Marine Science Review – 186
Aquaculture

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In this review:

A. Recent articles – no abstract available

Brooks, K.M. and Stucchi, D.J. **The effects of water temperature, salinity and currents on the survival and distribution of the infective copepodid stage of the salmon louse (*Lepeophtheirus salmonis*) originating on Atlantic salmon farms in the Broughton Archipelago of British Columbia, Canada (Brooks, 2005) - A response to the rebuttal of Krkosek et al. (2005a).** *Reviews in Fisheries Science* 14(1-2): 13-23, 2006.

B. Recent publications available online

FAO. 2006. **State of world aquaculture: 2006.** FAO Fisheries Technical Paper No. 500, Rome, FAO. 134pp.

Available at: ftp://ftp.fao.org/FI/DOCUMENT/t500_advanced/advanced_t500e.pdf

Notes: Aquaculture is developing, expanding and intensifying in almost all regions of the world, except in sub-Saharan Africa. Global population demand for aquatic food products is increasing, the production from capture fisheries has levelled off, and most of the main fishing areas have reached their maximum potential. Sustaining fish supplies from capture fisheries will, therefore, not be able to meet the growing global demand for aquatic food. Aquaculture appears to have the potential to make a significant contribution to this increasing demand for aquatic food in most regions of the world; however, in order to achieve this, the sector (and aquafarmers) will face significant challenges. The key development trends indicate that the sector continues to intensify and diversify and is continuing to use new species and modifying its systems and practices. Markets, trade and consumption preferences strongly influence the growth of the sector, with clear demands for production of safe and quality products. As a consequence, increasing emphasis is placed on enhanced enforcement of regulation and better governance of the sector. It is increasingly realized that this cannot be achieved without the participation of the producers in decision-making and regulation process, which has led to efforts to empower farmers and their associations and move towards increasing self-regulation. These factors are all contributing to improve management of the sector, typically through promotion of "better management" practices of producers. This document analyses the past trends that have led the aquaculture sector to its current status and describes its current status globally.

C. Recent articles with abstracts

Krkosek, M., Lewis, M.A., Volpe, J.P., and Morton, A. **Fish farms and sea lice infestations of wild juvenile salmon in the Broughton Archipelago - A rebuttal to Brooks (2005).** *Reviews in Fisheries Science* 14(1-2): 1-11, 2006.

Notes: Contrary to several recent studies, a review (Brooks, 2005) of sea lice (*Lepeophtheirus salmonis*) interactions between wild and farm salmon in the Broughton Archipelago, British Columbia, Canada, concluded that there is little potential for sea lice transmission from farm to wild salmon. In this rebuttal, we show that this conclusion was based on a flawed interpretation of

how salinity affects louse development, a misunderstanding of how the timing of salinity changes corresponds to the timing of the juvenile salmon migration, models of larval dispersion that overestimate the transport of louse larvae, and a selective and misleading assessment of the literature. We analyze and extend the current models of larval dispersion and demonstrate the (perhaps counter-intuitive) result that sustained high abundances of infectious larvae should be expected near lice-infested salmon farms. We also highlight important studies overlooked in Brooks (2005) and clarify some misinterpretations. Counter to the conclusions in Brooks (2005), the modeling and empirical work to date on sea lice interactions between wild and farm salmon are consistent and point to a strong association between salmon farming and recurrent infestations of wild juvenile salmon in the Broughton Archipelago.

Giraud, E., Douet, D.G., LeBris, H., Bouju-Albert, A., Donnay-Moreno, C., Thorin, C., and Pouliquen, H. **Survey of antibiotic resistance in an integrated marine aquaculture system under oxolinic acid treatment.** *FEMS Microbial Ecology* 55(3): 439-448, 2006.

Notes: The consequences of antibiotic use in aquatic integrated systems, which are based on trophic interactions between different cultured organisms and physical continuity through water, need to be examined. In this study, fish reared in a prototype marine integrated system were given an oxolinic acid treatment, during and after which the level of resistance to this quinolone antibiotic was monitored among vibrio populations from the digestive tracts of treated fish, co-cultured bivalves and sediments that were isolated on thiosulfate-citrate-bile-sucrose. Oxolinic acid minimum inhibitory concentration distributions obtained from replica plating of thiosulfate-citrate-bile-sucrose plates indicated that a selection towards oxolinic acid resistance had occurred in the intestines of fish under treatment. In contrast, and despite oxolinic acid concentrations higher than minimum inhibitory concentrations of susceptible bacteria, no clear evolution of resistance levels was detected either in bivalves or in sediments.

Whitmarsh, D.J., Cook, E.J., and Black, K.D. **Searching for sustainability in aquaculture: An investigation into the economic prospects for an integrated salmon–mussel production system.** *Marine Policy* 30(3): 293-298, 2006.

Notes: The pollution effects of cage aquaculture represent an external cost to society, and the challenge for environmental economists has been to estimate the magnitude of these costs and to suggest ways in which they can be mitigated or 'internalised'. One possible mitigation strategy involves the development of integrated production systems based on polyculture, and this paper examines the financial viability of such a system that integrates the farming of salmon and mussels. The results demonstrate the commercial potential of an integrated salmon-mussel production system under present market conditions, but highlight the critical role played by future price trends.

Morita, K., Morita, S.H., and Fukuwaka, M. **Population dynamics of Japanese pink salmon (*Oncorhynchus gorbuscha*): are recent increases explained by hatchery programs or climatic variations?** *Canadian Journal of Fisheries and Aquatic Sciences* 63(1): 55-62, 2006.

Notes: Hatchery programs involving the mass release of artificially propagated fishes have been implemented worldwide. However, few studies have assessed whether hatchery programs actually increase the net population growth of the target species after accounting for the effects of density dependence and climatic variation. We examined the combined effects of density dependence, climatic variation, and hatchery release on the population dynamics of Japanese pink salmon (*Oncorhynchus gorbuscha*) from 1969 to 2003. The population trends were more closely linked to climatic factors than to the intensity of the hatchery programs. The estimated contributions of hatchery-released fry to catches during the past decade are small. We concluded that the recent catch increases of Japanese pink salmon could be largely explained by climate change, with increased hatchery releases having little effect.

Soto, D., Arismendi, I., Gonzalez, J., Sanzana, J., Jara, F., Jara, C., Guzman, E., and Lara, A. **Southern Chile, trout and salmon country: invasion patterns and threats for native species.** *Revista Chilena de Historia Natural* 79(1): 97-117, 2006.

Notes: In order to evaluate the present distribution patterns of salmonids and their potential effects on native fish, we sampled 11 large lakes and 105 streams, encompassing a total of 13 main hydrographic watersheds of southern Chile (39º to 52ºS). Overall, trout (*Salmo trutta* and *Oncorhynchus mykiss*) accounted for more thin 60% of total fish abundance and more than 80% of total biomass, while 40% of the streams sampled did not have native fish. Salmon, introduced for aquaculture, such as *O. kisutc*h, *Salmo salar*, and *O. tshawytscha*, were only present in lakes with salmon farming and did not seem to be reproducing naturally in affluent streams. We tested the effect of river geographic origin (Andes mountains, central valley, or coastal range) on fish abundance and found that rainbow trout was more restricted to the Andean streams with higher water discharge, while brown trout was widely distributed and did not relate to any of several catchment attributes measured. The abundance of native fish was greater in lakes than in streams and the highest native fish biodiversity occurred in streams of the central valley. The most common native species were *Galaxias maculatus*, *G. platei*, *Brachygalaxias bullocki*, *Aplochiton zebra* and *Basilichthys australis*. Streams with higher conductivity, larger pool areas, more fine sediments, and low brown trout densities were more suitable for native fish. Thus, catchments with higher anthropogenic disturbance appeared as refuges for native species. Given the descriptive nature of our study we can only presume the negative impacts of trout and salmon on native fish; an effect which should be superimposed on biogeographical conditioning of present distribution. Yet based on the present abundance and distribution patterns of salmonids and native fish, negative effects are very likely. Conservation of native fish biodiversity in central valley streams, far from protected areas or national parks and fully exposed to human perturbations represents a great challenge. We propose to enhance conservation by exerting a stronger sport fishing pressure on trout in those streams.

Modica, A., Scilipoti, D., LaTorre, R., Manganaro, A., and Sara, G. **The effect of mariculture facilities on biochemical features of suspended organic matter (Southern Tyrrhenian, Mediterranean).** *Estuarine, Coastal and Shelf Science* 66(1-2): 177-184, 2006.

Notes: A comparison of a Mediterranean aquaculture impacted area and control areas was made to assess the effect of fish farm waste discharge on the biochemical features of the water column. Trophic variables commonly used in marine ecology such as total suspended matter, suspended chlorophyll-a, biochemical features of particulate organic matter (proteins, lipids and carbohydrates) and biopolymeric carbon were chosen as the best descriptors of trophic conditions. An initial analysis of data from the impact area was carried out in order to test the effect of farm waste using a gradient of distances downstream from the fish farm cages (50 m, 300 m, 1000 m). The results were then compared with a control site 750 m upstream. Subsequently, the cage data set was asymmetrically compared with data from five controls collected some years before, when no aquaculture activity was present in the Gulf. The analysis revealed differences in chlorophyll-a, carbohydrates and some trophic ratios between the farm impact area and the controls taken upstream. A clear pattern of trophic enrichment of the water column around the fish farm was evidenced since concentrations in the sites increased along with their distance from the cages. The downstream sites overall were significantly different, trophically speaking, from the five control areas, while the trophic variables of the upstream control were not different from the external controls. Results showed that fish farm facilities provided an organic enrichment of the water column up to at least 1000 m downstream from the cages, producing a deviation of trophodynamics from normal ambient conditions.

Shelton, W.L. and Rothbard, S. **Exotic species in global aquaculture - A review.** *Israeli Journal of Aquaculture - Bamidgeh* 58(1): 3-28, 2006.

Notes: The culture of exotic fishes contributes about 17% to global food aquaculture production. Transplanted native species add substantially to the aquatic harvest of food and sport fishes in many countries. Some countries are very dependent on the cultivation of non-native species; yields of exotics exceed 25% of the total harvest in China, 60% of the freshwater harvest in the Philippines, and 50% of the production in Brazil. Aquatic food production in Israel is predominately from introduced fishes. In the USA, transplanted species are economically important as food and sport fish and exotics are used in resource management as well as a major food source. Countries of origin for globally important fishes include China (endemic carps), USA (Atlantic salmon and rainbow trout), Europe (common carp), and Africa (tilapias). The aquaculture production of food fish will become increasingly vital as oceanic capture fisheries continue to stagnate. Exotic and transplanted fishes that are widespread today will represent a greater proportion of future aquaculture production because technology for their culture is already well known and can readily be applied, and because these species are more easily domesticated and genetically improved.

Trushenski, J.T., Kasper, C.S., and Kohler, C.C. **Challenges and opportunities in finfish nutrition.** *North American Journal of Aquaculture* 68(2): 122-140, 2006.

Notes: Much of the criticism leveled at aquaculture (e.g., dependency on animal-derived feedstuffs, nutrient-laden effluent discharges, and increased organic contamination in edible products) can be traced to the feeds in use. Accordingly, finfish nutritionists are being challenged to formulate feeds that not only meet the nutritional requirements of livestock but also minimize production costs, limit environmental impacts, and enhance product quality. These challenges not only add considerable complexity to finfish nutrition but also afford opportunities to avoid some of the mistakes made by other industries in the past. From a review of the current status of finfish nutrition with respect to major nutrient classes, we comment on future opportunities and promising avenues of research. Alternative protein sources, specifically those derived from marine bycatch, plants, and microbes, are discussed, as well as methods to facilitate their implementation in finfish feeds. Dietary lipid, its role in fish bioenergetics and physiology, and quality of aquaculture products is reviewed with special emphasis on alternative lipid sources and finishing diets. Carbohydrates and fiber are discussed in terms of nutrient-sparing, least-cost diet formulation and digestive physiology. Micronutrients are reviewed in terms of current knowledge of requirements and, along with other dietary immunostimulants. Are given further consideration in a review of nutriceuticals and application in finfish feeds. The status of nutritional research in new aquaculture species is also outlined. By integrating classical approaches with emerging technologies, dietary formulations, and species, finfish nutritionists may identify means to increase production efficiency and sustainability and provide for the continued success of aquaculture.

Lasiak, T.A., Underwood, A.J., and Hoskin, M. **An experimental assessment of the potential impacts of longline mussel farming on the infauna in an open coastal embayment.** *Aquatic Conservation: Marine and Freshwater Ecosystems* 16(3): 289-300, 2006.

Notes: 1. The existence of perceived ecological impacts and development of adaptive management solutions to mitigate these problems are important issues in sustainable aquaculture. This paper examines the general impacts of two newly established trial longline installations on the infauna in Twofold Bay, a large, coastal embayment in south-east Australia. 2. We hypothesized that the physical presence of these longline installations and the biological activities of the mussels they supported would result in temporal changes in densities of infaunal taxa below installations differing from those at undisturbed control sites. We also predicted different patterns of variability in infauna between longline and control sites from before to after the longlines were stocked. These hypotheses were tested by using a beyond-BACI sampling design and asymmetrical analyses of variance to compare changes in densities of taxa at several different spatial scales below the proposed longline sites with those at two adjacent control sites, before and after the longlines were stocked. 3. After 18 months of longline operations, there was no evidence of any impact on total number of taxa, nor densities of individual taxa. Short-term temporal trends in densities in plots at control sites from April to May 2001 were often as different from each other as from those at the longline site. This indicates that densities of taxa at the farm site were within the range typically found at undisturbed sites, so there were no ecological impacts from the farm. 4. These results do not concur with previous studies on impact of mussel farming in semi-enclosed coastal waters. Differences in location, scale of production, duration of operation and assimilative capacity of the environment probably contributed to this discrepancy. The infauna in Twofold Bay either do not respond to this form of disturbance or have not yet been exposed to disturbance of a sufficient magnitude, or for a sufficient period of time, to elicit a detectable response. Better definition of the potential ecological impacts associated with aquaculture, plus their scale and magnitude in different environments is needed to design experiments and monitoring programmes to detect specific impacts. This activity can only be considered sustainable once we know that these impacts are localized, reversible and short-term.

Sather, P.J., Ikonomou, M.G., and Haya, K. **Occurrence of persistent organic pollutants in sediments collected near fish farm sites.** *Aquaculture* 254(1-4): 234-247, 2006.

Notes: The sediment under four New Brunswick fish farm net pens was examined for the persistent organic pollutants (POPs): polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs), polybrominated diphenyl ethers (PBDEs), pesticides, and polyaromatic hydrocarbons (PAHs). Concentrations of these POPs were compared according to distance from the net pen (0 m, 25 m, 50 m, and 100 m), sediment quality (anoxic, hypoxic, nonnoxic, and a remediation site), and published levels from locations worldwide. In general, at the anoxic sites POP concentrations were

higher than at other sites, and they did not drop in concentration over distance to 100 m. The highest concentrations of the POPs examined here were low relative to polluted sites worldwide.

Debruyn, A.M.H., Trudel, M., Eyding, N., Harding, J., McNally, H., Mountain, R., Orr, C., Urban, D., Verenitch, S., and Mazumder, A. **Ecosystemic effects of salmon farming increase mercury contamination in wild fish.** *Environmental Science and Technology* 40(11): 3489-3493, 2006.

Notes: Net-pen salmon aquaculture has well-known effects on coastal ecosystems: farm waste increases sediment organic content and the incidence of sediment anoxia, supports increased production of deposit-feeding invertebrates, and attracts higher densities of demersal fish and other mobile carnivores. These impacts are widely considered to be localized and transitory, and are commonly managed by imposing a period of fallowing between cycles of production. The implications of these ecosystemic effects for contaminant cycling, however, have not previously been considered. We found elevated levels of mercury in demersal rockfishes near salmon farms in coastal British Columbia, Canada, attributable to a combination of higher rockfish trophic position and higher mercury levels in prey near farms. Mercury concentrations in long-lived species such as rockfishes change over a longer time scale than cycles of production and fallowing, and thus at least some important effects of fish farms may not be considered transitory.

Cabello, F.C. **Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment.** *Environmental Microbiology* 8(7): 1137-1144, 2006.

Notes: The accelerated growth of finfish aquaculture has resulted in a series of developments detrimental to the environment and human health. The latter is illustrated by the widespread and unrestricted use of prophylactic antibiotics in this industry, especially in developing countries, to forestall bacterial infections resulting from sanitary shortcomings in fish rearing. The use of a wide variety of antibiotics in large amounts, including non-biodegradable antibiotics useful in human medicine, ensures that they remain in the aquatic environment, exerting their selective pressure for long periods of time. This process has resulted in the emergence of antibiotic-resistant bacteria in aquaculture environments, in the increase of antibiotic resistance in fish pathogens, in the transfer of these resistance determinants to bacteria of land animals and to human pathogens, and in alterations of the bacterial flora both in sediments and in the water column. The use of large amounts of antibiotics that have to be mixed with fish food also creates problems for industrial health and increases the opportunities for the presence of residual antibiotics in fish meat and fish products. Thus, it appears that global efforts are needed to promote more judicious use of prophylactic antibiotics in aquaculture as accumulating evidence indicates that unrestricted use is detrimental to fish, terrestrial animals, and human health and the environment.

Kalantzi, L. and Karakassis, L. **Benthic impacts of fish farming: Meta-analysis of community and geochemical data.** *Marine Pollution Bulletin* 52(5): 484-493, 2006.

Notes: A number of 41 papers dealing with the benthic effects of fish farming were reviewed and the values of the variables studied were extracted to be used in a meta-analysis of effects. The papers used covered a wide range of farmed species, geographic regions, management practices and specific site characteristics (e.g., depth, exposure, and sediment type). Therefore, the total data-set may not be considered as biased towards a particular set of conditions as is often the case with data collected in a single study. More than 120 biological and geochemical variables were monitored, occasionally using different sampling and analytical protocols for the same variables. The rank correlation analysis between all possible pairs of variables in the data set showed a large number of significant positive or negative correlations, reflecting the response of these variables to benthic organic enrichment. The use of stepwise regression showed that most biological and geochemical variables are determined by a combination of distance from the farm with bottom depth and/or latitude. Results of stepwise regression, repeated separately for each type of sediment, showed that although the general pattern was similar among different types of sediments, the coefficients varied considerably indicating changes of the distance affected by settling particulate organic material for different sediment types. The overall conclusion is that the complicated interactions between variables and the lack of data, such as current speed, induce difficulties in setting common or uniform environmental quality standards for benthic effects of fish farming and these should take into account the existing considerable differences between geographic regions, depth zones and sediment types.

Villanueva, R.D., Yap, H.T., and Montano, M.N.E. **Intensive fish farming in the Philippines is detrimental to the reef-building coral *Pocillopora damicornis*.** *Marine Ecology Progress Series* 316: 165-174, 2006.

Notes: To determine the effects of fish farm effluent on the reef-building species *Pocillopora damicornis*, we exposed different life stages of the coral to a gradient of effluent concentrations. After 81 d no juvenile coral survived at the Fish Farm site or at the site receiving intermediate concentrations, and survival rates were low (< 20 %) at the site receiving minimal effluent concentrations and at the reference site. At the Fish Farm site, juveniles (on terracotta tiles) were completely overgrown by barnacles. Coral nubbins and mature colonies displayed similar survivorship trends along the effluent gradient, i.e. higher mortality with higher effluent concentrations. At the site of intermediate exposure, surviving nubbins had skeletal growth rates half of those from the site of minimal influence and from the reference site. The mean gross photosynthesis to respiration ratio of coral branches deployed at the fish farm was below the physiological compensatory value of 1, whereas values of about 1 were attained at the sites of diminishing effluent influence. Reduced larval output in mature colonies exposed to intermediate and minimal concentrations of fish farm effluent were observed as compared to those from the reference site. No reproductive measurements could be conducted for colonies at the Fish Farm site, due to high mortality. At the larval stage, metamorphosis was diminished both on substrates collected from, and tiles conditioned in, the Fish Farm environment, compared to those from sites of diminishing effluent influence. Hence, many aspects of coral biology are impaired by exposure to effluent from intensive fish farming.

Lyle-Fritch, L.P., Romero-Beltran, E., and Paez-Osuna, F. **A survey on use of the chemical and biological products for shrimp farming in Sinaloa (NW Mexico).** *Aquacultural Engineering* 35(2): 135-146, 2006.

Notes: The present work documents the use and application rates of chemicals and biological products for shrimp farming in Sinaloa, Mexico. Representative interviews of the coastal region of Sinaloa state were conducted; 23 shrimp farmers were interviewed. During the previous year of the survey (2001), eight different diseases were registered, the most frequent being those associated to gregarines, vibriosis, white spot syndrome virus and necrotizing hepatopancreatitis. A total of 106 different types of products were identified, on an average, 41.7 products were applied in each farm. The most commonly used products were feed additives, liming materials, inorganic fertilizers and antibiotics. In comparison with shrimp farms from Philippines and Thailand, farms from Sinaloa utilize a higher number of feed additives, vitamins and antibiotics and fertilizers, while the contrary occurs with the use of pesticides, disinfectants and soil and water treatment compounds. Finally, some regulations and ecotoxicological effects of chemical wastes on associated ecosystems are discussed.

Krkosek, M., Lewis, M.A., Morton, A., Frazer, L.N., and Volpe, J.P. **Epizootics of wild fish induced by farm fish.** *Proceedings of the National Academy of Sciences [USA]* 103(42): 15506-15510, 2006.

Notes: The continuing decline of ocean fisheries and rise of global fish consumption has driven aquaculture growth by 10% annually over the last decade. The association of fish farms with disease emergence in sympatric wild fish stocks remains one of the most controversial and unresolved threats aquaculture poses to coastal ecosystems and fisheries. We report a comprehensive analysis of the spread and impact of farm-origin parasites on the survival of wild fish populations. We mathematically coupled extensive data sets of native parasitic sea lice (*Lepeophtheirus salmonis*) transmission and pathogenicity on migratory wild juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon. Farm-origin lice induced 9-95% mortality in several sympatric wild juvenile pink and chum salmon populations. The epizootics arise through a mechanism that is new to our understanding of emerging infectious diseases: fish farms undermine a functional role of host migration in protecting juvenile hosts from parasites associated with adult hosts. Although the migratory life cycles of Pacific salmon naturally separate adults from juveniles, fish farms provide *L. salmonis* novel access to juvenile hosts, in this case raising infection rates for at least the first ~2.5 months of the salmon's marine life (~80 km of the migration route). Spatial segregation between juveniles and adults is common among temperate marine fishes, and as aquaculture continues its rapid growth, this disease mechanism may challenge the sustainability of coastal ecosystems and economies.

Rosenlund, G. and Skretting, M. **Worldwide status and perspective on gadoid culture.** *ICES Journal of Marine Science* 63(2): 194-197, 2006.

Notes: Currently, Atlantic cod (*Gadus morhua*) is the primary species being developed for commercial culture, with activities concentrated around the North Atlantic. In addition, closed life cycles have been established for haddock (*Melanogrammus aeglefinus*), pollock (*Pollachius pollachius*), and hake (*Merluccius australis*), but production of these species (in Canada, Spain, and Chile) is rather modest. In the short- to medium-term, Atlantic cod will be the dominant gadoid species in culture, and it is believed that production can reach levels similar to those of farmed salmon within the next 15-20 years. This development is possible because methods for year-round production of juveniles and significant hatchery capacity have been established. Also, there is a demand for farmed cod to fill the gap between increasing market needs and diminishing supply from fisheries. However, challenges must be met if cod farming is to reach its anticipated potential. Juvenile production must become more reliable in terms of survival and quality. For the on-growing phase, the supply of cost-efficient feeds produced from sustainable raw materials is of utmost importance. Consumer markets need to be developed with an emphasis on quality and food safety. Relatively little is known about health management for gadoid species.

Bekkevold, D., Hansen, M.M., and Nielsen, E.E. **Genetic impact of gadoid culture on wild fish populations: predictions, lessons from salmonids, and possibilities for minimizing adverse effects.** *ICES Journal of Marine Science* 63(2): 198-208, 2006.

Notes: Little is known about the effects of ranched gadoids escaping into wild populations, and plans for substantial up-scaling of gadoid mariculture raise concerns about detrimental effects on local gene pools. Genetic studies from salmonid populations subjected to intentional or unintentional releases of hatchery-produced fish suggest that wild gene pools are affected by introgression, but that the genetic impact can be minor relative to expectations from the often substantial numbers of released hatchery fish. However, even if resilience to introgression is a general trend, wild population fitness is still predicted to be jeopardized by releases. In this paper, we review theoretical genetic effects of escapes of cultivated individuals and the empirical evidence for introgression effects, which are based mainly on salmonid studies. Based on knowledge of gadoid population structure and life history traits, we make predictions for effects of gadoid mariculture on wild populations and discuss approaches for monitoring and minimizing introgression effects.

Jonsson, B. and Jonsson, N. **Cultured Atlantic salmon in nature: a review of their ecology and interaction with wild fish.** *ICES Journal of Marine Science* 63(7): 1162-1181, 2006.

Notes: When cultured Atlantic salmon are released into nature, they compete with wild fish for food, space, and breeding partners. As a result of morphological, physiological, ecological, and behavioural changes that occur in hatcheries, their competitive ability often differs from that of wild fish. These changes are partly phenotypic and partly genetic. Cultured juveniles' faster growth rate influences age and size at smelting and maturity, reproductive output, and longevity. Fast-growing parr tend to smolt younger, produce more but smaller eggs, attain maturity earlier, and die younger. Juvenile learning influences a number of behavioural traits, and differences in early experience appear to affect feeding and spawning success, migratory behaviour, and homing ability. Genetic change in hatcheries is chiefly the result of natural selection, with differential mortality among genotypes and broodstock selection based on production traits such as high adult body mass and fast growth rate. Experimental evidence has revealed that cultured parr's greater aggression often allows them to dominate wild parr, although smaller cultured part can be subordinated if they co-occur in fast-flowing water and if wild smolts have established prior residence. During spawning, the fitness of wild salmon is superior to that of cultured conspecifics. Cultured males are inferior to wild males in intra-sexual competition, courting, and spawning; cultured females have greater egg retention, construct fewer nests, and are less efficient at covering their eggs in the substratum than their wild counterparts. In rivers, the early survival of cultured offspring is lower than that of their wild counterparts. The lifetime reproductive success of farmed fish has been estimated at 17% that of similar-sized wild salmon. As a result of ecological interaction and through density-dependent mechanisms, cultured fish may displace wild conspecifics to some extent, increase their mortality, and decrease their growth rate, adult size, reproductive output, biomass, and production.

Fiske, P., Lund, R.A., and Hansen, L.P. **Relationships between the frequency of farmed Atlantic salmon, *Salmo salar* L., in wild salmon populations and fish farming activity in Norway, 1989-2004.** *ICES Journal of Marine Science* 63(7): 1182-1189, 2006.

Notes: In Norway, there have been restrictions on salmon farming in several fjords to reduce the potential negative impact on important stocks of wild Atlantic salmon. Little is known about the incidence of escaped farmed salmon in fisheries and broodstocks relative to the extent of fish farming in nearby areas. In this study, we analysed data on the incidence of escaped farmed Atlantic salmon in angling catches and broodstock fisheries in rivers for a 16-year period (1989-2004). These data were weighted using official catch statistics and combined at the county level, and the incidence of escapees was correlated with both the stock of farmed salmon in net pens and the reported number of escapees in different Norwegian counties. Our results indicate a significant positive correlation between the incidence of escaped farmed salmon in the rivers at the county level and the intensity of salmon farming, measured as the number of farmed salmon in net pens, suggesting that protection areas may reduce the impact of escapees in salmon populations nearby.

Hansen, L.P. **Migration and survival of farmed Atlantic salmon (*Salmo salar* L.) released from two Norwegian fish farms.** *ICES Journal of Marine Science* 63(7): 1211-1217, 2006.

Notes: Many salmon escape from fish farms during autumn and winter, making the migratory pattern and survival to sexual maturity of these fish an interesting topic of study. This study aimed to assess the migration and survival of large farmed salmon released from fish farms at different times during autumn and winter. Farmed salmon were individually tagged with external tags and released from two fish farms, one in southern Norway and the other in northern Norway. Salmon released in autumn one year before attaining sexual maturity appeared to survive poorly to sexual maturation, whereas salmon escaping later in winter showed greater survival. The released salmon appeared to move with the current and appeared to have a very weak homing instinct, if any. Based on the results of the tagging experiments, the direction and speed of ocean currents, and information about the abundance of fish farm escapees in salmon fisheries and stocks in several countries in the Northeast Atlantic, two hypotheses are advanced: first, salmon that escape during early autumn the year before they become sexually mature are transported with the currents to Arctic areas and subsequently do not survive the winter; second, large salmon escaping from fish farms in Ireland, Scotland, the Faroe Islands, and Norway during winter and spring move with the current and, during the following summer or autumn, may enter homewater fisheries and spawning populations far away from the site of escape, when they become sexually mature.

Whoriskey, F.G., Brooking, P., Doucette, G., Tinker, S., and Carr, J.W. **Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA.** *ICES Journal of Marine Science* 63(7): 1218-1223, 2006.

Notes: We sonically tagged and released farmed Atlantic salmon (*Salmo salar*) from a cage site in Cobscook Bay, Maine, USA. The fish were released in January (n = 75) and in April and May (n = 198) 2004 to study their movement patterns and survival and to assess the possibility of recapturing them. Inshore and offshore waters in this region are subject to intense tidal currents. Tagged salmon dispersed > 1 km from the cage site within a few hours of their release. Mortality was high within Cobscook Bay and the surrounding coastal region (56% of the winter (January) releases; 84% of the spring (March) releases), probably the result of seal predation. Most surviving fish exited the coastal zone and entered the Bay of Fundy along the routes of the dominant tidal currents, passing through Canadian waters. No tagged fish were detected during the wild salmon spawning season in autumn 2004 in any of the 43 monitored salmon rivers draining into the Bay of Fundy, or during 2005 either in the Magaguadavic River, the site of the hatchery in which the fish were reared to the smolt stage, or by a limited coastal receiver array.

Skaala, O., Wennevik, V., and Glover, K.A. **Evidence of temporal genetic change in wild Atlantic salmon, *Salmo salar* L., populations affected by farm escapees.** *ICES Journal of Marine Science* 63(7): 1224-1233, 2006.

Notes: A large number of farmed Atlantic salmon escape from sea cages and hatcheries annually. Selection programmes and domestication have changed the genetic composition of farmed salmon to improve their performance in the culture environment, which apparently occurs at the cost of their fitness in the natural environment. Therefore, gene flow from

farmed salmon to wild salmon populations may have altered the genetic composition of wild salmon populations. To investigate the temporal genetic stability in seven wild Norwegian salmon populations, genetic profiles were produced from historical and contemporary scale samples. Historical and contemporary samples of salmon from the Namsen, Erne, Opo, Vosso, Granvin, Eio, and Hi Rivers were genotyped at the following eight microsatellite loci: Ssal3.37, Ssa28, SsOSL85, Ssa197, Ssa20.19, SsaF43, Ssa202, and Ssa85. A significant change in genetic profiles was observed over time in the Opo, Vosso, and Eio Rivers, but no changes in genetic profiles were observed in the Namsen, Etne, Granvin, and Hi Rivers. A small reduction in FST values and genetic distances among populations was observed in the contemporary samples compared with the historical samples, indicating a reduction in population differentiation over time.

Hindar, K., Fleming, I.A., McGinnity, P., and Diserud, A. **Genetic and ecological effects of salmon farming on wild salmon: modelling from experimental results.** *ICES Journal of Marine Science* 63(7): 1234-1247, 2006.

Notes: Cultured salmonids are released or escape into the wild in large numbers and may make up significant proportions of wild salmonid populations in fresh- and saltwater, causing considerable concern for the fitness and productivity of these populations. This paper focuses on the effects of escaped farmed Atlantic salmon (*Salmo salar*) on wild salmon. Farmed salmon have been under artificial selection for growth and other economically important traits for 30 years and are genetically different in their origin at the molecular and quantitative genetic levels. Escaped farmed salmon spawn in the wild with limited success. Their offspring outgrow those of wild origin but suffer higher mortality. Whole-river experiments in Ireland and Norway have shown that the lifetime success of farmed salmon is reduced relative to wild salmon. Based on data from these experiments, we model the future of wild salmon populations experiencing invasions of escaped farmed salmon. Simulations with a fixed intrusion rate of 20% escaped farmed salmon at spawning suggest that substantial changes take place in wild salmon populations within ten salmon generations (~ 40 years). Low-invasion scenarios suggest that farmed offspring are unlikely to become established in the population, whereas high-invasion scenarios suggest that populations are eventually mixtures of hybrid and farmed descendants. Recovery of the wild population is not likely under all circumstances, even after many decades without further intrusion. Managers of wild salmon will have difficulty in obtaining broodstock of the original wild population after a few generations of high intrusion. We conclude that further measures to reduce escapes of farmed salmon and their spawning in wild populations are urgently needed.

O'Reilly, P.T., Carr, J.W., Whoriskey, F.G., and Verspoor, E. **Detection of European ancestry in escaped farmed Atlantic salmon, *Salmo salar* L., in the Magaguadavic river and Chamcook Stream, New Brunswick, Canada.** *ICES Journal of Marine Science* 63(7): 1256-1262, 2006.

Notes: The use of European Atlantic salmon strains for commercial culture by the salmon farming industry has never been permitted in Nova Scotia or New Brunswick, Canada. Despite this, varying levels of European ancestry were detected in escaped farmed salmon in the Magaguadavic River (in 1999 and 2000) and in Chamcook Stream (in 2003), New Brunswick. Of the 53 escaped farmed salmon smolts from the Magaguadavic River and 17 escaped farmed parr from Chamcook Stream analysed, a single European "type" allele was observed at a single locus in two escaped farmed salmon smolts from the Magaguadavic River and in two escaped farmed parr from the Chamcook Stream. Of the 35 escaped farmed salmon adults analysed, two captured at the Magaguadavic fishway had European "type" microsatellite alleles at multiple loci and one also exhibited European "type" mitochondrial DNA. These results highlight the need for better containment strategies for freshwater hatcheries and genetic screening programmes for farmed salmon broodstock to minimize the likelihood of the introgression of non-local genetic material into severely depressed wild Atlantic salmon populations in the Bay of Fundy region.

Carr, J.W. and Whoriskey, F.G. **The escape of juvenile farmed Atlantic salmon from hatcheries into freshwater streams in New Brunswick, Canada.** *ICES Journal of Marine Science* 63(7): 1263-1268, 2006.

Notes: The escape of juvenile Atlantic salmon from freshwater hatcheries supplying the salmon farming industry may lead to interactions between wild and farmed fish. The scale of this problem, however, has not been examined in detail. We monitored temporal trends in the abundance of escaped juvenile fanned salmon in the Magaguadavic River and Chamcook Stream for several years. In addition, in 2004 we assessed more than 90% of the commercial hatcheries producing salmon

smolts located next to freshwater streams in New Brunswick. Escaped juvenile fish were recorded in 75% of the streams electrofished close to hatcheries. Numbers varied by site and year. However, escaped juvenile salmon were found every year at sites near hatcheries in the Magaguadavic River and Chamcook Stream. In the Magaguadavic River, juvenile escapees outnumbered wild salmon parr in most years. These results highlight the need for implementation of a containment strategy for fresh-water hatcheries to reduce escapes.

Ayllon, F., Martinez, J.L., and Garcia-Vazquez, E. **Loss of regional population structure in Atlantic salmon, *Salmo salar* L., following stocking.** *ICES Journal of Marine Science* 63(7): 1269-1273, 2006.

Notes: Many wild Atlantic salmon populations have been stocked with cultured fish during the past century. To evaluate the degree and the direction of the resulting genetic changes in wild southern European populations of Atlantic salmon, the variation at microsatellite loci was examined in historical and modem scale samples from five Spanish and two French rivers. Significant genetic differentiation between neighbouring rivers, which is typical of Atlantic salmon and which existed before stocking, appears to have been lost after only a decade of stocking with fish of foreign origin. Apparent introgression of foreign-origin genes into local gene pools was detected in the populations studied. These results indicate that stocking risks the loss of genetic diversity in wild salmon populations.

Beamish, R.J., Jones, S., Neville, C.E., Sweeting, R., Karreman, G., Saksida, S., and Gordon, E. **Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada.** *ICES Journal of Marine Science* 63(7): 1326-1337, 2006.

Notes: Juvenile pink salmon that entered a marine ecosystem along the eastern margin of Queen Charlotte Strait in 2003 and returned as adults in 2004 had very high marine survival. The early seaward migration and midsummer rearing in 2003 were in an area containing 16 active Atlantic salmon farms. Two species of sea louse, *Lepeophtheirus salmonis* and *Caligus clemensi*, were commonly found on farmed salmon and juvenile Pacific salmon during the early rearing period of the pink salmon. Mobile *L. salmonis* and *C. clemensi* were most abundant on farmed Atlantic salmon from February to May and on pink salmon in June. *Chalimus* stages were the dominant stages on pink salmon to the end of May. Mobile stages of *C. clemensi* were the dominant stages and species of sea louse on farmed Atlantic salmon and pink salmon at about the same time in June. DNA studies showed that local juvenile pink salmon were in the area until August. The exceptional returns of the brood year suggest that pink salmon populations and farmed Atlantic salmon coexisted successfully during 2003 within an environment that included sea lice and farmed Atlantic salmon. The processes responsible for the high marine survival cannot be identified with certainty, but they could include increased freshwater discharge in 2003, which may have resulted in lower salinity less favourable to sea louse production, increased inflow of nutrient-rich water to the study area, and the introduction of a Provincial Action Plan that required mandatory louse monitoring and established a fallowed migration corridor for pink salmon.

Buschmann, A.H., Riquelme, V.A., Hernandez-Gonzalez, M.C., Varela, D., Jimenez, J.E., Henriquez, L.A., Vergara, P.A., Guinez, R., and Filun, L. **A review of the impacts of salmonid farming on marine coastal ecosystems in the southeast Pacific.** *ICES Journal of Marine Science* 63(7): 1338-1345, 2006.

Notes: The production of farmed salmonids in Chile reached 550 000 t in 2004. The industry is considered to be consolidated, but with potential for further expansion to the south into pristine coastal areas. The environmental impacts of the salmonid farming industry in Chile were reviewed in 1996, and evidence at that time did not suggest significant adverse effects. However, after almost ten years of sustained growth, current evidence indicates that significant loss of benthic biodiversity and localized changes in the physico-chemical properties of sediments have occurred in areas with salmonid farms. Furthermore, the presence of these farms significantly increases pulses in the density of dinoflagellates. Data suggest that escaped farmed fish may have an impact on native species, although their survival in the wild appears low. The abundance of omnivorous diving and carrion-feeding marine birds increased from twofold to fivefold in areas with salmon farms compared with control areas without them. It is urgent that an ecosystem approach be implemented to assess all impacts of salmonid farming on coastal ecosystems in southern Chile.

Brooking, P., Doucette, G., Tinker, S., and Whoriskey, F.G. **Sonic tracking of wild cod, *Gadus morhua*, in an inshore region of the Bay of Fundy: a contribution to understanding the impact of cod farming for wild cod and endangered salmon populations.** *ICES Journal of Marine Science* 63(7): 1364-1371, 2006.

Notes: Sea cage trials of Atlantic cod farming have begun in the Bay of Fundy region. We fitted inshore wild cod (n = 10) captured in the Quoddy region with sonic tags during the late summer of 2004 to provide data on their temporal and spatial residency and habitat usage, with a view to understanding the potential for impact between escaped farmed cod and wild cod and other fish species, particularly Atlantic salmon. Most of the tagged cod remained within a restricted corridor in the inshore zone, occupied deep water (75-130 m) within several kilometres of the release point, and undertook local movements. Three cod undertook more extensive movements; one fish emigrated offshore immediately, and two fish moved as far as 14 km from the release point before returning, 52-54 h later, to the area in which the other cod were located. The mean residence time in the inshore zone was 55 days. In the late autumn, there was a staggered pattern of departure from the coastal zone, although one fish over-wintered in Passamaquoddy Bay. Three of the nine cod that migrated offshore in autumn 2004 returned within a three-week period in May 2005, after a mean absence of 172 days, and reoccupied the inshore region inhabited the previous year. These cod left the region again after a mean residence of 120 days during the spring and summer. The presence of some of the tagged cod in the principal migration corridor for wild salmon smolts during the period of their migration suggests that escapes from cod farms could result in increased predation on salmon smolts from endangered populations.
