

In this review:

A. Recent articles with abstracts

O/A denotes an open access article or journal

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Whiteley, J. and Bendell-Young, L. **Ecological implications of intertidal mariculture: observed differences in bivalve community structure between farm and reference sites.** *Journal of Applied Ecology* 44(3): 495-505, 2007.

Notes: 1. Despite recent growth in shellfish aquaculture in British Columbia, Canada, the impacts of common practices on non-target species are poorly understood. Two practices employed on clam farms to increase production of the exotic clam *Venerupis philippinarum* include the addition of juvenile 'seed' clams to the sediment and covering seeded clam beds with protective netting, ostensibly to exclude large mobile epibenthic predators. 2. We expected the effects of predator exclusion to be most evident among other bivalves, which made up more than 80% of the infaunal macrobenthos at all sites surveyed. A field study across three regions collected infaunal bivalve density and biomass data. We compared species richness, composition and abundances of communities between clam farms and reference sites, paired on the basis of physical characteristics such as sediment type, slope and aspect. 3. *Venerupis philippinarum* was the only species found in higher abundance on farm sites in low intertidal areas (227 ± 241.6 clams m^{-2} , $P = 0.02$; 872.9 ± 792.9 g m^{-2} , $P = 0.037$). Farmed sites showed no difference in mid-intertidal areas, nor in density of the other 25 bivalve species, although an increase would be expected if netting excluded important predators. Although statistically non-significant, there were indications that biomass of species other than *V. philippinarum* may have been lower on farm sites. 4. Bivalve species composition was not significantly different between farm and reference sites. Nevertheless, farm sites were more similar to each other as a group than reference sites, leading to a loss of regional distinctness that was evident among reference sites. 5. Synthesis and applications. Our findings support the hypothesis that predation and competition play minor roles in structuring communities in soft-bottomed environments. Given the potential for cumulative effects of seeding and netting at large scales, a precautionary approach is recommended in future development of intertidal clam aquaculture.

Deutsch, L., Graslund, S., Folke, C., Troell, M., Huitric, M., Kautsky, N., and Lebel, L. **Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal.** *Global Environmental Change* 17(2): 238-249, 2007.

Notes: Like other animal production systems, aquaculture has developed into a highly globalized trade-dependent industry. A major part of aquaculture technology requires fishmeal to produce the feed for farmed species. By tracing and mapping patterns of trade flows globally for fishmeal we show the aquaculture industry's increasing use of marine ecosystems worldwide. We provide an in-depth analysis of the growth decades (1980-2000) of salmon farming in Norway and shrimp farming in Thailand. Both countries, initially net exporters of fishmeal, increased the number of import source nations of fishmeal, peaking in the mid-1990s. Thailand started locally and expanded into sources from all over the globe, including stocks from the North Sea through imports from Denmark, while Norway predominantly relied on northern region source nations to feed farmed salmon. In 2000, both have two geographically alternate sources of fishmeal supply: the combination of Chile and Peru in South America, and a regional complement. We find that fishmeal trade for aquaculture is not an issue of using ecosystems of the South for production in the North, but of trade between nations with industrialized fisheries linked to productive marine ecosystems. We discuss the expansion of marine ecosystem appropriation for the global aquaculture

industry and observed shifts in the trade of fishmeal between marine areas over time. Globalization, through information technology and transport systems, has made it possible to rapidly switch between marine areas for fishmeal supply in economically connected food producing systems. But the stretching of the production chain from local to global and the ability to switch between marine areas worldwide seem to undermine the industry's incentives to respond to changes in the capacity of ecosystems to supply fish. For example, trade information does not reveal the species of fish that the fishmeal is made of much less its origins and there is lack of feedback between economic performance and impacts on marine ecosystem services. Responding to environmental feedback is essential to avoid the trap of mining the marine resources on which the aquaculture industry depends. There are grounds to suggest the need for some global rules and institutions that create incentives for seafood markets to account for ecosystem support and capacity.

Liu, Y. and Sumaila, U.R. **Can farmed salmon production keep growing?** *Marine Policy* 32(3): 497-501, 2008.

Notes: Time series data was used to compute 5-year moving average rates of growth in salmon aquaculture production over time for four of the world's leading salmon farming countries, and globally. This analysis reveals a decline of 1.2% per year in global farmed salmon production since it peaked in 1966. Analysis of production data for all farmed finfish, both marine and freshwater, shows a decline of 0.34% per year in the growth rate from the peak year. These results have implications for global fisheries policy because it means that it is unlikely that aquaculture alone can meet the fish protein needs of humans.

Pusceddu, A., Fraschetti, S., Mirto, S., Holmer, M., and Danovaro, R. **Effects of intensive mariculture on sediment biochemistry.** *Ecological Applications* 17(5): 1366-1378, 2007.

Notes: The exponential growth of off-shore mariculture that has occurred worldwide over the last 10 years has raised concern about the impact of the waste produced by this industry on the ecological integrity of the sea bottom. Investigations into this potential source of impact on the biochemistry of the sea floor have provided contrasting results, and no compelling explanations for these discrepancies have been provided to date. To quantify the impact of fish-farm activities on the biochemistry of sediments, we have investigated the quantity and biochemical composition of sediment organic matter in four different regions in the temperate-warm Mediterranean Sea: Akrotiri Bay (Cyprus), Sounion Bay (Greece), Pachino Bay (Italy), and the Gulf of Alicante (Spain). In these four study regions, the concentrations of phytopigments, proteins, carbohydrates, and lipids in the sediments were measured, comparing locations receiving wastes from fish farms to control locations in two different habitats: seagrass beds and soft nonvegetated substrates. Downward fluxes were also measured in all of the regions, up to 200 m from the fish farms, to assess the potential spatial extent of the impact. In all four regions, with the exception of seagrass sediments in Spain, the biochemistry of the sediments showed significant differences between the control and fish-farm locations. However, the variables explaining the differences observed varied among the regions and between habitats, suggesting idiosyncratic effects of fish-farm waste on the biochemistry of sediments. These are possibly related to differences in the local physicochemical variables that could explain a significant proportion of the differences seen between the control and fish-farm locations. Biodeposition derived from the fish farms decreased with increasing distance from the fish-farm cages, but with different patterns in the four regions. Our results indicate that quantitative and qualitative changes in the organic loads of the sediments that arise from intensive aquaculture are dependent upon the ecological context and are not predictable only on the basis of fish-farm attributes and hydrodynamic regimes. Therefore, the siting of fish farms should only be allowed after a case-by-case assessment of the ecological context of the region, especially in terms of the organic matter load and its biochemical composition.

Naish, K.A., Taylor, J.E., Levin, P.S., Quinn, T.P., Winton, J.R., Huppert, D., and Hilborn, R. **An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon.** *Advances in Marine Biology* 53: 61-194, 2007.

Notes: The historical, political and scientific aspects of salmon hatchery programmes designed to enhance fishery production, or to recover endangered populations, are reviewed. We start by pointing out that the establishment of hatcheries has been a political response to societal demands for harvest and conservation; given this social context, we then critically examined the levels of activity, the biological risks, and the economic analysis associated with salmon hatchery programmes. A rigorous analysis of the impacts of hatchery programmes was hindered by the lack of standardized data on release sizes and survival

rates at all ecological scales, and since hatchery programme objectives are rarely defined, it was also difficult to measure their effectiveness at meeting release objectives. Debates on the genetic effects of hatchery programmes on wild fish have been dominated by whether correct management practices can reduce negative outcomes, but we noted that there has been an absence of programmatic research approaches addressing this important issue. Competitive interactions between hatchery and wild fish were observed to be complex, but studies researching approaches to reduce these interactions at all ecological scales during the entire salmon life history have been rare, and thus are not typically considered in hatchery management. Harvesting of salmon released from fishery enhancement hatcheries likely impacts vulnerable wild populations; managers have responded to this problem by mass marking hatchery fish, so that fishing effort can be directed towards hatchery populations. However, we noted that the effectiveness of this approach is dependant on accurate marking and production of hatchery fish with high survival rates, and it is not yet clear whether selective fishing will prevent overharvest of wild populations. Finally, research demonstrating disease transmission from hatchery fish to wild populations was observed to be equivocal; evidence in this area has been constrained by the lack of effective approaches to studying the fate of pathogens in the wild. We then reviewed several approaches to studying the economic consequences of hatchery activities intended to inform the social decisions surrounding programmes, but recognized that placing monetary value on conservation efforts or on hatcheries that mitigate cultural groups' loss of historical harvest opportunities may complicate these analyses. We noted that economic issues have rarely been included in decision making on hatchery programmes. We end by identifying existing major knowledge gaps, which, if filled, could contribute towards a fuller understanding of the role that hatchery programmes could play in meeting divergent goals. However, we also recognized that many management recommendations arising from such research may involve trade-offs between different risks, and that decisions about these trade-offs must occur within a social context. Hatcheries have played an important role in sustaining some highly endangered populations, and it is possible that reform of practices will lead to an increase in the number of successful programmes. However, a serious appraisal of the role of hatcheries in meeting broader needs is urgently warranted and should take place at the scientific, but more effectively, at the societal level.

Wallace, I.S., Gregory, A., Murray, A.G., Munro, E.S., and Raynard, R.S. **Distribution of infectious pancreatic necrosis virus (IPNV) in wild marine fish from Scottish waters with respect to clinically infected aquaculture sites producing Atlantic salmon, *Salmo salar* L.** *Journal of Fish Diseases* 31(3): 177-186, 2008.

Notes: This study represents the first large-scale investigation of IPNV in Scottish wild marine fish. Kidney samples were taken from 30 627 fish comprising 37 species and 45 isolations were made from nine different species, illustrating these as reservoirs of IPNV in Scottish waters. The estimated prevalence of IPNV in the Scottish marine environment was low at 0.15% (90% confidence intervals, (CI) of 0.11-0.19%). This was significantly greater in fish caught less than 5.0 km from IPN-positive fish farms in Shetland, at 0.58% (90% CI of 0.45-0.77%). This prevalence persisted and did not significantly decrease over the 16-month period of study. The estimated prevalence of IPNV for each positive species was less than 1% with the statistically non-significant exceptions of flounder, *Platichthys flesus* (L.), at 12.5% (90% CI of 0.64-47.06%) and saithe, *Pollachius virens* (L.), at 1.11% (90% CI of 0.49-2.19%). The 45 isolates were titrated and all but two were below the detection limit of the test (< 55 PFU g⁻¹). Titres of 3.8 x 10² PFU g⁻¹ and 2.8 x 10¹ PFU g⁻¹ were calculated from common dab, *Limanda limanda* (L.), and saithe, respectively. This study provides evidence that clinical outbreaks of IPN in farmed Atlantic salmon may cause a localized small increase in the prevalence of IPNV in wild marine fish.

Millar, K. and Tomkins, S. **Ethical analysis of the use of GM fish: Emerging issues for aquaculture development.** *Journal of Agricultural and Environmental Ethics* 20(5): 437-453, 2007.

Notes: Improvements in production methods over the last two decades have resulted in aquaculture becoming a significant contributor to food production in many countries. Increased efficiency and production levels are off-setting unsustainable capture fishing practices and contributing to food security, particularly in a number of developing countries. The challenge for the rapidly growing aquaculture industry is to develop and apply technologies that ensure sustainable production methods that will reduce environmental damage, increase productivity across the sector, and respect the diverse social and cultural dimensions of fish farming that are observed globally. The aquaculture industry currently faces a number of technology trajectories, which include the option to commercially produce genetically modified (GM) fish. The use of genetic modification in aquaculture has the potential to contribute to increased food security and is claimed to be the next logical step for the industry. However, the potential use of these technologies raises a number of important ethical questions. Using an ethical framework, the Ethical Matrix, this paper explores a number of the ethical issues potentially raised by the use of GM

technologies in aquaculture. Several key issues have been identified. These include aspects of distributive justice for producers; use of a precautionary approach in the management of environmental risk and food safety; and impacts on the welfare and intrinsic value of the fish. There is a need to conduct a comparative analysis of the full economic cycle of the use of GM fish in aquaculture production for developing countries. There is also a need to initiate an informed dialogue between stakeholders and strenuous efforts should be made to ensure the participation of producers and their representatives from developing nations. An additional concern is that any national licensing of the first generation of GM fish, i.e., in the USA, may initiate and frame an assessment cycle, mediated by the WTO, which could dominate the conditions under which the technology will be applied and regulated globally. Therefore, an integrated analysis of the technology development trajectories, in terms of international policy, IPR, and operational implications, as well as an analysis of a broader range of ethical concerns, is needed.

McKindsey, C.W., Landry, T., O'Beirn, F.X., and Davies, I.N. **Bivalve aquaculture and exotic species: A review of ecological considerations and management issues.** *Journal of Shellfish Research* 26(2): 281-294, 2007.

Notes: Bivalves have been grown and transported for culture for hundreds of years and the introduction of some species outside of their native range for aquaculture has been suggested to be one of the greatest modes of introduction of exotic marine species. However, there has yet to be a thorough assessment of the importance of aquaculture and bivalve culture in particular, to the introduction and spread of exotic species. This paper reviews some of the environmental and ecological implications of the relationship between bivalve aquaculture and the introduction and spread of exotic species, management implications and mitigation strategies. Two broad classes of introductions of exotic species may result from activities associated with bivalve aquaculture. First the intentional introduction of exotic species into an area for aquaculture purposes, i.e. the "target" species. These are typically foundation or engineering species and may have a considerable influence on receiving ecosystems. Second, the introduction of species that are either associated with introduced bivalves or facilitated by aquaculture activities (i.e. structures or husbandry practices). These may include both "hitchhiking" species (organisms that grow in association with or may be transferred with cultured bivalves) and disease causing organisms. Management options should include the use of risk assessments prior to transfers and quarantines. Various types of mitigation for exotic species have been evaluated but are generally not very successful. Because the risk of exotic species to ecosystems and the bivalve farming industry itself may be great, effort should be directed to better predict and halt introductions of potentially harmful species.

Krkošek, M., Gottesfeld, A., Proctor, B., Rolston, D., Carr-Harris, C., and Lewis, M.A. **Effects of host migration, diversity and aquaculture on sea lice threats to Pacific salmon populations.** *Proceedings of the Royal Society of London [B]* 274(1629): 3141-3149, 2007. **O/A**

Notes: Animal migrations can affect disease dynamics. One consequence of migration common to marine fish and invertebrates is *migratory allopatry*-a period of spatial separation between adult and juvenile hosts, which is caused by host migration and which prevents parasite transmission from adult to juvenile hosts. We studied this characteristic for sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) and pink salmon (*Oncorhynchus gorbuscha*) from one of the Canada's largest salmon stocks. Migratory allopatry protects juvenile salmon from *L. salmonis* for two to three months of early marine life (2-3% prevalence). In contrast, host diversity facilitates access for *C. clemensi* to juvenile salmon (8-20% prevalence) but infections appear ephemeral. Aquaculture can augment host abundance and diversity and increase parasite exposure of wild juvenile fish. An empirically parametrized model shows high sensitivity of salmon populations to increased *L. salmonis* exposure, predicting population collapse at one to five motile *L. salmonis* per juvenile pink salmon. These results characterize parasite threats of salmon aquaculture to wild salmon populations and show how host migration and diversity are important factors affecting parasite transmission in the oceans.

Ford, J.S. and Myers, R.A. **A global assessment of salmon aquaculture impacts on wild salmonids.** *PLoS Biology* 6(2): art. e33, 2008. **O/A**

Notes: Since the late 1980s, wild salmon catch and abundance have declined dramatically in the North Atlantic and in much of the northeastern Pacific south of Alaska. In these areas, there has been a concomitant increase in the production of farmed salmon. Previous studies have shown negative impacts on wild salmonids, but these results have been difficult to translate into

predictions of change in wild population survival and abundance. We compared marine survival of salmonids in areas with salmon farming to adjacent areas without farms in Scotland, Ireland, Atlantic Canada, and Pacific Canada to estimate changes in marine survival concurrent with the growth of salmon aquaculture. Through a meta-analysis of existing data, we show a reduction in survival or abundance of Atlantic salmon; sea trout; and pink, chum, and coho salmon in association with increased production of farmed salmon. In many cases, these reductions in survival or abundance are greater than 50%. Meta-analytic estimates of the mean effect are significant and negative, suggesting that salmon farming has reduced survival of wild salmon and trout in many populations and countries.

Cao, L., Wang, W., Yang, Y., Yang, C., Yuan, Z., Xiong, S., and Diana, J. **Environmental impact of aquaculture and countermeasures to aquaculture pollution in China.** *Environmental Science and Pollution Research* 14(7): 452-462, 2007.

Notes: *Goal, Scope and Background.* Aquaculture activities are well known to be the major contributor to the increasing level of organic waste and toxic compounds in the aquaculture industry. Along with the development of intensive aquaculture in China, concerns are evoked about the possible effects of ever-increasing aquaculture waste both on productivity inside the aquaculture system and on the ambient aquatic ecosystem. Therefore, it is apparent that appropriate waste treatment processes are needed for sustaining aquaculture development. This review aims at identifying the current status of aquaculture and aquaculture waste production in China. *Main Features.* China is the world's largest fishery nation in terms of total seafood production volume, a position it has maintained continuously since 1990. Freshwater aquaculture is a major part of the Chinese fishery industry. Marine aquaculture in China consists of both land-based and offshore aquaculture, with the latter mostly operated in shallow seas, mud flats and protected bays. The environmental impacts of aquaculture are also striking. *Results.* Case studies on pollution hot spots caused by aquaculture have been introduced. The quality and quantity of waste from aquaculture depends mainly on culture system characteristics and the choice of species, but also on feed quality and management. Wastewater without treatment, if continuously discharged into the aquatic environment, could result in remarkable elevation of the total organic matter contents and cause considerable economy lost. Waste treatments can be mainly classified into three categories: physical, chemical and biological methods. *Discussion.* The environmental impacts of different aquaculture species are not the same. New waste treatments are introduced as references for the potential development of the waste treatment system in China. The most appropriate waste treatment system for each site should be selected according to the sites' conditions and financial status as well as by weighing the advantages and disadvantages of each system. Strategies and perspectives for sustainable aquaculture development are proposed, with the emphasis on environmental protection. *Conclusions.* Negative effects of waste from aquaculture to aquatic environment are increasingly recognized, though they were just a small proportion to land-based pollutants. Properly planned use of aquaculture waste alleviates water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in effluent. It is highly demanding to develop sustainable aquaculture which keeps stocking density and pollution loadings under environmental capacity. *Recommendations and Perspectives.* The traditional procedures for aquaculture waste treatment, mainly based on physical and chemical means, should be overcome by more site-specific approaches, taking into account the characteristics and resistibility of the aquatic environment. Further research needs to improve or optimize the current methods of wastewater treatment and reuse. Proposed new treatment technology should evaluate their feasibility at a larger scale for practical application.

Cranford, P.J., Strain, P.M., Dowd, M., Hargrave, B.T., Grant, J., and Archambault, M.C. **Influence of mussel aquaculture on nitrogen dynamics in a nutrient enriched coastal embayment.** *Marine Ecology Progress Series* 347: 61-78, 2007.

Notes: The combined influences of intensive mussel aquaculture and watershed nutrient inputs on nitrogen dynamics in Tracadie Bay, Prince Edward Island, Canada, were examined using a nitrogen budget and an ecosystem model. Budget calculations, and inputs and parameters for the model were based on extensive field data. Both approaches showed that mussel aquaculture has a dominant influence on all aspects of the nitrogen cycle and dramatically alters pathways by which nitrogen reaches the phytoplankton and benthos. A large proportion of phytoplankton production is supported by land-derived nitrogen and this anthropogenic input is important for sustaining existing levels of mussel production. The amount of nitrogen removed in the mussel harvest is small compared with agricultural nitrogen inputs and the amounts excreted and biodeposited on the seabed. Mussel biodeposition greatly increases the flux of nitrogen to the benthos, with potentially serious eutrophication impacts. Results from the observation-based nitrogen budget and dynamic model were compared and both support the above conclusions. However, the ability of the model to test different scenarios and to provide additional information (e.g. fluxes) over a finer spatial scale led to insights unattainable with a nitrogen budget. For example, food

appears to be less available to mussels at the head of the Bay than at the mouth, despite the lower density of grow-out sites in the former location. The number of fundamental ecosystem processes influenced by the mussels and the complexity of their interactions make it difficult to predict the effects of mussels on many ecosystem properties without resorting to a model.

Roberge, C., Normandeau, E., Einum, S., Guderley, H., and Bernatchez, L. **Genetic consequences of interbreeding between farmed and wild Atlantic salmon: insights from the transcriptome.** *Molecular Ecology* 17(1): 314-324, 2008.

Notes: Large annual escapees of farmed Atlantic salmon enhance the risk of extinction of wild populations through genetic and ecological interactions. Recently, we documented evolutionary change in gene transcription between farmed and wild Atlantic salmon after only five generations of artificial selection. While differences for most quantitative traits are expected to gradually dilute through repeated backcrossing to wild populations, the genetic basis of gene transcription has been shown to be largely nonadditive and hybrid crosses may display unexpected inheritance patterns. This makes it difficult to predict to what extent interbreeding between farmed and wild individuals will change the genetic makeup of wild salmon populations. Here, we compare the genome-wide gene transcription profiles of Norwegian wild salmon to that of a second generation hybrid cross [backcross: (Farmed X Wild) X Wild]. Over 6% (298, q -value < 0.01) of the detected genes exhibited highly significantly different transcription levels, and the range and average magnitude of those differences was strikingly higher than previously described between pure farmed and wild strains. Most differences appear to result from nonadditive gene interactions. These results suggest that interbreeding of fugitive farmed salmon and wild individuals could substantially modify the genetic control of gene transcription in natural populations exposed to high migration from fish farms, resulting in potentially detrimental effects on the survival of these populations. This further supports the idea that measures to considerably reduce the number of escaped farmed salmon and their reproduction in the wild are urgently needed.

Defoirdt, T., Boon, N., Sorgeloos, P., Verstraete, W., and Bossier, P. **Alternatives to antibiotics to control bacterial infections: luminescent vibriosis in aquaculture as an example.** *Trends in Biotechnology* 25(10): 472-479, 2007.

Notes: The massive (mis)use of antibiotics to control infections in aquaculture has resulted in the development of resistant strains, which have rendered antibiotic treatments ineffective. Moreover, the horizontal transfer of resistance determinants to human pathogens and the presence of antibiotic residues in aquaculture products for human consumption constitute important threats to public health. Therefore, to make the aquaculture industry more sustainable, new strategies to control infections are urgently needed.

Hall-Spencer, J. and Bamber, R. **Effects of salmon farming on benthic Crustacea.** *Ciencias Marinas* 33(4): 353-366, 2007.
O/A

Notes: Scotland is the largest aquaculture producer in the European Union and utilizes almost all of its fjords for salmon culture. Recent UK policy has encouraged the movement of farm cages away from enclosed sites to areas with strong tidal flow because salmon farms are known to cause organic-enrichment of muddy substrata in areas with low tidal flow. This has resulted in a spate of applications to site cages over coralline algal gravel beds (termed maerl) that are usually strongly tidal and provide habitat for a diverse array of benthic Crustacea. In 2003 we studied the effects of farm waste on benthic crustaceans from a large salmon farm in Shetland that had been situated above a maerl bed since 1991. Annual monitoring reports showed a die-back of living maerl, periods of anoxia and an accumulation of organic material on the seabed within 25 m of the cages. Assessments of crustacean assemblages, quantified using 0.5-mm-sieved replicate ($n = 5$ per site) core samples, showed significant reductions in biodiversity near the farm. Some scavengers (e.g., the amphipod *Socarnes erythrophthalmus*) were far more abundant near the cages than at distances >75 m from the cages, but many small crustaceans (e.g., the tanaids *Leptognathia breviviremis*, *Typhlotanaia microcheles* and *Pseudoparatanais batei*; the cumaceans *Nannastacus unguiculatus*, *Cumella pygmaea* and *Vaunthompsonia cristata*; and the amphipod *Austrosyrrhoe fimbriatus*) were impoverished near the cages. We found that benthic Crustacea were significantly impacted by the salmon farm, despite the presence of strong currents, probably due to the combined effects of organic wastes and the use of toxins to combat parasitic copepods. We recommend that "fallowing", whereby farm cages are moved between sites to allow benthic recovery, is not carried out at sites where long-lived biogenic habitats such as maerl occur because this will likely increase the area of habitat degradation.

Díaz-López, B. and Bernal-Shirai, J.A. **Marine aquaculture and bottlenose dolphins' (*Tursiops truncatus*) social structure.** *Behavioral Ecology and Sociobiology* 62(6): 887-894, 2008.

Notes: In this study, we investigate association patterns of 249 bottlenose dolphin feeding groups off Sardinia Island (Italy) from January 2000-May 2007 and describe how their association behaviour is related to their response to food patches created by a marine fin fish farm. We also tested the hypothesis that dolphins have different social structures with different feeding activities: Associations should decrease during opportunistic feeding behaviours as it is easier to capture prey, and cooperation is not as necessary. Sixteen individually identified bottlenose dolphins were observed participating in both opportunistic and not opportunistic feeding activities, with a mean of 30 ± 8 times and 9.6 ± 1 times, respectively. Bottlenose dolphins show non-random social behaviour during feeding and this behaviour differs depending on their specific foraging activity. Dolphin associations during feeding can be divided into three categories: acquaintances, affiliates, and feeding associates. Association behaviour during fish farm feeding is consistent with our hypothesis that during opportunistic behaviours, benefits from cooperation decrease, as it is easier to capture prey. Group size homogeneity in both feeding activities demonstrates that the number of dolphins engaging in foraging is not necessarily related with cooperation levels. Moreover, an adult dolphin may prefer to associate with a specific individual, independent of the sex, who shares the same foraging priorities. This study is the first to show how aquaculture is not only directly affecting marine predators but could also indirectly affect their social structure and behaviour.

Araki, H., Cooper, B., and Blouin, M.S. **Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild.** *Science* 318(5847): 100-103, 2007.

Notes: Captive breeding is used to supplement populations of many species that are declining in the wild. The suitability of and long-term species survival from such programs remain largely untested, however. We measured lifetime reproductive success of the first two generations of steelhead trout that were reared in captivity and bred in the wild after they were released. By reconstructing a three-generation pedigree with microsatellite markers, we show that genetic effects of domestication reduce subsequent reproductive capabilities by $\sim 40\%$ per captive-reared generation when fish are moved to natural environments. These results suggest that even a few generations of domestication may have negative effects on natural reproduction in the wild and that the repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered.

Krkošek, M., Ford, J.S., Morton, A., Lele, S., Myers, R.A., and Lewis, M.A. **Declining wild salmon populations in relation to parasites from farm salmon.** *Science* 318(5857): 1772-1775, 2007.

Notes: Rather than benefiting wild fish, industrial aquaculture may contribute to declines in ocean fisheries and ecosystems. Farm salmon are commonly infected with salmon lice (*Lepeophtheirus salmonis*), which are native ectoparasitic copepods. We show that recurrent louse infestations of wild juvenile pink salmon (*Oncorhynchus gorbuscha*), all associated with salmon farms, have depressed wild pink salmon populations and placed them on a trajectory toward rapid local extinction. The louse-induced mortality of pink salmon is commonly over 80% and exceeds previous fishing mortality. If outbreaks continue, then local extinction is certain, and a 99% collapse in pink salmon population abundance is expected in four salmon generations. These results suggest that salmon farms can cause parasite outbreaks that erode the capacity of a coastal ecosystem to support wild salmon populations.

Agerso, Y., Bruun, M.S., Dalsgaard, I., and Larsen, J.L. **The tetracycline resistance gene tet(E) is frequently occurring and present on large horizontally transferable plasmids in *Aeromonas* spp. from fish farms.** *Aquaculture* 266(1-4): 47-52, 2007.

Notes: The aim of the study was to characterize 30 unrelated tetracycline resistant *Aeromonas* spp. from fish farms where none of the tetracycline resistance genes tet(A-E) were detected by multiplex RCR in a previous study. By cloning, sequencing and designing alternative PCR primers the tetracycline resistance gene tet(E) was found in (27/30) 90% of the previously

negatively tested *Aeromonas* spp. The strains originated from farmed fish, water and sediment in Denmark ($n = 27$) and Canada ($n = 3$). The tet(E) gene was in several cases located on large horizontally transferable plasmids (approx. 150 kb) capable of interspecies transfer to *Escherichia coli*. This is the first report of horizontally transferable tet(E). Additionally, 15 motile *Aeromonas* strains with previously identified tetracycline resistance genes were tested, and this on one hand verified former findings of tet(E), but also identified more than one tet gene in some strains. The use of multiplex PCR for detection of tet(E) should be done with caution. Tet(E) seems to occur frequently in *Aeromonas* spp. from fish farms and may spread horizontally among bacteria in the aquatic environment.

LeVay, L., Carvalho, G.R., Quintio, E.T., Leбата, J.H., Ut, V.N., and Fushimi, H. **Quality of hatchery-reared juveniles for marine fisheries stock enhancement.** *Aquaculture* 268(1-4): 169-180, 2007.

Notes: The potential for stock enhancement by release of hatchery-reared juveniles continues to be a topic of interest to researchers and fisheries managers. While, in many studies, the focus has tended to be on the technology for production of juveniles, the need for a more multidisciplinary approach is now becoming accepted. Ideally, this includes studies of population dynamics and recruitment limitation of wild stocks, environment-stock interactions, habitat availability, genetic studies of wild and released stocks and integration with appropriate fisheries management. While it may be relatively straightforward to culture large numbers of seed animals, the quality of hatchery-reared juveniles may limit the effectiveness of any release programme. The quality of juveniles may be defined either by their ability to attain the age and size to recruit to a commercial fishery or their fitness to survive to contribute to the spawning stock. Many factors will inevitably influence batch-to-batch variability in the viability of hatchery-reared juveniles and their ability to recruit and compete in the wild. Some effects of nutrition and environment in the hatchery are well-known or at least recognised and their manipulation offers the potential for improvement of survivorship of juveniles post-release. The choice and utilisation of broodstock also represent a crucial stage in enhancement programmes, and considerations of bottleneck effects arising from reduced effective population size due to skewed parental and family contributions must be given careful consideration. A broodstock design that encompasses sufficient numbers of animals that reflect the genetic, and preferably ecological, identity of the stocks to be enhanced should be adopted. In addition, environmental conditions and husbandry practices within the hatchery as well as broodstock and larval nutrition can all influence the quality of offspring. Further conditioning and/or selection during nursery culture may also be critical in maximising the physiological and behavioural fitness of hatchery juveniles post-release. Although evaluation of long-term performance of individual batches of juveniles requires considerable effort or may be impossible in some cases, this type of quantification is likely to be an important component in the determination of the effectiveness of release programmes. This paper reviews the effects of hatchery and nursery practice on larval and juvenile fitness for stock enhancement and presents examples of comparisons of the quality of wild and hatchery-reared juveniles and the effect of pre-release conditioning on subsequent survival and growth.

Pelletier, N. and Tyedmers, P. **Feeding farmed salmon: Is organic better?** *Aquaculture* 272(1-4): 399-416, 2007.

Notes: Feed provision accounts for the majority of material and energetic inputs and emissions associated with net-pen salmon farming. Understanding and reducing the environmental impacts of feed production is therefore central to improving the biophysical sustainability of salmon farming as a whole. We used life cycle assessment (with co-product allocation by gross energy content) to compare the cradle-to-mill gate life cycle energy use, biotic resource use, and global warming, acidifying, eutrophying and aquatic ecotoxicity impacts associated with producing ingredients for four hypothetical feeds for conventional and organic salmon aquaculture in order to assess the benefits, if any, associated with a transition to organic feed use. Fish and poultry-derived ingredients generated substantially greater impacts than crop-derived ingredients. Despite the fact that organic crop ingredients had markedly lower life cycle impacts compared to equivalent conventional ingredients, substituting organic for conventional crop ingredients therefore resulted in only minor reductions to the total impacts of feed production because the benefits of this substitution were effectively overwhelmed by the much larger impacts associated with animal-derived ingredients. Replacing fish meals/oils from dedicated reduction fisheries with fisheries by-product meals/oils markedly increased the environmental impacts of feed production, largely due to the higher energy intensity of fisheries for human consumption, and low meal/oil yield rates of fisheries by-products. Environmental impacts were considerably lower when feeds contained reduced proportions of fish and poultry-derived ingredients. These results indicate that current standards for organic salmon aquaculture, which stipulate the use of organic crop ingredients and fisheries by-product meals and oils, fail to reduce the environmental impacts of feed production for the suite of impact categories considered in this study. This

information should be of interest to feed producers and aquaculturists concerned with improving the biophysical sustainability of their products, and bodies responsible for aquaculture certification, ecolabeling, and consumer awareness programs.

Kesarcodi-Watson, A., Kaspar, H., Lategan, M.J., and Gibson, L. **Probiotics in aquaculture: The need, principles and mechanisms of action and screening processes.** *Aquaculture* 274(1): 1-14, 2008.

Notes: Aquaculture production of molluscs is worth US\$11 billion per year and represents 65% of world mollusc product. A significant limitation to the industry is loss of stock through bacterial disease. Traditional methods to combat disease with antibiotics have been questioned and alternatives have been sought. The field of probiotics as well as the screening methods used to acquire probiotic strains for the alternative management of disease in aquaculture is discussed. This review provides a comprehensive summary of probiotics in aquaculture with special reference to mollusc culture.

Lorenzen, K. **Understanding and managing enhancement fisheries systems.** *Reviews in Fisheries Science* 16(1-3): 10-23, 2008.

Notes: Aquaculture-based fisheries enhancement is a set of management approaches involving the release of cultured organisms to enhance, conserve, or restore fisheries. Enhancement has a long history, and substantial progress has been made in key areas of science underpinning the activity. Yet the contribution of enhancements to global fisheries production has remained small, and there are few outright "success stories." Enhancements enter into complex fisheries systems and, to be successful, must contribute to a broad set of biological, economic, social, and institutional management objectives. In doing so, enhancements need to add value to, or outperform, alternative measures such as fishing regulation or habitat management. This is possible only under certain conditions and may require transformations in multiple biological-technical as well as market and institutional attributes of the fisheries system. I outline a framework for the integrated analysis of enhancement fisheries systems and a systematic, transparent, and stakeholder- participatory development process.

Zohar, Y., Hines, A.H., Zmora, O., Johnson, E.G., Lipcius, R.N., Seitz, R.D., Eggleston, D.B., Place, A.R., Schott, E.J., Stubblefield, J.D., and Chung, J.S. **The Chesapeake Bay blue crab (*Callinectes sapidus*): A multidisciplinary approach to responsible stock replenishment.** *Reviews in Fisheries Science* 16(1-3): 24-34, 2008.

Notes: The Chesapeake Bay has traditionally been one of North America's most productive fishing grounds, supporting the world's largest blue crab fishery. During the last several decades, fishing mortality and environmental degradation led to 70% drop in the bay's blue crab abundance, 84% decline in its spawning stock, and historically low levels of juvenile recruitment as well as nursery habitats being below carrying capacity. This situation makes the Chesapeake Bay blue crab an appropriate candidate for responsible stock enhancement. A multidisciplinary, multi-institutional program was developed to study the basic biology and life cycle of the blue crab, develop hatchery and nursery technologies for mass production of blue crab juveniles, and assess the potential of using cultured juveniles to enhance blue crab breeding stocks and, in turn, bay-wide abundance and harvests. Basic biology and culture studies enabled closing the life cycle of the blue crab in captivity. Juvenile crabs have been produced year round, with excellent survival. During 2002-2006, over 290,000 cultured crabs were tagged and experimentally released into the bay's nursery habitats. Cultured crabs survived as well as their wild counterparts, increased local populations at release sites by 50-250%, grew quickly to sexual maturity, mated, and migrated from the release sites to spawning grounds, contributing to the breeding stock as soon as 5 to 6 months post-release. Findings reported in this text and other articles in this volume are indicative of the feasibility of our approach of using hatchery juveniles to replenish the blue crab breeding stocks in the Chesapeake Bay.

Arnold, W.S. **Application of larval release for restocking and stock enhancement of coastal marine bivalve populations.** *Reviews in Fisheries Science* 16(1-3): 65-71, 2008.

Notes: The coastal zone in the United States and in other areas worldwide is under increasing stress from human population growth and associated development, and that stress extends to the animal populations that occupy coastal habitats.

Considerable effort is being expended to restore the habitats and animals that characterize this biome. I herein describe historic and recent developments regarding the application of the larval release approach to marine animal population restocking efforts. Beginning with cod (*Gadus morhua*) larvae in the late 1800s, the larval form has been exploited for restocking of various fish and invertebrate species with mixed results. Success has been elusive when working with cod and hard clams (*Mercenaria* spp.), but efforts using striped bass (*Morone saxatilis*), abalone (*Haliotis* spp.), and most recently bay scallops (*Argopecten irradians*) have been at least partially successful. In the case of bay scallops, competent (ready-to-settle) larvae released into containment enclosures were tracked through the post-settlement, juvenile, and adult life stages. That sampling scheme provided evidence that the released larvae ultimately contributed to a substantial increase in the subsequent year-class. However, those results are equivocal, and rigorous genetic sampling will be required to fully document the linkage between larval release and subsequent year-class strength. It is concluded that larval release, while not suitable for all species in all situations, may be an effective strategy for rebuilding marine animal populations.

Young, A.C., Johnson, E.G., Davis, J.L.D., Hines, A.H., Zmora, O., and Zohar, Y. **Do hatchery-reared blue crabs differ from wild crabs, and does it matter?** *Reviews in Fisheries Science* 16(1-3): 254-261, 2008.

Notes: Successful use of hatchery-reared juveniles to enhance recruitment-limited populations or severely depleted stocks is contingent upon their ability to survive and grow upon release into the wild. Hatchery conditions often result in juveniles that exhibit morphological, physiological, or behavioral characteristics different from their wild counterparts. Managers of stock enhancement or restocking programs need to assess whether any such deficiencies translate into differences in performance between hatchery-reared and wild juveniles in the field. If so, the deficits may be minimized through conditioning strategies. In this review, we summarize various aspects of the morphology and behavior of cultured and wild blue crabs, *Callinectes sapidus*, and compare our work on these crabs to studies on other invertebrates. We identify similarities and differences between cultured blue crabs and wild conspecifics. In some cases where differences existed, conditioning of the hatchery-reared crabs before release rapidly mitigated the defects, and, overall, any remaining differences did not translate into decreased survival. We conclude that there are no significant impediments to the fitness of hatchery-reared blue crabs used in release programs.

Hara, M., Onoue, S., and Taniguchi, N. **Assessing the impact of releasing exogenous hatchery-reared juveniles of Pacific abalone, *Haliotis discus*.** *Reviews in Fisheries Science* 16(1-3): 278-284, 2008.

Notes: We studied the impact of releasing exogenous hatchery-reared juveniles on populations in Pacific abalone based on 10 microsatellite loci at the population and individual level. Standard measures of genetic variation (RS and HE) for collections from Ezo- and Kuro-abalone habitats did not differ. However, samples from Ezo- and Kuro-abalone habitats, respectively, were clearly divided into genetically distinct clusters; a result that was consistent with the FST analysis. In population-assignment testing, most individuals collected from Kuro-abalone habitats, where intensive release of hatchery-reared Ezo-abalone juveniles have been carried out, were assigned to a genetically defined Kuro-abalone group, suggesting that most of exogenous hatchery-reared Ezo-abalone had difficulty reproducing successfully in Kuro-abalone habitats. However, in the warm-water sampling area stocked with the greatest number of exogenous Ezo-abalone hatchery-reared juveniles, the numbers of misassigned individuals were highest. This suggests that the reproductive contribution of stocked hatchery-reared Ezo-abalone cannot be ruled out completely. Therefore, hatchery-mediated introgression of exogenous Ezo-abalone genes into the Kuro-abalone subspecies remains a possibility. To support the goal of a genetically fit and sustainable abalone fishery, further detailed studies and evaluation of the potential impact of introgression are needed.

Jorstad, K.E., van der Meeren, T., Paulsen, O.I., Thomsen, T., Thorsen, A., and Svasand, T. **"Escapes" of eggs from farmed cod spawning in net pens: Recruitment to wild stocks.** *Reviews in Fisheries Science* 16(1-3): 285-295, 2008.

Notes: Escapes of farmed fish from aquaculture installations, as well as large scale stock enhancement and sea ranching activities, are regarded as risk factors for negative genetic impacts on native gene pools. These aspects have been discussed for several decades, and a number of recent experiments on Atlantic salmon have clearly demonstrated dramatically reduced overall fitness of farmed offspring compared with offspring of wild origin. The Atlantic cod (*Gadus morhua* L.) is now the most promising new marine species for large scale farming in Norway, and more than 500 commercial farming licenses have been issued, corresponding to a maximum annual production capacity of about 300,000 tonnes. In comparison with the

environmental problems caused by escapes from the salmon farming industry, cod farming presents new challenges. As a marine species, cod are able to spawn in the net pens during the on-growing period and thus release genetic material into the environment. Coastal cod stocks in Norwegian waters are depleted and therefore may be particularly vulnerable to genetic interaction with farmed cod. Thus, there is an urgent need for more detailed knowledge of potential hazards. A pilot experiment performed in Heimarkspollen in Austevoll (a practically landlocked fjord) demonstrated for the first time that farmed cod are capable of producing viable cod larvae that mix with larvae from wild cod. The farmed cod used in the pilot experiment were homozygotic for a rare allele (GPI-1*30), and mature fish were placed in a net pen to allow spawning and egg drift into the surrounding water to take place. Surveys of eggs found the highest densities in the vicinity of the net pen. Later larval surveys found that 20% to 25% of the larvae sampled in the area possessed the unique genetic marker and could therefore be traced to the spawning cod in the net cage. Numerous genetically marked larvae were also found outside Heimarkspollen, indicating a high degree of dispersal of eggs and larvae by tidal advection.

Bartley, D.M. and Bell, J.D. **Restocking, stock enhancement, and sea ranching: Arenas of progress.** *Reviews in Fisheries Science* 16(1-3): 357-365, 2008.

Notes: There are concerns about the sustainability of the world's capture fisheries at the current total level of ~ 96 million tons per year. The warning signals are an increase in the proportion of depleted or recovering stocks, from about 10% in 1974 to 28% in 2004, and a corresponding decrease of under-to moderately exploited stocks from about 40% to 24%. It is widely acknowledged that reductions in fishing effort and restoration of fish habitats are needed to improve resilience of capture fisheries. Nevertheless, for some coastal fisheries, application of aquaculture technology through restocking, stock enhancement, and sea ranching also promises to help restore lost production and possibly increase harvests beyond historical levels. However, application of this technology still has a long way to go before integrated management systems are in place that successfully address all the biological, ecological, social, cultural, and economic issues. The main challenges include identifying when and where to use the interventions to add value to other forms of management; integrating these initiatives with institutional and fisheries management regimes; monitoring success of the interventions; producing cultured juveniles cost-effectively; and releasing them in the wild so that they survive in high proportions. We summarize progress to date by describing the main lessons learned from 30 years of research into the potential for releasing cultured juveniles into coastal fisheries, and from application of this technology at various scales. We also describe other lessons to be learned from stocking freshwater habitats and other emerging issues for enhanced coastal fisheries, such as market opportunities and the need to develop widely accepted definitions for "restocking," "stock enhancement," and "sea ranching." These definitions are needed so that nations can report and monitor different strategies used to improve productivity of capture fisheries.
