on floating docks and at low frequencies in the intertidal zone and in areas of low salinity. Mg had higher survival and growth rates than Mt in all experimental areas except the high intertidal.

148. Showalter, S. 2006. Mussel byproducts from harvesting rafts are not pollutants. Association to Protect Hammersley, Eld, and Totten Inlets v. Taylor Resources, Inc., 299 F.3d 1007 (9th Cir. 2002).

- http://www.olemiss.edu/orgs/SGLC/SandBar/1.2mussels.htm
- "The ninth Circuit Court of Appeals recently ruled that mussel harvesting facility in Puget Sound did not violate the Clean Water Act by operating without a discharge permit. The court adopted a narrow interpretation of the term "pollutant", excluding the natural by byproducts of mussels grown utilizing harvesting rafts."

149. Stenton-Dozey, J.M.E, L.F. Jackson, and A.J. Busby. 1999. Impact of mussel culture on macrobenthic community structure in Saldanha Bay, South Africa. Marine Pollution Bulletin 39:357-366.

- **Abstract.** The impact of raft mussel-culture in Saldanha Bay, South Africa on macrobenthic community structure (abundance and biomass) was studied. Sampling was conducted in January between 1993 and 1996 to assess: (1) the composition of macrobenthos below rafts relative to outside the farm; (2) effects of raft position and age

within the farm; and (3) recovery rate of benthos after raft removal. Analyses included ABC plots, hierarchical clustering and species diversity indices. Disturbed communities were found under 78% of raft sites sampled. The level of disturbance (Warwick Statistics) and the dominant opportunistic species (Bray–Curtis Similarities) changed from year to year, polychaetes and scavenging gastropods being most common. The degree of disturbance appeared related to raft sites positioned in the middle of the farm rather than raft age. Whereas ABC plots and hierarchical cluster analyses best identified the disturbance of benthic communities, diversity indices detected marginal recovery four years after raft removal. Although deposit feeders dominated all sites, suspension feeders increased in number and biomass at reference sites. This study presented a "yes/no" scenario that will be addressed in subsequent research in the modelling of culture ecosystems.

- **Author Keywords:** abundance; biomass; community disturbance; macrobenthos; mussel culture; sedimentation

150. Stenton-Dozey, J., T. Probyn, and A. Busby. 2001. Impact of mussel (*Mytilus galloprovincialis*) raft-culture on benthic macrofauna, in situ oxygen uptake, and nutrient fluxes in Saldanha Bay, South Africa. Can. J. Fish. Aquat. Sci. 58(5): 1021-1031.

- **Abstract:** Culture of the mussel *Mytilus galloprovincialis* in a South African bay created organic enrichment and anoxia in sediments. Particulate organic matter (POM) was high under rafts versus the references, especially in the first 10 cm (C=7.5 versus 0.4%, N=0.7 versus 0.08%). Total reducible sulphides (TRS) increased threefold downcore (from 0.04 to 0.12%). High C:N ratios (12–15) indicated accumulation of refractory POM, derived mainly from faeces and decaying mussels and foulers. Although O2 uptake by raft sediments was the lowest, rates could not conclusively be separated from the references. Ammonium dominated N efflux, the highest and most variable rates being under mussels (825 ± 500 μmol NH4 ·m–2 ·h–1). Phosphate efflux (25–140 μmol ·m–2 ·h–1) could not be ascribed to culture biodeposition, but there was an inconclusive trend for the molar N:P ratio to be highest in these sediments. Macrofauna biomass was reduced and trophic groups and taxa altered. Under rafts, macrofauna and organic debris were linked to O2 uptake rates, whereas at the reference sites, macrofauna appeared to be the major O2 consumer. It was concluded that POM and TRS in sediment as well as macrofauna biomass, and potentially molar N:P ratios, were more sensitive indicators of benthic impact from mussel culture than O2 uptake rates or nutrient fluxes

151. Tenbrinke, W.B.M., P.G.E.F. Augustinus, G.W. Gerger. 1995. Fine-grained sediment deposition on mussel beds in the oosterschelde (The Netherlands), determination from echosoundings, radio-isotopes and biodeposition field experiments. Estuarine, Coastal and Shelf Science 40(2):195-217.

- Abstract. Sedimentation rates of 5–20 cm year□1 were calculated from 137Cs+134Cs activity profiles and echosoundings in a mussel cultivation area in the western part of the Oosterschelde. Sedimentation rates based on 210Pb activity profiles are far too low, mainly due to the deposition of 'aged' sediment, i.e. sediment eroded elsewhere inside the basin and not fully enriched with 210Pb at the moment of deposition. Also, specific adsorption to the finest sediment components, mixing, winnowing, and mobilization of the caesium have affected the lead and caesium profiles. Field experiments on mussel plots showed that mussels deposit 5–10 cm of fine-grained sediment during the summer. This biodeposition about equals the settling from flocculation in the water column. Micro-fabric microscope studies revealed that pellets do not dominate the sediments, indicating that some of the pellets are broken down or resuspended.

152. Tenore, K.R. and N. González. 1975. Food chain patterns in the Ría de Arosa, Spain: an area of intense mussel aquaculture. 10th European Symposium on Marine Biology, Ostend, Belgium, Sept. 17-23, 1975. Vol. 2:601-619.

- **Abstract**. The Rías of Galicia in northwest Spain, particularly the Ría de Arosa, are among the world's greatest producers of commercially-valuable shellfish, especially by raft culture of the edible mussel. We have investigated the nutrient conditions and biota of the Ría de Arosa to understand: 1) the role of nutrient intrusion and upwelling and concomitant primary productivity and 2) the effect of the intense mussel culture on food chain patterns.

- The Ría de Arosa is in reality an oceanic system with coastal wind patters and the stratigraphy of the ría causing displacement upwelling of nitrate-rich oceanic water. This periodic upwelling results in high primary productivity and phytoplankton standing crops that support the large mussel culture.
- Surveys of the mussels and associated epifauna and infaunal benthos indicate that the three dimensional raft culture provides habitat and that the associated food resource of mussels biodeposits provides a food resource that enhances secondary production in the ría. The food chain pattern of the ría appears to effectively exploit the primary production and the detritus produced by the mussels supports a great production of macrobenthic epifauna that in turn are fed upon by fish and crab populations.

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- **Abstract**. Experimental mussel seafarming activities were initiated in the Baie de Plaisance, Magdalen Islands (Quebec), insummer 2002. An environmental assessment was done prior to the beginning of these activities. Samples of sediment, and benthic macrofauna and meiofauna were collected between May 29 and July2, 2002. A current meter was positioned in proximity to the site in order to monitor the current reime between July and October 2002. This study reports on the coastal benthic communities of the Baie de Plaisance. Results will be useful for impact studies of future mussel farming activities in the Baie de Plaisance.

Oyster Culture

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155. 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. J. of Shellfish Res. 23(3):867-874.

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- Rhode Island; conclude that modified rack and bag gear for grow out of American oyster *Crassostrea virginica* has greater habitat value than shallow nonvegetated seabed in a tidal estuary, and has equal or better value to submerged aquatic vegetation (eelgrass *Zostera marina*). Habitat value as assessed from abundances of marine organisms and species diversity indices. Found increased surface area (shell, wire, and plastic mesh) and physical structure of rack and bag gear provided habitat for many organisms throughout the year, particularly early life history stages of native species of fish and invertebrates. Many good references to ecological importance of oyster and artificial reefs.
- **Keywords**: shellfish aquaculture, oyster, habitat value, submerged aquatic vegetation.

156. De Grave, S., S.J. Moore, and G. Burnell. 1998. Changes in benthic macrofauna associated with intertidal oyster, Crassostrea gigas (Thunberg) culture. Journal of Shellfish Research 17(4):1137-1142.

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157. 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 Corps of Engineers.

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159. 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 23:141-176.

- **Abstract** 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 (*Crassostrea 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 non-target 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.
- The nursery role of complex intertidal habitat including oyster aquaculture to juvenile 0+ Dungeness crab (Cancer magister) is well documented (Felman et al, 2000)' cited in Dumbauld's WRAC Project Termination Report.

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164. Forrest, B.M. and R.G.Creese. 2006. Benthic impacts of intertidal oyster culture, with consideration of taxonomic sufficiency. Environmental Monitoring and Assessment 112(1-2):159-176.

- Abstract 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 aquaculture - benthic impacts - estuary - monitoring - New Zealand - Pacific oyster - taxonomic sufficiency

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- **Abstract.** Seasonal patterns of Chl *a* in water samples, sedimentation rates (total dry weight per area per day) and content of total carbon, total nitrogen, and total phosphorus in sediment trap samples, as well as in sediment samples, were measured at several stations in Ofunato estuary, Japan. High rates of sedimentation to the bottom were observed in March and September, corresponding to elevated concentrations of Chl *a*. In the middle part of the estuary, the peaks of sedimentation rate and fluxes of chemical elements through the 20-m deep layer in September amounted to 23 g m−2d−1, 2200 mg C m−2d−1, 290 mg N m−2d−1, and 28 mg P m−2d−1, coinciding with oxygen depletion in deeper layers. Seasonal changes in sedimentation can be explained by marked increases in biodeposits from oysters cultured in the surface layers. However, no marked seasonal changes in chemical elements were found within the sediment, suggesting high degradation rates of biodeposits at the sediment–water interface. Biodeposits from culture rafts were estimated using a population dynamic model for the Japanese oyster. This model gave predictions in agreement with observed seasonal changes in biodeposition fluxes through the 20-

m layer in September, with a minimum estimation of 5.1 g m−2d−1with uniform seawater dispersion, and a maximum estimation of 390 g m−2d−1without dispersion.

- **Author Keywords:** biodeposits, Chl *a*, estuary, flux, oyster, total carbon, total nitrogen, total

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168. Lin, H.-J., T.-C. Wang, H.-M. Su, and J.-J. Hung. 2005. Relative importance of phytoplankton and periphyton on oyster-culture pens in a eutrophic tropical lagoon. Aquaculture 243(1-4): 279-290.

- **Abstract** The relative importance of biomass and productivity of phytoplankton and periphyton on oyster-culture pens was quantified from the tidal inlet to the inner region along a transect across a eutrophic tropical lagoon representing a gradient in flushing time over a complete seasonal cycle. Water flushing modified nutrient concentrations in the water column and the responses of phytoplankton and periphyton to nutrient enrichment. Nutrient concentrations were greater at sites in the inner region subject to poor flushing and lower at sites in the outer region subject to fast flushing. Phytoplankton chlorophyll *a* was greater at sites in the inner region. However, periphyton biomass decreased with increasing flushing times. Daily production rates of phytoplankton were also greater at sites in the inner region, but no significant differences in those of periphyton were observed among the study sites. On the basis of lagoon area, periphyton contributed <6% of the daily system gross production. The relative contribution of periphyton to net production was negligible when compared to that of phytoplankton. Nevertheless, there was a spatial shift in their relative contribution to the system biomass. Periphyton biomass exceeded that of phytoplankton at a well-flushed site with a large number of oyster farms available for periphyton colonization. Our results clearly demonstrate the modifying effects of tidal flushing as well as substratum area on the relative importance of periphyton biomass on oyster-culture pens in response to nutrient enrichment in coastal lagoons.
- **Keywords:** Nutrients; Water residence time; Productivity; Biomass; Oyster farming
- Implications for carrying capacity studies.

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- Keywords: Shellfish farming; Oyster culture; Environmental impact; Sulfide; Redox; Sedimentation rates
- **Abstract** 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.

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    - **Abstract** 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.

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    - Have hardcopy of abstract only
    - Investigate composition and temporal components of biofouling communities, notably ascidians and polychaetes.
    - Oyster culture/biofouling complex have significant combined influence on nitrogen/nutrient recycling in Thau lagoon, France, particularly in summer when benthic fluxes are insufficient to meet nitrogen requirements of phytoplankton.

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    - **Abstract** Suspension-feeding eastern oysters, *Crassostrea virginica*, were once abundant in Chesapeake Bay and may then have exerted top-down control on phytoplankton and also reduced turbidities, thereby increasing light available to benthic plants. Alternatively, oysters may have simply recycled inorganic nutrients rapidly back to the water column, with no long-lasting reduction in phytoplankton biomass resulting from oyster feeding activity. To help distinguish between these scenarios, we explored changes in nitrogen fluxes and denitrification in laboratory incubations of sediment cores held under oxic and anoxic conditions in response to loading by pelletized phytoplankton cells, an experimental analog for oyster feces and pseudofeces. When organics were regenerated under aerobic conditions, typical of those associated with oyster habitat, coupled nitrification–denitrification was promoted, resulting in denitrification of ~20% of the total added nitrogen. In contrast, under anoxic conditions, typical of current summertime conditions in main-stem Chesapeake Bay where phytoplankton is microbially degraded beneath the pycnocline, nitrogen was released solely as ammonium from the added organics. We postulate that denitrification of particulate nitrogen remaining in oyster feces and pseudofeces may enhance nitrogen removal from estuaries. In aerobic incubations with sufficient light (70 µmol m-2 s-1), a benthic microalgal/cyanobacterial community grew that not only absorbed the inorganic nitrogen released from the added organics but also fixed N_2. This result suggests that an ecosystem dominated by benthic primary production may

develop in shallow waters when reduced turbidity associated with bivalve feeding increases light penetration to a level that can sustain benthic microalgal production.

- **Keywords**: oysters, phytoplankton, turbidity, light penetration, feces/pseudofeces, benthic microalga/cyanobacteria.

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

- Hardcopy
- **Abstract**. 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.

175. Pietros, J.M. and M.A. Rice. 2003. The impacts of aquacultured oysters, *Crassostrea virginica* (Gmelin, 1791) on water column nitrogen and sedimentation: results of a mesocosm study. Aquaculture 220: 407-422.

- Experimental mesocosm study showed tanks with oysters had increased rates of sedimentation but less than expected possibly due to maximal activity of decomposing bacteria in the benthos; a shift in large diatom population from domination by *Skeletonema* (selective feeding?) to *Nitzchia*; and lack of change in levels of ammonia and other forms of inorganic nitrogen implied rapid regeneration by phytoplankton in the test tanks. Good source of references on role of oysters in nutrient cycling and importance of oyster reefs.
- **Source** (pdf): http://www.pcsga.org/Research/documents/655.pdf

176. Yokoyama, H. 2002. Impacts of fish and pearl farming on benthic environments in Gokasho Bay: evaluation from seasonal fluctuations of the macrobenthos. Fisheries Science 68(2):258

- **Abstract**. In order to clarify the influence of mariculture on the benthic fauna, samples of the macrobenthos were collected from Gokasho Bay, where intensive fish culture and pearl oyster culture have been carried out. Monthly samples collected from the fish farm and pearl farm sites during June 1995 to July 1996 revealed that the community structure of the two sites showed distinct differences with seasonal fluctuations. At the fish farm site, azoic conditions were found from July to November; after December, the diversity increased markedly through successive recruitments of small-sized species such as the polychaetes *Capitella* sp. and *Pseudopolydora paucibranchiata*, and the amphipods *Aoroides* spp.; macrofaunal density, biomass and species richness peaked from March to April. At the pearl farm site, a higher diversity, including larger-sized species, and no clear seasonal fluctuations in abundance was found, and the community structure was similar to that at the control site. These results show the large impact by fish farming on the macrofauna, whereas pearl farming causes less effect on the benthic fauna. It is suggested that the difference in the level of organic input between the two sites results in the differences in the dissolved oxygen content of the bottom water, sulfide content of the sediments and, subsequently, the macrobenthic assemblages.

Seaweed/Kelp

177. Bodvin, T. 1995. Clean technology in aquaculture: a production without waste products. Proceedings of the XVth International Seaweed Symposium. Valdivia, Chile.

178. Chopin, T., G. MacDonald, N. Ridler, S. Robinson, K. Haya, F. Page. In Progress. Development of integrated Aquaculture (Fish/Shellfish/Seaweed) for enviromentally and economically-balanced diversification and social acceptability. Aquanet 2004-2006 Funded Research Projects.

- Source: http://www.aquanet.ca/English/research/ei17_04.php

179. Chopin, T; Bastarache, S; Belyea, E; Haya, K; Sephton, D; Martin, JL; Eddy, S; Stewart, I. 2003. Development of the cultivation of Laminaria saccharina as the extractive inorganic component of an integrated aquaculture system and monitoring of therapeutants and phycotoxins. Journal of Phycology Vol. 39, no. S1, p. 10. Jun 2003.

- **Abstract:** The development of sustainable integrated aquaculture systems requires combining fed aquaculture (finfish) with extractive inorganic aquaculture (seaweed) and extractive organic aquaculture (shellfish). With the support of AquaNet, the Network of Centers of Excellence in Aquaculture in Canada, we are developing such a system at an industrial pilot scale by co-cultivating salmon (Salmo salar), kelp (Laminaria saccharina) and blue mussel (Mytilus edulis) at aquaculture sites in the Bay of Fundy, Canada. This presentation will focus on the development of the extractive inorganic component. The entire cycle of rearing Laminaria saccharina has been completed and improved, both in the laboratory and at the integrated sites: release in the laboratory of spores from mature macroscopic sporophytes, seeding of ropes, germination of microscopic gametophytes, sexual maturation of male and female gametophytes, development of zygotes into juvenile sporophytes, which are then transplanted to the sites for rapid grow-out. Another aspect of the project, food safety monitoring of chemical therapeutants and phycotoxins in mussel and kelp cultured in proximity to salmon, will also be described. The productivity, nutrient absorption capacity, and role of the seaweed component are being analyzed so that its appropriate scale to the other components can be defined in order to develop responsible aquaculture practices in which metabolic/physiological processes of the different co-cultured organisms counter-balance each other within acceptable operational limits. Adopting polytrophic strategies will be key to the aquaculture industry to develop its environmentally and economically-balanced diversification and increase its social acceptability within a broader coastal management framework.

180. Feng, Y.Y., L.C. Hou, M.X. Ping, T.D. Ling, and C.I. Kyo. 2004. Development of mariculture and its impacts in Chinese coastal waters. Reviews in Fish Biology and Fisheries 14(1):1-10.

- **Abstract** China has a long history of aquaculture. Since the 1980s, mariculture has been considered by the government as an increasingly important sub-sector of aquaculture. Mariculture provides nutritional and economic benefits, and decreases the intensity of exploitation on declining wild living resources. China now has the highest mariculture production in the world. Kelp made up 50–60% the total Chinese mariculture production in 1967–1980. Production of *Laminaria japonica*Aresch, the leading species, reached 252, 907 t (dry wet) in 1980. The percentage of kelp production decreased after 1981 because of proportionally greater production of molluscs, shrimps and finfish. Marine finfish and mollusc production increased sharply after 1990. In 2001, the total mariculture production reached 11,315,000 t from a production area of 1,286,000 ha. The rapid development and changes in mariculture species have aroused increasing concern about maricultures impact on the coastal environment. The impact of coastal aquaculture, such as water quality deterioration and contaminants, will have a significant bearing on the expansion of mariculture. The key of improving and maintaining the long-term health of mariculture zones lies in adopting sustainable culture systems. It is imperative that the density of stocking fish and other economically important organisms such as oysters, and scallops, be controlled, in addition to restricting the total number of net-cages in the mariculture zones. The authors suggest moving rafts (cages) periodically and to development of a fallow system in which area fish culture will be suspended for 1–2 years to facilitate recovery of the polluted sediment. Moving fish culture offshore into deeper waters is also suggested. The authors also believe that large-scale seaweed cultivation will reduce eutrophication in coastal culture zones in China.

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    - Source: http://www.ecowin.org/china/publications.htm

Shellfish General

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183. Arzul, G., M. Seguel and A. Clément. 2001. Effect of marine animal excretions on differential growth of phytoplankton species. ICES J. Mar. Sci., 58(2):386-390.
    - Abstract. 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.
    - **Author Keywords**: marine animal excretions, phytoplankton growth, organic

184. Asami, H., M. Aida, and K. Watanabe. 2005. Accelerated sulfur cycle in coastal marine sediment beneath areas of intensive shellfish aquaculture. Appl. Environ. Microbiol., 71(6): 2925-2933.
    - **Source:** http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1151846
    - **Abstract.** Prokaryotes in marine sediments taken from two neighbouring 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 δ-Proteobacteria were the most abundant, and those affiliated with γ-Proteobacteria were the second-most abundant. In contrast, the Kamaishi library was occupied by phylotypes affiliated with Planctomycetes, γ-Proteobacteria, δ-Proteobacteria, and Crenarchaeota. In the γ-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.
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    - **Source** (Exec Summ. Only): http://www.dfo-mpo.gc.ca/science/environmental-environnement/sok_enviroeffects_aquaculture/exec_cranford_e.htm

193. Crawford, C. 2003a. Environmental management of marine aquaculture in Tasmania, Australia. Aquaculture 226(1-4):129-138.
    - pdf
    - 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.

- **Author Keywords:** Marine farming; Monitoring; Environmental management; Organic enrichment; Pacific oysters; Atlantic salmon

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    - Good section on comparing Tasmanian culture methods to world.
    - **Abstract.** Community concerns about the detrimental effects of shellfish farming on the environment have been increasing over the last decade in many shellfish producing countries, including in Tasmania, Australia. Environmental effects of shellfish farming can be assessed and managed using risk management processes, which have been developed for a wide range of human activities. In this study the risk of shellfish farming activities having detrimental impacts on the ecology of the Tasmanian marine environment was assessed using standard risk assessment methodology. This was based on local environmental information and on the level of production, stocking densities, and known husbandry practices in Tasmania compared to farm operations and levels of impact observed in other countries. The risk management process used in this study appears to be applicable to a variety of aquaculture activities. The qualitative risk assessment of detrimental impacts of shellfish farming rated the risk of spread of introduced pests and/or pathogens as high. However, this high risk rating would also apply to many other activities in the marine environment, such as commercial and recreational fishing and sea transport. The level of risk due to habitat disturbance was rated as moderate within the lease area, but would not be expected to extend outside the farm. Risks of organic enrichment of the seabed and reduced food resources for other filter feeders were both rated as low.

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200. Dowd, M. 2005. A bio-physical coastal ecosystem model for assessing environmental effects of marine bivalve aquaculture. Ecological Modelling 183(2-3):323-346.

- A simple lower trophic level, bio-physical marine ecosystem model is developed for the purpose of assessing the environmental effects of bivalve aquaculture in coastal embayments. The ecosystem box model includes pelagic and benthic components and describes the cycling of a most-limiting nutrient. The pelagic compartment is comprised of phytoplankton, zooplankton, nutrients and detritus. These populations interact following predator–prey dynamics and biogeochemical processes. Mixing processes within the bay, and exchange of waters with the adjacent open ocean, are included. The pelagic ecosystem is coupled to a simple benthos containing a dynamically active organic matter pool. Benthic–pelagic coupling includes episodic resuspension, remineralization, sinking, and permanent burial. A population of grazing bivalves is superimposed on this system as a diagnostic variable. The model is applied to a coastal bay and used to determine how bivalve populations affect nutrient cycling in the ecosystem. This is done by examining changes in the standing stock of the various populations, as well as associated nutrient (mass) fluxes, for cases both with and without intensive bivalve culture. It was demonstrated that bivalves divert production from the pelagic to benthic food webs. Phytoplankton and detritus are depleted from the water by bivalve filter feeding and biodeposited to the benthos as fecal matter. This organic loading causes order of magnitude changes in the benthic detrital pool and the associated benthic–pelagic fluxes. It was also shown that water motion and mixing is important in structuring the ecological dynamics in the bay. To faciliate future applications and observational studies, a retrospective analysis of parameter identifiability and uncertainty was also undertaken.
- **Keywords:** Aquaculture; Benthic–pelagic coupling; Nutrient cycling; Box model; Differential equations; Regression

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- **Abstract:** 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.

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- **Abstract** The consequences of anthropogenic impact on the water area of Amur Bay (the Sea of Japan) near Vladivostok include the eutrophication of coastal waters and littering with various objects used as artificial substrates, which protect sedentary animals from predators and contribute to the survival of their larvae. An indicator of eutrophication, the diatom *Skeletonema costatum* accounting for 81–96% of the total abundance of phytoplankton (Stonik and Selina, 1995), is consumed mainly by barnacles and the Pacific oyster. Thus, these animals gain an advantage in the colonization of artificial substrates. The results of the study suggest that eutrophication will lead to changes in the structure of the marine community.
- **Key words** eutrophication - artificial substrates - larvae of marine invertebrates - temperature - salinity - abundance of juveniles - survival

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- The field culture of bivalve molluscs is dependent on the production and supply of phytoplankton and other food sources, its consumption by these suspension feeders, and its transformation into bivalve tissue. An understanding of the processes by which food is captured and utilized is fundamental to prediction of bivalve growth and management of shellfish aquaculture. The following perspective considers the role of food quality and quantity in the ingestion and absorption of food particles, as well as the influence of temperature, water circulation and other environmental variables on bivalve energy budgets and growth rate. A particular focus is the role of simulation modelling in quantifying the influence of these variables on scope for growth. Seston depletion is a major influence on cultured animals such that bivalves are limited by both food quality and quantity. Seston depletion can be managed by taking advantage of particle maxima (e.g. resuspension), matching culture species to turbidity gradients, and arranging hanging culture to take advantage of seston renewal in oblique flow. Food limitation interacts with temperature in cold temperate areas where high primary production occurs at low temperatures. Model simulations of mussel growth demonstrate the importance of temperature acclimation of filtration and its relationship to the timing and magnitude of the spring bloom. In addition to the energetics of individual animals, energy flow through culture ecosystems is considered in terms of bivalve processing of organic matter and competition with Zooplankton and fish. Because bioenergetics is at the root of all of these issues, simulation

modelling of scope for growth and related components of the ecosystem is a vital tool in prediction and management of commercial bivalve aquaculture.

- **Author Keywords:** Bivalve aquaculture; Shellfish; Bioenergetics; Modelling ; zooplankton

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    - Hardcopy; Good review

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

222. 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.

- Hardcopy
- **Abstract --** 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 (0ncorhynchus 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 pesticides 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.

223. Souchu, P., A. Vaquer, Y. Collos, S. Landrein, J-M. Deslous-Paoli, and B. Bibent. 2001. Influence of shellfish farming activities on the biogeochemical composition of the water column in Thau lagoon. Marine Ecology Progress Series 218:141-152.
    - Abstract. Thau lagoon is a Mediterranean shellfish ecosystem with large biomasses of oysters growing in waters with high residence time due to low tidal ranges, The influence of filter feeders (oysters and their epibiota) on the spatial distribution of particulate and dissolved compounds in the water column of Thau lagoon was studied through its variation with time, In 1991/1992, daily variations were investigated in pens, corridors and outside shellfish farming zones for nutrients, chlorophyll a and primary production. Salinity, dissolved oxygen, nutrients, organic matter and chlorophyll a were also monitored in surface waters inside and outside shellfish farming zones each week from January 1993 to March 1994. The presence of shellfish farms led to a decrease by only a few percent of oxygen concentrations in their vicinity, but the mean (+/- SE) deficits of chlorophyll a and POC concentrations were 44 +/- 4 % and 26 +/- 9 % respectively in the eastern zone (8 m). The shift induced by filter feeders in phytoplankton composition favoured picophytoplankton with higher growth rates. But the summer increase in phytoplankton growth rate was stronger than the positive feedback due to filter feeder filtration. Summer was determinant for the growth of oysters owing to enhanced regenerated primary production. During this period, filter feeders were not food limited, while they tended to control phytoplankton biomasses and production the rest of the year. The nutrient excess in shellfish farming zones was highly significant, with increases of 73 +/- 16, 36 +/- 12 and 19 +/- 8 % for ammonia, phosphates and silicate respectively in the eastern zone. In the western zone, the nutrient excess was less strong by half for ammonia and phosphate, because the lower depth (4 m) allows light to reach the bottom and enables benthic macroflora to grow on nutrients of benthic origin. The decline of phytoplankton biomasses in shellfish farms induced a decrease in the nutrient demand, especially for ammonia. This situation was likely to favour nitrification, which led during autumn to higher nitrate concentrations within shellfish farming zones than outside. Therefore, filter feeders were able to alter the dominant biogeochemical process in the water column by stimulating nitrification.

224. Sustainable Shellfish Aquaculture Initiative (SSAI) at SFU, Centre for Coastal Studies. Projects include Nutrient cycling, migratory birds, and intertidal biodiversity (see Whiteley in CLAMS).
    - **Source:** http://www.sfu.ca/coastalstudies/ssai/activities-research.htm

225. The Scottish Association for Marine Science and Napier University. 2002. Review and synthesis of the environmental impacts of aquaculture. Prepared for the Scottish Executive Central Research Unit.
    - **Source:** www.scotland.gov.uk/cru/kd01/green/reia.pdf

226. Tasmania Department of Primary Industries, Water and Environment. 2004. Tasmanian Marine Farming Environmental Monitoring Report: Benthic Monitoring (1997-2002). Marine Environment Section, Marine Farming Branch, Marine Resources Group, Department of Primary Industries, Water and Environment, DPIWE, Government of Tasmania. Hobart, Tasmania.

- **Source:** http://www.dpiwe.tas.gov.au/inter.nsf/WebPages/HMUY-6298KJ?open
- Results from 6 years of baseline and monitoring studies completed for finfish but shellfish only has baseline as yet.
- Survey methods; Monitoring data in appendices

227. TerrAqua Environmental Science and Policy, LLC. 2003. Potential Impacts of Small-Scale Commercial Mariculture in Southampton Public Waters – Feasibility Study.

- Pdf in Os/
- Interesting section on recommended actions.

228. Tlusty, M., D. Bengtson, H. Halvorson, S. Oktay, J. Pearce, and R.B. Rheault, Jr., editors. 2001. Marine Aquaculture and the Environment. Proceedings of a workshop "Marine Aquaculture and the Environment: A Meeting for Stakeholders in the Northeast" held January 11-13, 2001, University of Massachusetts, Boston, MA.

- **Source:** www.onefish.org
- Impacts on habitat: determining what is acceptable. W. Silbert.
- Acceptability limits and standards. C. Heinig.
- Aquaculture from a different angle: the seaweed perpective, and the rationale for promoting integrated aquaculture. T. Chopin et al.
- Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication. M Rice.
- Eelgrass is great, but shellfish aquaculture is better. B. Rheault.

229. Weeber, B. and M. Gibbs. 1998. Marine Farming Guide – the law, the environment, and how to have your say. Prepared for the Forest and Bird Protection Society of New Zealand.

- **Source:** www.forestandbird.org.nz/Marine/farming/guide.pdf
- Good review of issues and literature section.

230. Yokoyama, H. 2002. Impacts of fish and pearl farming on the benthic environments in Gokasho Bay: evaluation from seasonal fluctuations of the macrobenthos. Fisheries Science 68(2):258-.

- Abstract. In order to clarify the influence of mariculture on the benthic fauna, samples of the macrobenthos were collected from Gokasho Bay, where intensive fish culture and pearl oyster culture have been carried out. Monthly samples collected from the fish farm and pearl farm sites during June 1995 to July 1996 revealed that the community structure of the two sites showed distinct differences with seasonal fluctuations. At the fish farm site, azoic conditions were found from July to November; after December, the diversity increased markedly through successive recruitments of small-sized species such as the polychaetes *Capitella* sp. and *Pseudopolydora paucibranchiata*, and the amphipods *Aoroides* spp.; macrofaunal density, biomass and species richness peaked from March to April. At the pearl farm site, a higher diversity, including larger-sized species, and no clear seasonal fluctuations in abundance was found, and the community structure was similar to that at the control site. These results show the large impact by fish farming on the macrofauna, whereas pearl farming causes less effect on the benthic fauna. It is suggested that the difference in the level of organic input between the two sites results in the differences in the dissolved oxygen content of the bottom water, sulfide content of the sediments and, subsequently, the macrobenthic assemblages

Salt Marsh

231. Minello, R.J., K.W. Able, M.P. Weinstein, S.G. Hays. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth and survival through meta-analysis. Marine Ecology Progress Series 246:39-59.

- **Source** (Abstracts): www.int-res.com/abstracts/meps/v246/p39-59/
- When density, growth and survival are all considered, the relative nursery value of salt marshes for nekton (fish and decapod crustaceans) appears higher than open water but lower than seagrass and vegetated marsh appeared to have a higher nursery value than nonvegetated marsh. Oyster reef was ranked low for fish density and decapod density, but high for nekton survival

Waterfowl

232. AXYS Environmental Consulting Ltd., Kingzett Professional Services, and J. Clowater. 2000. A Review of the Impacts of Shellfish Aquaculture Lease Operations on Marine and Shorebird Species in Baynes Sound, British Columbia. Prepared for A. Tompkins, Planning and Assessment, Vancouver Island Region, Ministry of Environment Lands and Parks. 60 p.

- Hardcopy.

233. Booth, J. and H. Rueggeberg. 1989. Marine birds and aquaculture in British Columbia: assessment of geographical overlap. Technical Report Series No. 73. Wildlife Service, Pacific and Yukon Region, British Columbia. 53 p. + app.

- Hardcopy.
- Notes that in 1989 high overlap in bird use and aquaculture sites for goldeneye sp., but medium for Bufflehead, scoters, cormorants, grebes, gulls, loons, Mallards, mergansers, and raptors. Little overlap existed between aquaculture and colonies of the birds studied and none of the species studied appeared to be significantly impacted by aquaculture in terms of number of colonies or the amount of important habitat area (colonies, breeding areas, moulting areas) that overlap with aquaculture operations. BUT concern raised over long term impacts of expanding aquaculture sites and increasing overlap with important moulting areas and breeding habitat, particularly for species that have few, large colonies that make intensive use of the surrounding area and have few alternate breeding habitats (e.g., auklets and puffins).

234. Ross, B.P. and R.W. Furness. 2000. Minimising the impact of eider ducks on mussel farming. University of Glascow, Association of Scottish Shellfish Growers, and Scottish Natural Heritage. 54 p.

- Hardcopy
- p. 17 Notes increase in eider duck population possibly due to mariculture and certainly mariculture influencing local geographical distribution of eiders at some times of year, also eiders concentrated around mariculture structures, both mussel and salmon, rather than other areas and in some areas in large numbers where few were seen before.

235. Rueggeberg, H. and J. Booth. 1989. Marine birds and aquaculture in British Columbia: preventing predation by scoters on a west coast mussel farm. Technical Report Series No. 74. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia. 27 p.

- Hardcopy
- Note mortalities when predator exclusion netting is draped across the top of rafts such that when birds do dive beneath side panels and surface within the raft they are trapped. Recommend avoiding the use of top lying netting.

Supporting Documents

236. BC Ministry of the Environment, Water Management Branch. 2005. A Users' Guide to Working in and Around Water: Understanding the regulation under British Columbia's Water Act.

- Pdf

237. Department of Primary Industries, Water and Environment, Tasmania. 2001. Marine Farming Development Plan. Port Sorell Estuary.

- **Source:** http://www.dpiwe.tas.gov.au/inter.nsf Follow links Sea Fishing & Aquaculture, Marine Farming/Aquaculture, Marine Farming Development Plans.
- Development plans and Environmental Impact Statements for many regions of Tasmania at this site.
- Recommends site development limits for environmental controls relating to carrying capacity including: 1.1 km of stocked racking per hectare of lease area or 4.4 km of stocked post and wire farming equipment (commonly known as the BST system) per hectare of lease are or 330 metres of effective backbone longline per hectare of lease area, and all longlines and associated equipment for filter feeding shellfish must be maintained at least 1 metre clear of the seabed.

238. Hamouda, L., K.W. Hipel, and D.M. Kilgour. 2004. Shellfish conflict in Baynes Sound: a strategic perspective. Environmental Management 34(4):474-486.

- **Abstract** The shellfish aquaculture industry (SAI) has operated in Baynes Sound, British Columbia (BC) since the early 1900s. Recognizing the economic potential of the area, the industry has requested additional farming opportunities. However, Baynes Sound upland residents and many other stakeholders have expressed concerns that SAI activities are having a negative impact on the environment, quality of life, and other nonaquaculture resource uses in the area. In order to address these issues, the Action Plan was initiated by a BC government interagency project team in November 2001. To assist in assessing the strategic aspects of this conflict, the decision support system GMCR II is employed here to apply a new methodology, the graph model for conflict resolution, to systematically analyze the ongoing conflict over shellfish aquaculture development in Baynes Sound within a social, economic, and environmental framework. Valuable insights are procured to guide decision-makers toward sustainability of the shellfish industry.
- Keywords: Fisheries management - Aquaculture - Conflict resolution - Decision support system - Graph model - Stability and sensitivity analyses