Attachment C

Annotated Bibliography

Attachment C to SEPA Checklist
Rainbow Trout Net-Pen Aquaculture: Annotated Bibliography

Prepared by

Walton Dickhoff, Ph.D.[1] and Don Weitkamp, Ph.D.[2]

Cooke Aquaculture Pacific Marine Aquaculture Permit Application to Transition from Raising Atlantic Salmon to Raising Sterile All-Female Triploid Rainbow Trout/Steelhead at the Cooke Existing Marine Net Pen Sites in Puget Sound, Washington

INTRODUCTION

This document provides summaries in abstract format for technical publications that address one or more basic issues of concern identified by the Washington Department of Fish & Wildlife for their review of the Cooke Aquaculture application for re-approval of their Marine Finfish Aquaculture Permit (WAC 220-370-100) to convert Atlantic Salmon farms to domesticated stocks of a mono-sex, sterile Rainbow Trout (*Oncorhynchus mykiss*). This review focuses on publications produced since 2000 due to the substantial changes that have occurred during the last two decades in net-pen aquaculture techniques and practices. Information derived from these technical publications was used to inform the Cooke Aquaculture responses to WDFW questions and information requests in SEPA Checklist Attachment B.

Each publication is presented in a reference/abstract format listed in alphabetical order according to the senior author's last name. The abstracts are grouped according to the basic net pen rearing issues that the papers address. Several abstracts are listed under more than one issue because of the multiple issues they address. The abstracts generally are those provided by the authors with minor alterations. A few are brief summaries of lengthy summaries of unpublished reports.

[1] waltdickhoff@gmail.com
[2] deweitkamp@dew-fish.com

BASIC NET-PEN ISSUES

Baskett, M.L., S.C. Burgess, and R.S. Waples. 2013. Assessing strategies to minimize unintended fitness consequences of aquaculture on wild populations. Evolutionary Applications 6(7):1090-1108.

Artificial propagation programs focused on production, such as commercial aquaculture or forestry, entail strong domestication selection. Spillover from such programs can cause unintended fitness and demographic consequences for wild conspecifics. The range of possible management practices to minimize such consequences vary in their control of genetic and demographic processes. The authors use a model of coupled genetic and demographic dynamics to evaluate alternative management approaches to minimizing unintended consequences of aquaculture escapees. They found if strong natural selection occurs between escape and reproduction, an extremely maladapted (i.e., nonlocal-origin, highly domesticated) stock could have fitness consequences analogous to a weakly diverged cultured stock; otherwise, wild population fitness declines with increasing maladaptation in the cultured stock. Reducing escapees through low-level leakage is more effective than reducing an analogous number of escapees from large, rare pulses. This result arises because low-level leakage leads to the continual lowering of wild population fitness and subsequent increased proportional contribution of maladapted cultured escapees to the total population. Increased sterilization efficacy can cause rapid, nonlinear reductions in unintended fitness consequences. Finally, sensitivity to the stage of escape indicates a need for improved monitoring data on how the number of escapees varies across life cycle stages.

Colt, J., S. Summerfelt, T. Pfeiffer, S. Fivelstad, and M. Rust. 2008. Energy and resource consumption of land-based Atlantic Salmon smolt hatcheries in the Pacific Northwest (USA). Aquaculture 280 (1-4):94-108.

The authors evaluate the resource and energy requirements of six different types of land-based, hatchery production systems located in the U.S. Pacific Northwest: flow-through with a gravity water supply, flow-through with a pumped water supply, flow-through with pure oxygen, partial reuse system, partial reuse with heating, and a reuse system for the production of Atlantic Salmon (*Salmo salar*) smolts. Key parameters used in the evaluation include direct energy, indirect energy, transportation energy, greenhouse gas emissions, and pollutant discharges. Power (electricity and natural gas) and feed energy accounted for the majority of the required energy for all the rearing option evaluated. The sum of the fixed capital and chemicals components accounted for less than 2-12% of the total energy budget for any rearing option. The energy efficiency (energy output/energy input) of the six options ranges from 0.97% for flow-through with pumped supply to 3.49% for the flow-through with gravity supply. The rearing options with the three highest energy efficiencies were flow-through with gravity supply (3.49%), partial reuse (2.75%), and reuse (2.64%). On a kg of smolt produced basis, the six rearing options showed a wide range in performance. The reuse system had the lowest water (2 m^3 /kg) and land (0.13 m^2/ kg) requirements and the third lowest total energy requirement (288 MJ kg^{-1}). The partial reuse system had the second lowest total power requirement (276 MJ /kg), a low land requirement (0.21 m^2/kg), and moderate water requirements (33 m^3/kg). The partial reuse with temperature control had the second highest total power requirement (657 MJ /kg) and land and water requirements similar to the partial reuse system without temperature control. The flow-through system with pumped water supply had the highest water (289 m^3 kg^{-1}), land (2.19 m^2/kg), and energy requirements (786 MJ /kg) of any of the rearing options. By comparison, the flow-through system with gravity water supply had the lowest energy requirement (218 MJ/kg), a moderate land requirement (0.78 m^2/ kg), and a high-water requirement (214 m^3/kg). The ranking of the six rearing options based capital and operating costs are likely to be quite different from those based on energy, water, and greenhouse gas emissions.

Costa-Pierce, B.A. and C.J. Bridger. 2002. The role of marine aquaculture facilities as habitats and ecosystems. Responsible Marine Aquaculture 2002:105-144.

Too often the public is provided with a bleak image of marine aquaculture facilities as industrial waste areas, depleting the natural environment and its biodiversity, and creating a desert from an ocean oasis. However, this image frequently has little rigorous scientific basis. Environmental problems have been found only in aquaculture settings with poor management plans, wasteful feeding strategies and where overproduction exceeds the carrying capacity of the natural environment causing the degradation of clean water − the very basis of a successful aquaculture venture. Cage aquaculture facilities provide habitats and nursery areas for juvenile and adult wild fish, and numerous invertebrate and algal species essential to sustaining healthy marine ecosystems and wild fish stocks. There is an unbalanced focus on marine animal husbandry causing a concomitant lack of appreciation for the positive environmental attributes of marine agronomy, a vital economic sector of global aquaculture. Indeed, tidal wetland, mangrove forest and seagrass restoration aquaculture − in addition to establishment and maintenance of oyster reefs - are important examples of aquaculture creating, enhancing and maintaining productive marine ecosystems, habitats and water quality in a long-term, sustainable manner. There is an urgent need for additional research to generate *primary* data on the positive and negative roles of marine aquaculture in the biogeochemical cycles, habitats and ecosystems of coastal oceans worldwide. The little research that has been done to date has documented numerous examples of marine aquaculture facilities that revitalize natural habitats, ecosystems and marine fisheries, as opposed to degrading the natural environment and competing with the wild fisheries sector. Without more comprehensive assessments and additional research, plans for the sustainable expansion of marine aquaculture will suffer from a lack of a scientific basis for rational planning and policy, and continue to be replaced by heresy, junk science and advocacy.

Felsing, M., B. Glencros, and T. Telfer. 2005. Preliminary studies on the effects of exclusion of wild fauna from aquaculture cages in a shallow marine environment. Aquaculture. 243:159–174.

Previous investigations into the environmental impacts at a shallow-water oligotrophic marine experimental cage aquaculture site in Western Australia have found no accumulation of organic material, and limited changes in macrofaunal communities. It was hypothesized that wild fish populations in the area consumed particulate wastes emanating from the cage, thus reducing the benthic impacts. An experiment was designed to quantify the accumulation of organic material on the seabed occurring in the presence and absence of wild fauna. Three treatments were arranged in duplicate, cages without exclusion nets (normal situation) (CAGE-FISH); cages surrounded by a 35-mm mesh exclusion net (preventing wild fish access to the sea bed and water column near the cage) (CAGE-FISH-EXCL); and empty cages surrounded by exclusion nets (to control for effects from the exclusion net) (CAGE-EXCL). In addition, four reference sites without cages (REF) were sampled. Following baseline sampling, Rainbow Trout (Oncorhynchus mykiss) were stocked into the CAGE-FISH and the CAGE-FISH-EXCL treatments at an initial stocking density of 2.4 kg/m. The experiment was terminated after 62 days, at a final stock density of 5.6 kg/m. Sampling found significantly greater accumulation of nutrients and fine sediments under the cages enclosed in the exclusion net than in other treatments and sites. Levels of organic carbon deposition at cages with exclusion nets was found to be 4.5±1.0 g C/m /day (mean ± S.E.) compared to 0.7 to 1.1 g C//m/day at control and reference sites. The accumulation of nutrients at the CAGE-FISH-EXCL sites was correlated to distinct changes in macrofaunal community composition, with a sharp increase in overall macrofaunal abundance and a growing dominance of capitellid polychaetes. Based on a comparison between sedimentation rates within and outside excluded areas, the proportions of the total sediment nutrients consumed by wild fish were calculated to be 40 to 60%. It was concluded that in the natural coastal system of Western Australia or comparable environments, wild fish are potential important consumers of cage aquaculture waste materials. The fact that sediment C, N and P did not increase below cages with fish and

no exclusion nets suggests that the benthic fauna, including surface grazing fish, at these sites were able to assimilate much of the remaining total sedimentary nutrients.

Goddard, S. 2012. Feed management in intensive aquaculture. Springer Science & Business Media.

This book has been written as a guide to the management and use of formulated feeds in intensive fish and shrimp culture. While its focus is on the use of commercially produced feeds in intensive production systems, it is anticipated that many of the practical issues covered formulated feeds in less intensive systems. Feeds and feeding are the major variable operating costs in intensive aquaculture and the book is primarily intended to aid decision making by fish farm managers in areas of feeding policy.

The dramatic increases in aquaculture production seen over the past 15 years have been made possible, in large part, by gains in our understanding of the food and feeding requirements of key fish and shrimp species. A global aquaculture feeds industry has developed and a wide range of specialist feeds is now sold. The new options in feeds and feeding systems, which are becoming available, necessitate continual review by farmers of their feeding policies, where choices must be made as to appropriate feed types and feeding methods. While growth rates and feed conversion values are the prime factors of interest to farmers, other important issues, such as product quality and environmental impacts of farm effluents, are also directly related to feed management practices. While there is an extensive literature dealing with the known nutritional requirements of farmed fish and shrimp, less attention has been focused on feed management practices. However, as the various sectors of the industry have matured, and markets have become more competitive, it has become evident that farmers seeking to control their production costs, in order to remain competitive, must critically examine the selection, use, and performance of aquaculture feeds.

While this book emphasizes the practical issues of feed management, it also seeks to provide insight into the biological and environmental factors that underlie the feeding responses of fish and shrimp, and which must be taken into account when determining appropriate feeding policies for specific farming operations. No attempt has been made here to describe in detail the feeding regimens used for any particular species. The examples used throughout the text have been chosen from many different sectors of the industry in an attempt to illustrate the general principles of feed management.

Hardy, R.W. 2010. Utilization of plant proteins in fish diets: effects of global demand and supplies of fishmeal. Aquaculture Research. 41(5):770-6.

Aquafeed ingredients are global commodities used in livestock, poultry and companion animal feeds. Cost and availability are dictated less by demand from the aquafeed sector than by demand from other animal feed sectors and global production of grains and oilseeds. The exceptions are fishmeal and fish oil; use patterns have shifted over the past two decades resulting in nearly exclusive use of these products in aquafeeds. Supplies of fishmeal and oil are finite, making it necessary for the aquafeed sector to seek alternative ingredients from plant sources whose global production is sufficient to supply the needs of aquafeeds for the foreseeable future. Significant progress has been made over the past decade in reducing levels of fishmeal in commercial feeds for farmed fish. Despite these advances, the quantity of fishmeal used by the aquafeed sector has increased as aquaculture production has expanded. Thus, further reduction in percentages of fishmeal in aquafeeds will be necessary. For some species of farmed fish, continued reduction in fishmeal and fish oil levels is likely; complete replacement of fishmeal has been achieved in research studies. However, complete replacement of fishmeal in feeds for marine species is more difficult and will require further research efforts to attain.

Harvey, A.C. 2016. Investigating fitness consequences of hybridisation between farmed and wild Atlantic salmon. Dissertation, Prifysgol Bangor University.

Farmed fish display genetic differences from wild fish in a variety of morphological, behavioral and physiological traits as a result of the domestication process and selective breeding. Farmed salmon typically outgrow wild salmon by large ratios under hatchery conditions, although observed growth differences are much less in the wild. It is possible that farmed salmon have become adapted to regulated domestic environments, while concurrently they are unable to perform as well in more variable wild environments. Escaped farmed salmon interact with wild salmon through resource competition and disease transmission, and can interbreed with wild salmon. The introduction of mal-adapted domestic genotypes into wild populations can lower their productivity. Comparative studies that assess the effects of hybridization on life-history traits linked to fitness are important in understanding how interbreeding will affect the resilience of wild populations. This thesis investigated the freshwater growth and survival of multiple families derived from various farmed, wild and F1 hybrid salmon populations when reared at contrasting 1) temperatures, 2) densities and rearing conditions, 3) food availabilities, and 4) diets. In all experiments farmed salmon outgrew wild and hybrid salmon, and their hybrids displayed intermediate growth. Relative growth differences detected at contrasting temperatures were population-specific; indicating that the competitive balance between conspecifics may depend upon genetic background and river temperature. Findings highlight the merits of adopting a more spatially resolved approach to risk management of wild populations. In all other experiments the relative growth differences among groups did not differ across treatments, indicating that farmed fish have retained their plasticity in response to respective experimental treatments. Although experiments were conducted under controlled conditions, findings suggest that the investigated treatments are not individually responsible for elevated growth differences observed in hatchery conditions or the lower growth differences observed between farmed and wild salmon in the wild.

Liu, S., Y. Palti, K.E. Martin, J.E. Parsons, and C.E. Rexroad III. 2017. Assessment of genetic differentiation and genetic assignment of commercial Rainbow Trout strains using a SNP panel. Aquaculture 468:120-125.

Rainbow Trout (*Oncorhynchus mykiss*) is the most widely cultured cold freshwater fish in the world. Troutlodge, Inc., one of the largest commercial rainbow trout egg producers in the world, has eight breeding populations of rainbow trout. Assessment of population genetic differentiation is critical for selective breeding, and genetic assignment is often required to address production issues arising on fish farms. Previously, they developed a SNP (single nucleotide polymorphism) panel for parentage assignment in rainbow trout. The objectives of this study were: 1) to characterize the genetic differentiation of the eight Troutlodge breeding populations; and 2) to evaluate the accuracy of genetic assignment to identify Troutlodge fish using the same SNP panel previously developed for parentage assignment. A total of 1,732 breeders of the eight Troutlodge breeding populations were genotyped with the SNP panel. The global F_{ST} over all SNPs was 0.13 and the pairwise F_{ST} between any two breeding populations ranged from 0.056 to 0.195. Both phylogenetic tree and structure analyses revealed that the odd year and even year populations for the same strain were closely related to each other. Also, the eight populations were clustered into two groups. Based on the results of self-assignment, 97.1% of the Troutlodge breeders were correctly assigned to the population of origin. To further evaluate the accuracy of genetic assignment, we also genotyped 280 egg production fish from three Troutlodge populations of known origin, 49 fish from a Canadian farm, 70 fish from a farm in Idaho and 188 fish from four known non-Troutlodge strains. Among the 280 production fish, 98.2% fish were correctly assigned to the Troutlodge strain of origin. Consistent with the purchasing records, the fish from the two farms were also correctly assigned to two Troutlodge strains. Based on the SNP genotypes, 185 out of 188 fish (98.4%) from the four non-Troutlodge strains could be excluded as Troutlodge fish. In conclusion, our previously developed SNP panel for parentage assignment is also useful to characterize genetic differentiation and has sufficient power for genetic assignment of commercial rainbow trout strains used in this study.

Mobrand, L.E., J. Barr, L. Blankenship, D.E. Campton, T.T.P. Evelyn, T.A. Flagg, C.V.W. Mahnken, L.W. Seeb, P.R. Seidel, and W.W. Smoker. 2005. Hatchery reform in Washington State: principles and emerging issues. Fisheries 30(6):11-23.

Hatcheries support nearly all major fisheries for Pacific salmon (*Oncorhynchus* spp.) and steel-head (anadromous *O. mykiss*) in the Pacific Northwest. However, hatcheries have been a major source of controversy for over 30 years. The Hatchery Scientific Review Group (HSRG) was tasked by Congress to identify solutions to well-known problems so hatcheries could better meet their goals of supporting sustainable fisheries and assisting with the conservation of natural populations. The authors reviewed more than 100 facilities and 200 programs and identified three principles of hatchery reform: 1) goals for each program must be explicitly stated in terms of desired benefits and purposes; 2) programs must be scientifically defensible; and 3) hatchery programs must respond adaptively to new information. They also identified several emerging issues critical to the success of hatcheries. They concluded that hatcheries must operate in new modes with increased scientific oversight and that they cannot meet their goals without healthy habitats and self-sustaining, naturally-spawning populations.

Nash, C.E., P.R. Burbridge, and J.K. Volkman. 2005. Guidelines for ecological risk assessment of marine fish aquaculture. National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-NWFSC-71, Silver Spring, MD.

Significant sea lice infestation of farmed salmon has never been an issue because net-pens are located in areas where the salinity is too low for lice proliferation in Washington.

Noakes, D.J. 2014. Environmental impacts of salmon net pen farming. Salmon: biology, environmental impact and economic importance. Nova Science Inc., New York, NY, p. 239-256.

The absolute and relative abundance of farmed and wild is a factor in determining potential impacts. Genetic and ecological impacts are likely to be greatest in Norway and Scotland where farmed Atlantic Salmon interact with depressed populations of wild Atlantic Salmon. Similar impacts are also possible in the United States but these are likely to be insignificant when compared to similar interactions involving cultured salmon produced by the large-scale enhancement programs in the Pacific. Waste discharge and pollution from salmon farming appear to be primarily near-field with reversable impacts within 100 m of farm sites.

Price, C.S. and J.A. Morris, Jr. 2013. Marine cage culture and the environment: Twenty-first century science informing a sustainable industry. National Oceanic and Atmospheric Administration. Technical Memorandum NOS-NCCOS-164. Silver Spring, MD. Available online: http://aquaticcommons.org/14685/1/NOS%20NCCOS%20164.pdf

This report provides a comprehensive review of some predominant environmental risks that marine fish cage culture aquaculture, as it is currently conducted, poses in the marine environment and designs and practices now in use to address these environmental risks in the U.S. and elsewhere. Today's finfish aquaculture industry has learned, adapted and improved to lessen or eliminate impacts to the marine habitats in which it operates. The authors conducted a critical review of the large body of scientific work published since 2000 on the technological innovation that has made it possible to grow marine finfish in the coastal and open ocean. Along with this opportunity comes environmental risk. As a federal agency charged with stewardship of the nation's marine resources, NOAA requires tools to evaluate the benefits and risks that aquaculture poses in the marine environment, to implement policies and regulations which safeguard our marine and coastal ecosystems, and to inform production designs and operational procedures compatible with marine stewardship.

There is an opportunity to apply the best available science and globally proven best management practices to regulate and guide a sustainable United States marine finfish farming aquaculture industry. There are strong economic incentives to develop this industry, and doing so in an environmentally responsible way is possible if stakeholders, the public and regulatory agencies have a clear understanding of the relative risks to the environment and the feasible solutions to minimize, manage or eliminate those risks. This report spans many of the environmental challenges that marine finfish aquaculture faces to serve as a useful tool to those interested in and responsible for the industry and safeguarding the health, productivity and resilience of our marine ecosystems.

Water Quality: The primary potential effects to water quality associated with marine cage culture include dissolved nitrogen and phosphorus, turbidity, lipids and dissolved oxygen fluxes. Usually there are no measurable effects 30 m beyond the cages when farms are sited in well-flushed waters. The trend of many studies over the last 20 y indicates that improvements in feed formulation and feeding efficiency are the major reasons for decreased nutrient loading and acceptable water quality in and near farms, and explains why significant enrichment to the water column at offshore farms is generally not detected.

Benthic Effects: Well-managed farms may exhibit little perturbation and, where chemical changes are measured, impacts are typically confined to within 100 m of the cages. Benthic chemical recovery is often rapid following harvest. Within an adaptive management framework, a good monitoring program can be used to adjust farm management to avert serious and persistent impacts to the benthos.

Marine Life: If farm nutrients accumulate and persist in the water column or sediment, marine organisms can be impacted. At appropriately-sited and well-managed farms, natural processes can be sufficient to assimilate nutrients. At some farm sites, a phytoplankton response to nutrient loading was reported, but generally this is a low risk and causal linkages to algal blooms are not evident. Changes in the benthic community are evident when sediments become enriched with organic farm waste nutrients. At well flushed sites in deep water and with efficient feed management, ecological impacts tend to be minimal and confined to the area just beneath the cages. The excess food and waste released from fish cages may be food for wild fish, especially benthic feeders. Cages may also provide shelter and foraging habitat for wild fish. These characteristics may be beneficial to the local and regional environment.

Chemicals: The use of antibiotics, therapeutants and antifoulants at marine fish farms has declined greatly (up to 95%) in the last 20 y, resulting in decreased potential for secondary harmful effects of these chemicals on the marine environment. Heavy metals from feed and antifoulants are known to accumulate beneath cages, but are often in low concentrations and sequestered in the sediment.

Quinn, P., J.R. Winton, D. Huppert, and R. Hilborn. 2008. An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon. Advances in Marine Biology 53:61-194.

The historical, political and scientific aspects of salmon hatchery programs designed to enhance fishery production, or to recover endangered populations, are reviewed. The authors point out that the establishment of hatcheries has been a political response to societal demands for harvest and conservation; given this social context, they then critically examined the levels of activity, the biological risks, and the economic analysis associated with salmon hatchery programs. A rigorous analysis of the impacts of hatchery progress was hindered by the lack of standardized data on release sizes and survival rates at all ecological scales, and since hatchery program objectives are rarely defined, it was also difficult to measure their effectiveness at meeting release objectives. Debates on the genetic effects of hatchery programs on wild fish have been dominated by whether correct management practices can reduce negative outcomes, but they note 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, the effectiveness of this approach is dependent 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. 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. They reviewed several approaches to studying the economic consequences of hatchery activities intended to inform the social decisions surrounding programs, 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. Economic issues have rarely been included in decision making on hatchery programs.

Refstie, S., S.J. Helland, and T. Storebakken. 1997. Adaptation to soybean meal in diets for Rainbow Trout, *Oncorhynchus mykiss*. Aquaculture 153(3-4):263-272.

Three experiments were conducted with rainbow trout maintained in fresh water. In Experiment 1, growth was measured in groups of 34-g trout fed either a fish meal control diet (Diet 1) or a diet 60% soybean meal (Diet 2) for two periods of 28 days each. In Experiment 2, Diets 1 and 2 were fed to groups of 100-g trout for 10 days prior to stripping of feces and digestibility determination. In Experiment 3, groups of 200-g trout were fed either a fish meal control diet containing 100 mg Y_2O_3/kg diet as an inert marker (Diet 3), or a diet containing 40% soybean meal and 100 mg Yb_2O_3/kg diet as an inert marker (Diet 4) for an adaptation period of 7 days. Thereafter, both diets were offered in excess in a 1:1 mixture for 2 days. Qualitative preference for the two diets was estimated as the proportions of Y_2O_3 and Yb_2O_3 in feces. Subsequently, digestibility was determined for all diets.

Refstie, S., Ø. J. Korsøen, T. Storebakken, G. Baeverfjord, I. Lein, and A.J. Roem. 2000. Differing nutritional responses to dietary soybean meal in Rainbow Trout (*Oncorhynchus mykiss*) and Atlantic Salmon (*Salmo salar*). Aquaculture 190(1-2):49-63.

This study was carried out to compare the responses of Rainbow Trout and Atlantic Salmon to temperature (LT)-fish meal as the sole protein ingredient or 32% fish meal and 30% soybean meal, were each fed to triplicate groups of 0.1 kg trout or 0.2 kg salmon maintained in 7 ºC freshwater. The experiment lasted 84 days, divided into three periods. Weight gain of the trout was similar with both diets, whereas the salmon gained 44% more weight with the fish meal diet than with the soybean meal diet. The apparent digestibilities were 6% higher for nitrogen, 8% higher for fat, and 11% higher for energy in the trout than in the salmon. The feed conversion ratio (FCR) was 24% lower, the nitrogen retention 34% higher, and the energy-retention 28% higher in the salmon than in the trout. Within each species, the digestibility of nitrogen was similar for both diets. In trout, the digestibilities of fat and energy were 4% higher, the nitrogen retention 8% higher, and the energy retention 9% higher with the fish meal than with the soybean meal diet. Similarly, but more severe within the salmon, the respective digestibilities of fat and energy were 16 and 9% higher, the nitrogen retention 19% higher, and the energy retention 23% higher with the fish meal than with the soybean meal diet. Both species developed enteritis in the distal intestine when fed the soybean meal diet.

Reinbold, D., G.H. Thorgaard, and P.A. Carter. 2009. Reduced swimming performance and increased growth in domesticated Rainbow Trout, *Oncorhynchus mykiss*. Canadian Journal of Fisheries and Aquatic Science 66:1025–1032.

Domesticated populations of Rainbow Trout probably have been selected for high growth rates and large body size, which may have resulted in reduced sprint swimming performance. The authors hypothesized

that more domesticated populations of Rainbow Trout would have higher growth rates and larger body size, but slower swim speed, relative to semi-wild populations. They tested this hypothesis by measuring body mass, body length, and sprint swim speed multiple times over 92 d in progeny from crosses between males from three clonal lines and an outbred female. They found significantly higher body masses and significantly slower swim speeds in the highly domesticated Arlee and Hot Creek progeny groups compared with the semi-wild Swanson hybrid progeny group, supporting our hypothesis. Growth rates also differed significantly among groups, but at the ages measured, the Swanson hybrid progeny had an intermediate growth rate. However, given the differences in body mass, either growth rates were higher in the more domesticated progeny groups at young unmeasured ages and (or) they hatched at a significantly larger body mass than the semi-wild Swanson hybrid.

Rooney, R.C., and C.L. Podemski. 2009. Effects of an experimental Rainbow Trout (*Oncorhynchus mykiss*) farm on invertebrate community composition. Canadian Journal of Fisheries and Aquatic Sciences 66:1949–1964.

The authors examined the development of changes in the zoobenthos along a transect from an experimental Rainbow Trout farm in Lake 375, Experimental Lakes Area, northwestern Ontario, Canada. After 2 months, invertebrate abundance was reduced under the fish cage (2542 ± 569 individualsm–2) compared with samples collected 45 m away (16137 ± 2624 individualsm–2). Taxa richness was also depressed, but changes in biomass were variable. Reductions in abundance and richness at high organic loading levels are consistent with earlier models developed for the marine environment of responses to organic loading in marine systems. After two production cycles, the significant principal components axis explaining 76% of total variance in abundance was correlated with distance from the cage (Spearman rank correlation, $r = -0.775$, $p = 0.014$) and with chemical variables recommended for freshwater aquaculture monitoring (Pearson's correlation coefficient, $r = 0.78$, 0.76, and 0.75 with $p = 0.013$, 0.018, and 0.020 for pore-water ammonia and sediment Cu and Zn, respectively). The effects of farming were localized, dissipating within 15 m of the cage edge. Invertebrate abundance demonstrated the most potential for incorporation into monitoring schemes at new farms. At established farms, richness may be a valuable monitoring metric.

Rust, M.B., K.H. Amos, A.L. Bagwill, W.W. Dickhoff, L.M. Juarez, C.S. Price, J.A. Morris Jr, and M.C. Rubino. 2014. Environmental performance of marine net-pen aquaculture in the United States. Fisheries 39(11):508-524.

The United States has a small net-pen salmon industry dating back over 40 y and a nascent net-pen industry for other marine fish. The United States net-pen aquaculture sector has improved its resource efficiency in terms of the amount of fish meal and fish oil used in feeds and reduced its environmental impacts in terms of the mass loading and impact of nutrient discharge on the receiving ecosystem, the incidence and treatment of fish diseases, the use of antibiotics, and the number and impact of fish escapes, while increasing production. These changes can be attributed to a combination of advances in science and technology, rising cost of fish meal/oil, improved management, and informed regulatory practices. Net-pen aquaculture has become an efficient food production system. Existing laws and regulations in the United States effectively address most of the potential adverse environmental effects of net-pen aquaculture.

In Washington, significant sea lice infestation of farmed salmon has never been an issue because net-pens are located in areas where the salinity is too low for lice proliferation (Nash et al. 2005); therefore, treatment has not been necessary.

U.S. fish farms must monitor discharges to the benthos and water column to meet the standards of the Clean Water Act, which established the National Pollutant Discharge Elimination System (NPDES). In 2004, the U.S. Environmental Protection Agency (USEPA) developed a national effluent rule for net-pen aquaculture (USEPA 2004), establishing effluent limitations for aquaculture facilities into waters of the United States.

Environmental impact models now allow regulators to assess the suitability of sites, understand the potential risks and benefits of proposed net-pen operations, and estimate the limits of acceptable farm biomass before they are permitted.

Troyer, R.M., S.E. LaPatra and G. Kurath. 2000. Genetic analyses reveal unusually high diversity of infectious haematopoietic necrosis virus in rainbow trout aquaculture. Journal of General Virology 81(12):2823-2832.

Infectious haematopoietic necrosis virus (IHNV) is the most significant virus pathogen of salmon and trout in North America. Previous studies have shown relatively low genetic diversity of IHNV within large geographical regions. In this study, the genetic heterogeneity of 84 IHNV isolates sampled from rainbow trout (*Oncorhynchus mykiss*) over a 20-y period at four aquaculture facilities within a 12 mile stretch of the Snake River in Idaho, USA was investigated. The virus isolates were characterized using an RNase protection assay (RPA) and nucleotide sequence analyses. Among the 84 isolates analyzed, 46 RPA haplotypes were found and analyses revealed a high level of genetic heterogeneity relative to that detected in other regions. Sequence analyses revealed up to 7±6% nucleotide divergence, which is the highest level of diversity reported for HNV to date. Phylogenetic analyses identified four distinct monophyletic clades representing four virus lineages. These lineages were distributed across facilities, and individual facilities contained multiple line ages. These results suggest that cocirculating IHNV lineages of relatively high genetic diversity are present in the IHNV populations in this rainbow trout culture study site. Three of the four lineages temporal trends consistent with rapid evolution.

U.S. Environmental Protection Agency (USEPA). 2004. Aquaculture operations—laws, regulations, policies and guidance. Available online: www.epa.gov/agriculture/anaqulaw. html#Effluent%20Guidelines.

In 2004, the U.S. Environmental Protection Agency (USEPA) developed a national effluent rule for net-pen aquaculture (USEPA 2004), establishing effluent limitations for aquaculture facilities into waters of the United States. Environmental impact models now allow regulators to assess the suitability of sites, understand the potential risks and benefits of proposed net-pen operations, and estimate the limits of acceptable farm biomass before they are permitted.

Utter, F. and J. Epifanio. 2002. Marine aquaculture: genetic potentialities and pitfalls. Reviews in Fish Biology and Fisheries, 12(1):59-77.

The authors made several recommendations for future aquaculture efforts based on their extensive review of available information.

1. Articulate simple and clearly-defined goals;
2. Use indigenous populations, or;
3. Use fully contained non-native populations;
4. Commit to monitoring and evaluation; and
5. Take prompt and effective remedial actions when required.

Containment through sterility provides a valuable model an aquaculture operation where releases increase genetic risk to indigenous populations.

ESCAPEMENT ISSUES

Abrantes, K.G., J.M. Lyle, P.D. Nichols, and J.M. Semmens. 2011. Do exotic salmonids feed on native fauna after escaping from aquaculture cages in Tasmania, Australia? Canadian Journal of Fisheries and Aquatic Sciences 68(9):1539-1551.

Atlantic Salmon, and Rainbow Trout, are farmed in Tasmania, Australia, where fish sometimes escape into the natural environment. If escapees are able to survive and feed on native fauna, it is likely that they will have ecosystem impacts. Stomach content, body condition (muscle lipid content and Fulton' K), stable isotope, and fatty acid analysis were used to determine if escaped salmonids feed on native fauna. Results indicate that, in general, escaped salmonids do not feed on native fauna. Salmonids loose condition after escaping, and escapee stomachs were mostly empty or contained non-nutritious material or feed pellets. Nevertheless, almost a quarter of rainbow trout stomachs contained native fauna. The majority of escapees had biochemical composition similar to caged animals, indicating that these fish had not switched to feed on local food sources. However, a small fraction of escapees conclusively showed changes in biochemical parameters indicative of a shift to feeding on native fauna. Given the numbers and frequency of escapes, this can have an important impact on native species and on the ecology of Macquarie Harbor.

Amos, K.H., J. Thomas, and B. Stewart. 2001. Pathogen transmission between wild and cultured salmonids: risk avoidance in Washington State, United States of America. Pages 83–89 in C.J. Rodgers, editor. Proceedings of an international conference on risk analysis in aquatic animal health. World Organization for Animal Health, Paris.

Most escaped farmed fish have low fitness for the wild and quickly become easy victims of predators such as marine mammals, other fish, and birds. Escapees are unlikely to generate an infectious dose (or infective pressure) sufficient to result in disease in a healthy, wild population. The mere presence of a pathogen alone will not cause disease without environmental factors that play a large role in triggering disease events.

Baskett, M.L., S.C. Burgess, and R.S. Waples. 2013. Assessing strategies to minimize unintended fitness consequences of aquaculture on wild populations. Evolutionary Applications 6(7):1090-1108.

Spatiotemporal patterns of distribution of Sea Bass, *Dicentrarchus labrax*, and Sea Bream, *Sparus aurata*, and their influence on artisanal fisheries are explored before and after an escape event that released 1.5 million fish into the wild off La Palma (Canary Islands). Data were collected by *in situ* visual census and first sale data as a proxy of artisanal fisheries landings. Permutational ANOVA of escapee abundances in shallow coastal habitats revealed consistent spatial patterns that linked densities of these fish to distance from escape point, whereas temporal patterns were related to a higher biomass released during winter. A nearby marine protected area did not show different densities of escaped fish. Local artisanal fleet catches accurately reflected the massive escape event and offer the main contingency force to mitigate the potential negative effects of massive escape events over shallow coastal habitats.

Blanchfield, P.J., L.S. Tate, and C.L. Podemski. 2009. Survival and behaviour of Rainbow Trout (*Oncorhynchus mykiss*) released from an experimental aquaculture operation. Canadian Journal of Fisheries and Aquatic Sciences 66(11):1976-1988.

The potential for farmed fish that have escaped from open-cage aquaculture operations to affect native populations will depend on their survival and behavior in the wild. Used standard commercial practices to rear 10 tons of Rainbow Trout in a 23 ha lake at the Experimental Lakes Area (Ontario, Canada). Each fall (2003–2005), they released farmed Rainbow Trout (escapees) into the study lake and monitored their movements using automated positioning telemetry. Rainbow Trout experienced high annual mortality

(~50%), with none surviving beyond 3 years. Farmed fish had narrowly defined pelagic distributions that comprised the upper few meters of the water column, even when at the cage site. Although released Rainbow Trout dispersed throughout the study lake, most spent significant portions of time at the cage site, especially during normal operation when commercial feed was available. Core use areas (50% Kernel) included the farm for half of the released fish. Surviving Rainbow Trout showed continued reliance upon the cage site in their second year. However, wide dispersal, high growth rate, and lack of reliance on the cage site by some escaped fish warrant further research to assess potential effects of open-cage aquaculture in the water bodies where the industry occurs.

Bridger, C.J., R.K. Booth, R.S. McKinley, and D.A. Scruton. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. ICES Journal of Marine Science 58:510–516.

A combined acoustic and radio telemetry system was deployed within Bay d'Espoir, Newfoundland, to determine whether cultured steelhead trout (*Oncorhynchus mykiss*) released in the vicinity of a commercial aquaculture site remain at the site (site fidelity) or disperse from it. Two sets of fish releases (summer and winter 1998) were performed to determine seasonal effects on movements in the wild. Simulated escapes in summer involved 68 fish released from the cage system and 66 fish released from a cage towed approximately 1 km away from the grow-out site. The winter releases involved three batches of 30 fish each, one from the cage system and two off-site over the side of a boat (at 200 and 1000 m distance) after transport on board, with no cage towing involved. The results suggest site fidelity among steelhead released during the growing season. Fidelity was only slightly larger for on-site releases than off-site releases. Off-site released steelhead make a rapid return to their rearing sites, suggesting homing behavior. During the winter, the movement to the overwintering release site was less directed with a higher degree of dispersal. Released steelhead eventually dispersed from the release site, and in both seasons displayed a directed movement to the hydroelectric spillway, which is also the location of the local salmonid hatchery. Implications of the results are discussed in light of the development of recapture methodologies for aquaculture salmonids.

Brown, R., B. Pflugrath, D. Trott, and G. McMichael. 2012. Movement of net-pen–released Rainbow Trout in Lake Rufus Woods and Lake Pateros. Report to The Confederated Tribes of the Colville Reservation. 42 p. Available online: https://www.researchgate.net/profile/Geoffrey_Mcmichael2/publication/267268810_Movement_of_Net-Pen-Released_Rainbow_Trout_in_Lake_Rufus_Woods_and_Lake_Pateros/links/544930890cf2f63880810153.pdf

Large Rainbow Trout *Oncorhynchus mykiss* (>10 lb) have been present in the reservoir since net-pen aquaculture began in 1989. Many of these fish are escapees from aquaculture facilities or have been purchased by the Colville Tribes for release into the reservoir to augment the fishery. To maintain this fishery, the Fish and Wildlife Department of the Colville Tribes began research in 2008 to examine angling pressure, catch rates, and trout harvest. Understanding the extent of entrainment of rainbow trout at Chief Joseph Dam was also an important goal. To determine appropriate management strategies for the fishery, an acoustic telemetry study was initiated in fall 2010. Net-pen–reared Rainbow Trout were surgically implanted with acoustic transmitters and released from the net-pen location at river kilometer (rkm) 915.5. Releases of 99, 100, and 94 fish were made in November 2010, and January and March 2011. Autonomous receivers (called nodes) were used to detect the tagged fish at several locations upstream and downstream of the release area, including the forebay of Chief Joseph Dam and two sites downstream of the dam. Fish were monitored until the end of July 2011. Entrainment of net-pen–released rainbow trout appeared to be associated with the rates of spill past Chief Joseph Dam because a large number of fish were entrained at the onset of spill. There was no clear relationship between the size of fish and their likelihood of

entrainment. Because the fish appeared to be removed from Lake Rufus Woods fairly quickly, due to either harvest or entrainment, it would be unlikely that release of smaller fish (~1 lb) from net-pens instead of larger fish would yield a high number of larger, trophy-size fish. However, the probability that released fish will remain in the reservoir would likely be higher if the releases are made when there is little if any spill. It was clear from several sources of data (residence time, last detection location, location of recovered tags, and travel times) that there are two main areas where implanted fish spent a large amount of time and were likely to be harvested. These locations were the forebay of Chief Joseph Dam and the area adjacent to the net-pens where the fish were released. Another area used to a moderate extent was near rkm 933, close to another set of fish farms.

Charles, C., P.J. Blanchfield, and D.M. Gillis. 2017. Site fidelity of escaped rainbow trout to an experimental freshwater aquaculture facility and habitat overlap with native fish fauna." Aquaculture Environment Interactions 9: 415-428.

The distribution and habitat use of escaped farmed fish is often difficult to assess after their dispersal from commercial open-pen aquaculture facilities. The authors examined site fidelity of rainbow trout *Oncorhynchus mykiss* after release from an experimental farm (escaped fish) in a small lake, as well as habitat overlap (3D kernel utilization distributions) with a native salmonid, lake trout *Salvelinus namaycush*. Fish were implanted with telemetry transmitters, and their movements were monitored by acoustic arrays during (2006−2007) and after (2008−2009) commercial production. This latter period allowed for assessment of habitat use by escapees in the absence of any influence of cage production, simulating conditions similar to fallowing or long-distance dispersal. Escaped rainbow trout were regularly present at the cage site (23% of total positions) during production, typically at times of the day which coincided with feeding, but were rarely near the cage site (2% of total positions) during the post-production period, and instead greatly increased their occupancy of the near-shore region. Lake trout did not display an affinity to the cage site in either the production or post-production periods (~1% of total positions), and volumetric overlap with rainbow trout was relatively low throughout the entire study. Their results indicate that in the absence of ongoing production at commercial aquaculture operations. Rainbow Trout escapees can readily switch to foraging on native fauna in the near-shore regions of the lake and did not directly compete with native lake trout.

Clark, D., K.L. K. Murphy, and A. Windrope. 2017. Cypress Island Atlantic Salmon net pen failure: an investigation and review. Washington Department of Natural Resources, Olympia, WA. 120 p.

On August 19, 2017, a ten-cage net pen rearing 305,000 Atlantic salmon off Cypress Island in northern Puget Sound collapsed. Previously on July 24-25 in which moorings twice failed and the net pen moved hundreds of feet. The probable cause of both the incidents was failure to adequately clean the nets containing the fish.

- Insufficient cleaning, led to excessive biofouling by mussels and other marine organisms.
- Breakdowns in net cleaning machines contributed to this condition.
- The excessive biofouling significantly increased the drag (force) on the net pen array from tidal currents.
- Increased drag exceeded the holding power of the mooring system in both incidents.
- On July 24-25, the mooring system experienced both anchor dragging and breaking of attachment points between the moorings and the net pen.
- On August 19, some combination of anchor dragging, failure of mooring attachment points, and failure of structural members of the net pen framing resulted in the collapse of the net pen.
- Failure to address the biofouling effectively after the July incident directly contributed to the August failure.

Tidal currents were the mechanism of the July incident and August failure. The tidal currents on July 24 were the strongest during the summer of 2017 but were not unprecedented. The tidal currents on August 19 were less than those of July 24-25. While tidal currents continued to increase on August 20 and 21, the August 21 solar eclipse did not alter the normal pattern of seasonal tidal strength.

Properly designed, sited, and maintained, salmon net pens should be able to withstand combinations of tidal currents, wind, and wave forces that reasonably could be expected to occur at a site. This net pen had been operated without incident at this site for seven years (and for nine years previously at a location several hundred feet away).

State agencies concluded that:

- There were 305,000 fish in the net pen prior to failure.
- In August and September, Cooke reported harvesting/extracting 145,000 fish from the collapsed net pen.
- The Panel concluded that Cooke could only have extracted 42,000 to 62,000 fish, 43% of what Cooke reported.
- The Panel estimates that between 243,000 and 263,000 fish actually escaped.
- Of the escaped fish, 57,000 have been recovered.
- Between 186,000 and 206,000 Atlantic salmon remain unaccounted for.

Cooke Aquaculture Pacific, Northwest Resources Law letter dated January 29, 2018. Cooke Comments to Incident Review Panel (IRP) regarding IRP draft report, *Cypress Island Atlantic Salmon net pen failure: an investigation and review.*

The comment letter from Cooke Aquaculture Pacific reviews the *Draft Report on the Cypress Island Atlantic Salmon net pen failure: an investigation and review*, which was produced by the IRP on January 30, 2018. Cooke was given a brief amount of time by the IRP (from 9:00 a.m. on Friday, January 26, 2018 to 9:00 a.m. on Monday, January 29, 2018) to review the report and to make only factual corrections. Cooke produced this letter, dated January 29, 2018, summarizing their concerns and factual corrections to the draft report. While Cooke Aquaculture Pacific disagreed with a number of the conclusions in the report (as set forth in the January 29, 2018 letter), it concurs with the conclusions regarding a lack of environmental impacts associated with escaped fish. The letter also states the following:

Several factually correct findings found in the draft report that are worth enumerating:

- Cooke agrees that its fish were healthy at the time of release, with no endemic bacterial, viral, or parasitic (such as sea lice) pathogens detected in the group sampled immediately after release.
- Cooke agrees that the fish stock used do not eat in the wild and can confirm that all gastrointestinal tracts sampled by DFW, Cooke, and tribes were empty.
- Cooke agrees that the declining condition and weight of released fish were an important factor post-release in decreasing survival of fish in Puget Sound.
- Cooke agrees that the stress of an unfamiliar environment and lack of regular feedings resulting in a decreasing nutritional profile likely played a significant role in reducing survival of escaped fish.
- Cooke agrees with the assessment that the escaped fish in saltwater were all likely dead by November/December 2017.
- Cooke agrees with the assessment of freshwater survival and agrees with the need to monitor the Skagit and other rivers where Atlantic salmon have been detected. In fact, Cooke has already offered to fund that monitoring.

Consuegra, S., N. Phillips, G. Gajardo, and C.G. de Leaniz. 2011. Winning the invasion roulette: Escapes from fish farms increase admixture and facilitate establishment of non-native rainbow trout. Evolutionary Applications 4(5):660-671.

Aquaculture is a major source of invasive aquatic species, despite the fact that cultured organisms often have low genetic diversity and tend to be maladapted to survive in the wild. Yet, to what extent aquaculture escapees become established by means of high propagule pressure and multiple origins is not clear. The authors analyzed the genetic diversity of 15 established populations and four farmed stocks of non-native rainbow trout in Chile, a species first introduced for recreational fishing around 1900, but which has in recent decades escaped in large numbers from fish farms and become widespread. Hybrids between farm escapes and established trout were present in all rivers at frequencies ranging between 7% and 69%, and population admixture was positively correlated with genetic diversity. They suggest that non-native salmonids introduced into the Southern Hemisphere could benefit from admixture because local adaptations may not have yet developed, and there may be initially little fitness loss resulting from outbreeding depression.

Dempster, T., P. Arechavala-Lopez, L.T. Barrett, I.A. Fleming, P. Sanchez-Jerez, and I. Uglem. 2018. Recapturing escaped fish from marine aquaculture is largely unsuccessful: alternatives to reduce the number of escapees in the wild. Reviews in Aquaculture 10(1):153-167.

Farmed fish that escape and mix with wild fish populations can have significant ecological and genetic consequences. To reduce the number of escaped fish in the wild, recapture is often attempted. The authors review the behaviors of escapees post-escape, and how recapture success varies with escaped fish size, the size of the initial escape event and recapture methods. Success rates of fishing gears varied among species, with gill-nets and coastal barrier nets most effective for recapture of salmonids. Recapture success was strongly negatively correlated with both fish size and the number of fish escaped, regardless of species. Recapture success was universally low across all studied species (8%). Numerous tracking studies of escaped fish indicate that recapture efforts should be initiated within 24 h of an escape incident for highest recapture success. However, most large escape events are due to storms, which mean recapture efforts rarely start within this timeframe. Recapture of escaped fish is broadly ineffective in marine habitats, with rare exception. High bycatch rates during ineffective recapture attempts imply that large-scale recapture efforts should be weighed against the possibility of affecting wild fish populations negatively. They suggest three alternative approaches to reduce escapee numbers in wild habitats: (i) protect populations of predatory fish around sea-cage farms from fishing, as they prey upon smaller escapees; (ii) construct impact offset programs to target recapture in habitats where escapees can be efficiently caught; and (iii) ensure technical standards are legislated so that fish farmers invest in preventative technologies to minimize escapes.

Kendall, N.W., G.W. Marston, and M. M. Klungle. 2017. Declining patterns of Pacific Northwest steelhead trout (*Oncorhynchus mykiss*) adult abundance and smolt survival in the ocean. Canadian Journal of Fisheries and Aquatic Sciences 74(8):1275-1290.

Examination of population abundance and survival trends over space and time can guide management and conservation actions with information about the spatial and temporal scale of factors affecting them. The authors analyzed steelhead trout (anadromous *Oncorhynchus mykiss*) adult abundance time series from 35 coastal British Columbia and Washington populations along with smolt-to-adult return (smolt survival) time series from 48 populations from Washington, Oregon, and the Keogh River in British Columbia. More than 80% of the populations have declined in abundance since 1980. A multivariate autoregressive state-space model revealed smolt survival four groupings: Washington and Oregon coast, lower Columbia River, Strait of Juan de Fuca, and Puget Sound – Keogh River populations. Declines in smolt survival rates were seen for three of the four groupings. Puget Sound and Keogh River populations have experienced low rates since the early 1990s. Correlations between population pairs' time series and distance apart illustrated that

smolt survival rates were more positively correlated for proximate populations, suggesting that important processes, including those related to ocean survival, occur early in the marine life of steelhead.

Kostow, K.E., A.R. Marshall, and S.R. Phelps. 2003. Naturally spawning hatchery steelhead contribute to smolt production but experience low reproductive success. Transactions of the American Fisheries Society 132(4):780-790.

The authors used genetic mixture analyses to show that hatchery summer-run steelhead *Oncorhynchus mykiss*, an introduced life history in the Clackamas basin of Oregon, where only winter-run steelhead are native, contributed to the naturally produced smolts out-migrating from the basin. Hatchery-produced summer steelhead smolts were released starting in 1971, and returning adults were passed above a dam into the upper Clackamas River until 1999. In the 2 y of study, summer steelhead adults, mostly hatchery fish, made up 60 to 82% of the natural spawners in the river. Genetic results provided evidence that interbreeding between hatchery summer and wild winter steelhead was likely minor. Hatchery summer steelhead reproductive success was relatively poor. They estimated that they produced only about one-third the number of smolts per parent that wild winter steelhead produced. However, the proportions of summer natural smolts were large (36–53% of the total naturally produced smolts in the basin) because hatchery adults predominated on the spawning grounds during our study. Very few natural-origin summer adults were observed, suggesting high mortality of the naturally produced smolts following emigration. Counts at the dam demonstrated that hatchery summer steelhead predominated on natural spawning grounds throughout the 24-y hatchery program. Their data support a conclusion that hatchery summer steelhead adults and their offspring contribute to wild winter steelhead population declines through competition for spawning and rearing habitats.

Martens, M.T., A.J. Wall, G.G. Pyle, B.A. Wasylenko, W.A. Dew, R.H. Devlin, and P.J. Blanchfield. 2014. Growth and feeding efficiency of wild and aquaculture genotypes of Rainbow Trout (*Oncorhynchus mykiss*) common to Lake Huron, Canada. Journal of Great Lakes Research 2014.

Selective breeding of salmonid fishes for the purpose of commercial aquaculture has resulted in domesticated strains possessing a divergent physiological and behavioral phenotype from that of wild conspecifics. Freshwater production of Rainbow Trout has been occurring in regions of Lake Huron, Canada, for decades yet the growth and performance of domestic (aquaculture) versus wild (naturalized) strains are poorly understood. The authors conducted two trials to examine growth differences between size-matched wild and domestic strains of juvenile Rainbow Trout: 1) reared separately and fed to satiation; and 2) reared together and fed a reduced ration to induce competition. They used bioenergetics models to assess strain-specific growth rates across a range of water temperatures (5, 10, 15 and 18°C) as well as Lake Huron temperatures during the open-water season. Domestic rainbow trout showed a growth advantage throughout the 102 d trials, and by the end of the study had achieved a mass two-fold that of the wild strain and had greater fork length, condition, and thermal growth coefficient (TGC) under both treatments. Rapid growth of domestic strain fish was achieved through the combination of enhanced feed consumption (by ~40%) and feeding efficiency (up to 60% lower feed conversion ratio) relative to wild fish. Divergence in growth rates between strains was most pronounced (N3×) when modeled with Lake Huron open-water temperatures. They demonstrate that the growth and feed- conversion efficiency differ significantly between these two strains of Rainbow Trout under laboratory conditions, suggesting that differences could be even greater in nature.

Jacobsen, J.A., and L.P. Hansen. 2001. Feeding habits of wild and escaped farmed Atlantic Salmon, *Salmo salar* L., in the Northeast Atlantic. ICES Journal of Marine Science 58:916– 933.

The stomach contents of 2,992 wild and 863 putative escaped farmed Atlantic Salmon caught on floating long-lines in a Faroese research fishery in the late autumn (November–December) and winter (February–March) in the Northeast Atlantic (63–66°N and 1–10°W) during three consecutive fishing periods 1992/1993–1994/1995 were analyzed. Hyperiid amphipods of the genus *Themisto*, euphausiids and mesopelagic shrimps are important sources of food for salmon in the autumn period and various mesopelagic fish as lantern fishes, pearlsides and barracudinas become equally important during the late winter period. The occasional presence in the stomachs of larger fish such as herring, blue whiting and mackerel is not considered to be evidence that these fish are a main source of food for salmon in the sea north of the Faroes. The proportion of stomachs containing food was significantly lower during autumn (53%) than during winter (78%). However, temperature-dependent evacuation rates could partly explain the apparent lower stomach content during the autumn, since the average ambient sea-surface temperature is 7°C in autumn compared to 3°C in winter. There was evidence of selective foraging. Fish were preferred over crustaceans, and amphipods were chosen over euphausiids. Large salmon (3+SW) tended to be more piscivorous than smaller fish. There was no difference in condition factor, number and weight proportions of prey, or in diet between wild and escaped farmed salmon, which suggests that escaped farmed salmon adapt well to the "wild" life in the ocean.

Jensen, Ø., T. Dempster, E.B. Thorstad, I. Uglem, and A. Fredheim. 2010. Escapes of fishes from Norwegian sea-cage aquaculture: causes, consequences and prevention. Aquaculture Environment Interactions 1(1):71-83.

The escape of fish from aquaculture is perceived as a threat to wild fish populations. The escapes problem is largely caused by technical and operational failures of fish farming equipment. In Norway, 3.93 million Atlantic Salmon *Salmo salar*, 0.98 million Rainbow Trout *Oncorhynchus mykiss* and 1.05 million Atlantic Cod *Gadus morhua* escaped from 2001 to 2009. Salmonids primarily escape after structural failures of containment equipment, while a far greater proportion of cod than salmon escape through holes in the nets. Correlative evidence suggests that after the Norwegian technical standard (NS 9415) for sea-cage farms took effect in 2004, the total number of escaped Atlantic Salmon declined from >600,000 (2001 to 2006) to <200,000 fish/y (2007 to 2009), despite the total number of salmon held in sea-cages increasing by 44% during this period. No similar decrease in escaped cod has occurred, suggesting that other measures, such as improved netting materials for sea-cages, are required. In addition to escaping as juveniles or adults, cod may reproduce in sea-cages, and thus fertilized eggs escape to the environment. The ecological effects of 'escape through spawning' are unclear, and methods to inhibit escape by this mechanism are being explored. To prevent escapes of juvenile and adult fish as sea-cage aquaculture industries develop, the authors recommend that policy-makers implement a five-component strategy: 1) establish mandatory reporting of all escape incidents; 2) establish a mechanism to analyze and learn from the mandatory reporting; 3) conduct mandatory, rapid, technical assessments to determine the causes of escape incidents involving more than 10,000 fish; 4) introduce a technical standard for sea-cage aquaculture equipment coupled with an independent mechanism to enforce the standard; and 5) conduct mandatory training of fish farm staff in escape-critical operations and techniques.

Johnsson, J.I., and M.V. Abrahams. 1991. Interbreeding with domestic strain increases foraging threat of predation in juvenile steelhead trout (*Oncorhynchus mykiss*): an experimental study. Canadian Journal of Fisheries and Aquatic Sciences 48:243–247.

The foraging behavior of laboratory-reared juvenile steelhead trout and steelhead/domesticated rainbow trout hybrids were compared. In 10 replicate experiments, 10 fish from each strain were allowed to choose between foraging in a safe area or an area containing a predator. The hybrid trout were significantly more

willing to risk exposure to the predator than were the steelhead. It was possible that differences in the relative willingness to risk exposure may have reflected differences in their susceptibility to predation. A second experiment measured the susceptibility of these two strains to the predator by simulating standardized encounters between predator and prey. Both strains suffered identical mortality rates and therefore were considered to be equally susceptible to the predator. This experiment confirmed that the hybrid trout were significantly more willing to take risks than the wild steelhead. These results indicate that interbreeding between escaped hatchery and wild fish may have a potentially damaging effect on the wild population.

Klinger, D. and R. Naylor. 2012. Searching for solutions in aquaculture: charting a sustainable course. Annual Review of Environment and Resources, 37, pp. 247-276.

Aquaculture is currently the fastest growing animal food production sector and will soon supply more than half of the world's seafood for human consumption. Continued growth in aquaculture production is likely to come from intensification of fish, shellfish, and algae production. Intensification is often accompanied by a range of resource and environmental problems. The authors review several potential solutions to these problems, including novel culture systems, alternative feed strategies, and species choices. They examine the problems addressed; the stage of adoption; and the benefits, costs, and constraints of each solution. Policies that provide incentives for innovation and environmental improvement are also explored. They end the review by identifying easily adoptable solutions and promising technologies worth further investment.

Knudsen, R., P.A. Amundsen, and A.H. Rikardsen. 2011. Individual feeding specialisation of a naïve vs. veteran predators. Ecology of Freshwater Fish 20(4):522-528.

The authors explored the incidence of individual feeding specialization among a naïve predator (non-native Rainbow Trout post-smolts) and two native experienced predators (sea-run Arctic char and sea-trout) in a subarctic Norwegian fjord. Interindividual foraging niche stability was obtained by combining information on stomach contents (recent dietary niche) with trophically transmitted parasite infestation (time-integrated historical dietary niche) of individual predators. Individual fish showed a high degree of resource specialization as prey items such as gammarids and small fish (both potential intermediate host of parasites) rarely co-occurred in stomachs. In both naïve and veteran predators, positive associations between the intensity of a specific parasite species and the occurrence of their respective intermediate host (gammarids or fish) in the stomachs of individual predators demonstrated temporally interindividual feeding specializations. Several behavioral phenotypes clearly co-existed in both naïve and veteran predator populations, including gammaridivore (benthic feeders), piscivore (pelagic feeders) or insectivore (pleuston feeders) individuals. The likely mechanism of this observed interindividual resource specialization in the non-native naïve predators involves a behavioral component of which rapid learning seems to be a key factor.

Leggatt, R.A., P.T. O'Reilly, P.J. Blanchfield, C.W. McKindsey, and R.H. Devlin. 2010. Pathway of effects of escaped aquaculture organisms or their reproductive material on natural ecosystems in Canada. Fisheries and Oceans Canada. Scientific Advisory Secretariat Research Document 2010:70.

This document provides an overview of the pathways of effects escaped aquaculture fish (specifically finfish and bivalves) may have on natural ecosystems in Canada. Escape, survival, dispersal and reproduction of aquaculture organisms have been noted in many areas in Canada, although the scale of escapes in Canada is not known. In general, escaped fish have poor survival, foraging, and reproductive capacity relative to wild conspecifics. However, substantial evidence indicates escaped Atlantic Salmon can affect wild conspecifics through juvenile competition resulting in decreased productivity of wild juveniles, and through hybridization resulting in partial transfer of culture phenotypes to wild populations. However, the potential for escaped fish to affect wild populations through predation, marine competition,

reproductive interference, and disease transfer pathways has been poorly studied. As well, a high degree of uncertainty exists for other escape species (e.g., marine finfish, other salmonids) due to insufficient evidence and uncertainty regarding extrapolation of existing information from other species and ecosystems. For shellfish, information from outside of Canada suggests that release of farmed bivalves can cause ecological disruptions where they are non-native. Effects are expected to be very context-specific and can be influenced by health of the receiving environment, geography, species and strain types, climate, life-stages released, among others. Overall, there is significant potential for escaped aquaculture organisms to impact natural ecosystems in Canada and this potential can be influenced by numerous environmental and genetic factors. However, the effects escaped fish may have on overall community dynamics or ecosystem function are not yet known.

Lindberg, M., P. Rivinoja, L.O. Eriksson, and A. Alanärä. 2009. Post-release and pre-spawning behaviour of simulated escaped adult Rainbow Trout *Oncorhynchus mykiss* in Lake Övre Fryken, Sweden. Journal of Fish Biology 74(3):691-698.

Using radio telemetry, the present study simulated the escape of 48 adult Rainbow Trout *Oncorhynchus mykiss* from a net-cage fish farm in the Lake Övre Fryken, Sweden. The post-release dispersal of *O. mykiss* was fast, showed long-range dispersal behavior, low winter survival and lacked the ability to find suitable spawning habitats. Thus, the present study suggested that reproducing for the first time may be an obstacle to the establishment of escaped farmed *O. mykiss*.

Naylor, R., K. Hindar, I.A. Fleming, R. Goldburg, S. Williams, J. Volpe, F. Whoriskey, J. Eagle, D. Kelso, and M. Mangel. 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. Bioscience 55(5):427-437.

The farming of salmon and other marine finfish in open net pens continues to increase along the world's coastlines as the aquaculture industry expands to meet human demand. Farm fish are known to escape from pens in all salmon aquaculture areas. Their escape into the wild can result in interbreeding and competition with wild salmon and can facilitate the spread of pathogens, thereby placing more pressure on already dwindling wild populations. The authors assess the ecological, genetic, and socioeconomic impacts of farm salmon escapes, using a risk-assessment framework. They show that risks of damage to wild salmon populations, ecosystems, and society are large when salmon are farmed in their native range, when large numbers of salmon are farmed relative to the size of wild populations, and when exotic pathogens are introduced. They then evaluate the policy and management options for reducing risks and discuss the implications for farming other types of marine finfish.

Naylor, R.L., J. Eagle, and W.L. Smith. 2003. Salmon aquaculture in the Pacific Northwest a global industry with local impacts. Environment: Science and Policy for Sustainable Development 45 (8):18-39.

From the docks of declining coastal villages to the desks of corporate and government offices, salmon farming has been hailed as a new hope for the world's ailing offshore fishing industry and a way to reduce pressure on severely depleted fish stocks. However, the aquaculture industry has grown so quickly that, in many areas-including the Pacific Northwest-it has outstripped the wherewithal to address its adverse ecological impacts. Will fish farms, in the end, do more harm than good? Or can they deliver on their sustainable promise?

Patterson, K. 2010. The fate of farmed Rainbow Trout (*Oncorhynchus mykiss*) released from commercial aquaculture operations in Lake Huron. Thesis, University of Manitoba, Winnipeg, 193 p.

The fate of farmed fish after escape is poorly understood. The extent to which these fish might impact freshwater ecosystems is dependent upon their survival and distribution in the wild. She simulated small- and large-scale escape events from two commercial aquaculture operations in Lake Huron over 2 years. She combined the use of telemetry (120) and Floy (1000) tags to determine the fate of escaped farmed Rainbow Trout (*Oncorhynchus mykiss*). Once released, escapees dispersed rapidly, showed low site fidelity (~15% after 3 months) and were capable of long-distance movements (up to 360 km). Rainbow Trout experienced low survival (~50%) but maintained high growth rates both at and away from the farms. The results of this study provide a strong basis for understanding the potential risks that farmed fish may pose to the Lake Huron fish community and ecosystem in an escape event.

Rikardsen, A.H., and S. Sandring. 2006. Diet and size-selective feeding by escaped hatchery Rainbow Trout *Oncorhynchus mykiss* (Walbaum). ICES Journal of Marine Science 63:460– 465.

Escaped hatchery rainbow trout at post-smolt (120–340 g) and adult stages (800–3400 g) adapted differently to natural marine prey after escaping from two fish farms in northern Norway. About 1 month after escape (July), more than 57% of the post-smolt fed actively on fish larvae, which contributed 63–75% of the diet by weight. Surface insects were consumed by more than half the post-smolts and represented 24–48% of the diet during the 3-month period of sampling (June–August). One month after escaping, forage ratios (weight stomach/weight fish × 100) exceeded 1, similar to ratios recorded for other wild anadromous salmonid species in the area. Post-smolt weight increased during the sampling period and the condition factor was stable. In contrast, the condition factor of escaped adult fish reduced significantly and the forage ratios were consistently low (0.05–0.77) during the 15 months of sampling (March–August) following their escapement. These fish fed primarily on a variety of different indigestible items (especially particles of seaweed and small pieces of wood) that contributed about 70% of the stomach content weight. The authors took fish larvae only in July. Although generally contributing little to their overall diet, marine prey of great variety was consumed by the adult fish. The results indicate that young domestic rainbow trout more easily adjust to natural feeding after escape than the older, larger fish, which often fed on indigestible items similar in shape to the commercial pellets to which they were accustomed.

Rust, M.B., K.H. Amos, A.L. Bagwill, W.W. Dickhoff, L.M. Juarez, C.S. Price, J.A. Morris Jr, and M.C. Rubino. 2014. Environmental performance of marine net-pen aquaculture in the United States. Fisheries 39(11):508-524.

Efforts to reduce escapes in salmon farming in Washington State and British Columbia, Canada, have been successful. From 1987 to 1996, the average annual escape rate was 3.7% of annual harvest, whereas more recently (2000–2009) escape rate averaged 0.3%. The primary concern of escaped fish is the potential for them to interbreed with wild conspecifics and reduce the long-term fitness of the wild population.

Shallenberger, E., C.C. Tribes, D.C. Richards, J.E.J. Rensel, Z. Siegrist, F.J. O'Brien, and D. Kiefer. 2011. Rufus Woods Lake–Columbia River Reservoir Morphometrics, Initial Food Web and Rainbow Trout Fishery Studies. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.470.8385&rep=rep1&type=pdf

Commercial net pens are used in Rufus Woods Lake (RWL) within Colville Confederated Tribal jurisdiction to rear and intentionally release some sterile Rainbow Trout (RBT). Most of the fish caught in the RWL fishery are from net pen origin. Relatively large size RBT released by the CCT into RWL are purchased from the net pen growers. RBT are released at different intervals throughout the year for fishing by CCT members and non-treaty anglers. Their study incorporates information from companion studies

conducted by the CCT Fish and Wildlife Department that involved collection of fish stomachs for analyses of contents by their team.

A total of 409 fish stomach samples were collected during creel surveys and from a gillnet study. Organisms in stomachs were identified to lowest practical taxon along with documentation of remnants of fish pellets and other contents. We calculated several summary statistics and graphically analyzed the stomach content data, again focusing primarily on RBT stomach contents. A large proportion (61%) of the total collected were less than 1.6 kg, the mean size of releases. Most of the acoustically tagged net pen RBT that were later recovered lost weight (about 5% loss) but this was for an average period of only 17 days. Given that most acoustically tagged fish were tracked and present for a short time (a few days to several months) and the mean residence time of acoustic tagged fish recovered was only a few weeks, as well as the fact that the mean weight loss of the acoustically tagged fish recovered averaged 5%, we believe that some of these smaller fish may have been RWL or Lake Roosevelt net pen escaped fish.

Diets of the 409 fish examined varied significantly among fish within and between time periods. At least 96 separate prey taxa were found in the stomach samples. Twenty-five percent of the RBT stomachs (N = 73) were empty but there was significant variation of mean percent empty among sampling periods. Aquatic based food items made up more of the RBT diet than did terrestrial food items. The vast majority of individual organisms in RBT stomachs were very small pelagic crustaceans (e.g. daphnia, copepods, ostracods, etc.) followed by diptera (midges and flies), snails, and terrestrial arthropods (insects and spiders).

From 14 to 17% of the RBT stomachs examined contained crayfish (9%) or fish (5-8%). However, most of the crayfish and fish occurred in only a few trout stomachs. This could indicate that few RBT had acquired the skill or ability to feed on this often abundant food source in RWL, particularly in light of the fact that most of the RBT were large fish (> 30 to 40 cm).

Skilbrei, O.T. 2012. The importance of escaped farmed Rainbow Trout (*Oncorhynchus mykiss*) as a vector for the salmon louse (*Lepeophtheirus salmonis*) depends on the hydrological conditions in the fjord. Hydrobiologia, 686(1):287-297.

The objectives of the study were to see if escaped Rainbow Trout spread rapidly or not from fish farms, and to test whether the hydrological conditions in a fjord influence their vertical distribution and importance as vector for the salmon lice. Fifty farmed rainbow trout were tagged with acoustic transmitters including depth sensors and released from two of 11 fish farms in the fjord system. In addition, unintentionally escaped rainbow trout were recaptured for analysis of salmon lice and stomach content. Dispersal out of the fjord system was limited. Most fish stayed in the vicinity of and moved between the fish farms but fed primarily on a variety of indigestible items. They moved in the warm relatively fresh surface layer from late spring until early autumn where the risk of being infested with salmon lice was low. They swam gradually deeper and became much more infested with salmon lice as the surface layers cooled and salinity and temperature gradients became less distinct over the course of the winter. The observed post-escapement behavior may challenge the control of the spread of diseases and parasites between neighboring farms and to wild fish, but also increases opportunities for recapture.

Skilbrei, O.T., and T. Jørgensen. 2010. Recapture cultured salmon following a largescale escape experiment. Aquaculture Environ. Inter. 1:107–151.

A large-scale escape experiment using 1,031 adult Atlantic Salmon *Salmo salar* was performed in the Hardangerfjord in western Norway to study the dispersal of escaped salmon, evaluate the effect of a gill-net fishery targeting escaped salmonids and test whether surface trawling is an effective way of recapturing escaped salmon in a large fjord system. The salmon of mean weights 1.56 and 5.5 kg were released from 2

commercial fish farms in late September 2006. All fish were tagged with external tags, and 48 were also equipped with acoustic transmitters. A surface pair-trawl (50 m wide and 8 m deep) was constructed to optimize catchability and maneuverability in the fjord environment. Trawling was unsuccessful, and caught only 6 simulated escapees. Telemetry data confirmed that the fish were available along the towing tracks, and they assume that towing speed and/or trawl size may have been suboptimal with regard to avoidance by fish in the fjord environment. Gill-netting proved to be an efficient method of recapture. The total reported recapture rate (of 114 fishers) was 40%, but a significantly higher recapture rate (67%) of the more highly rewarded acoustic transmitters, and the distribution of the fish in time and space, suggest that the actual catch may have been substantially higher. Approximately 90% of the catches were taken within 40 km of the release sites over the course of 4 wk. The authors conclude that a significant proportion of escaped adult salmon can be recaptured if the catch effort within the fjord basin is widespread and lasts for at least 4 wk.

Thorstad, E. B., I. A. Fleming, P. McGinnity, D. Soto, V. Wennevik, and F. Whoriskey. 2008. Incidence and impacts of escaped farmed Atlantic Salmon *Salmo salar* in nature. Report from Technical Working Group on Escapes of the Salmon Aquaculture Dialogue, 112 p.

Since the mid-1960s, Atlantic salmon Salmo salar farming has grown into a large industry beyond the native range of the species. This report examines and evaluates i) the incidence and impacts of escaped farmed salmon in nature, and ii) the technologies and efforts to prevent escapes and to reduce their impacts upon wild salmon and the environment.

Detailed information on salmon production, reported escapes from fish farms and monitoring of escaped farmed salmon in nature is given for each of the salmon producing countries. Escapes from fish farms occur from marine net pens in all salmon producing countries, as both repeated "trickle" losses of relatively small numbers of fish, and through large-scale episodic events. Numbers of farmed salmon escaping to the wild are large relative to the abundance of their wild conspecifics. Negative effects by escaped farmed salmon on wild Atlantic salmon populations have been scientifically documented, including both ecological interactions and genetic impacts of inter-breeding. It has been shown that inter-breeding of farm with wild salmon can result in reduced lifetime success, lowered individual fitness, and decreases in production over at least two generations.

The Atlantic salmon is a poor colonizer outside its native range. The probability that escaped Atlantic salmon will establish populations where the species is exotic seems low, but cannot be ruled out. It is difficult to predict if or how Atlantic salmon will adapt to the regions where they are exotic. The most important management issue at present is the need to reduce the numbers of escaped farmed salmon in nature. Among technologies and efforts to reduce impacts of escapes, sterilization and farm exclusion zones look to be among the most promising.

Tlusty, M. F., J. Andrew, K. Baldwin, and T. M. Bradley. 2008. Acoustic conditioning for recall/recapture of escaped Atlantic salmon and rainbow trout. Aquaculture 274:57–64.

Escape of salmon from sea cages is a problem that continues to plague the aquaculture industry. Data collected during the past 15 years from Norway, Scotland, Ireland, Canada and U.S. suggest significant impacts on natural runs of fish and economic losses to producers. The present report investigated the feasibility of using acoustic conditioning as a means of recalling/recapturing escaped fish. Atlantic Salmon (*Salmo salar*) and Rainbow Trout (*Oncorhynchus mykiss*) were found to respond to frequencies in the range of 50 – 400 Hz equally well. Subsequently, both species were conditioned to a 250 Hz acoustic tone during feeding. Juvenile and sub-adult fish readily conditioned to the acoustic signal within four days, with the maximum number of fish responding (85% salmon, 96% trout) by day seven. To assess retention of conditioning, fish were exposed to a single tone without feed reinforcement every one, two or four weeks.

Salmon and trout continued to respond for a seven-month period with no significant decrease (88% salmon, 97% trout) in response. No significant differences were observed in the response of *either* species to tones differing in frequency by up to 200 Hz (89% salmon, 96 trout) and intensity by 20 dB (91% salmon, 96% trout). Both species were reproducibly recalled to a cage or feeding ring in a 3.7 m tank, but were reluctant to re-enter the cage. The findings indicate that salmon and trout are readily conditioned to acoustic signals and retain that conditioning for an extended period of time without reinforcement. These characteristics suggest that acoustic conditioning has potential as a means to recall escaped salmon and when coupled with recapture, can reduce interactions with wild stocks and losses to the producer.

Veinott, G., and R. Porter. 2013. Discriminating Rainbow Trout sources using freshwater and marine otolith growth chemistry. North American Journal of Aquaculture 75(1):7-17.

Rainbow Trout *Oncorhynchus mykiss* are nonindigenous to Newfoundland. Subsequent to the development of marine cage rearing of Rainbow Trout in the Atlantic provinces in the early 1970s. Rainbow Trout have been captured in 33 rivers on the west and south coast of Newfoundland. These escapees may have negative impacts on wild populations, particularly Atlantic Salmon *Salmo salar* and Brook Trout *Salvelinus fontinalis*. In this study, the chemical fingerprints in the freshwater and marine growth sections of otoliths were used to distinguish three groups of Rainbow Trout of known origins: two hatcheries and one wild population. The results were then used to assign fish of unknown origin to the three known-origin groups and thus estimate the proportion of escapees. The three known sources produced distinct chemical fingerprints in the freshwater growth of the otoliths (cross validation test, average accuracy of over 93%); whereas, the marine growth in the otoliths produced a single chemical fingerprint for the two hatchery-origin groups distinct from the wild population. Results indicated that at least 60% of the unknown-origin fish were aquaculture escapees. Vaterite was encountered in 70–80% of the known hatchery-origin fish, 0% in the wild population, and 50% in the escapees. It appears that escapees with vaterite had a lower survival rate. The presence–absence of vaterite did not appear to be useful in distinguishing escapees from a wild population.

Volpe, J.P., E.B. Taylor, D.W. Rimmer, and B.W. Glickman. 2000. Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river. Conservation Biology 14 (3):899-903.

The authors present evidence of the first successful natural spawning of Atlantic Salmon (*Salmo salar*) documented on the Pacific coast of North America. Twelve juvenile Atlantic salmon composed of two, year classes were captured in the Tsitika River, British Columbia. They analyzed restriction-length polymorphisms of PCR-amplified 5S rDNA and mtDNA to confirm that these individuals were Atlantic salmon. Scale analysis strongly suggested they were the products of natural spawning by feral adults. The gut contents, size, and condition of these individuals suggest that Atlantic salmon are successfully maturing in the Tsitika River, BC. This event has raised concerns that the presence and possible establishment of feral Atlantic Salmon may further jeopardize the continued persistence of already fragile native Pacific salmonids through competition for resources and occupation of niches that are currently underutilized.

Benthic Impacts

Belle, S.M., and C.E. Nash. 2008. Better management practices for net pen aquaculture. Pages 261–330 in C.S. Tucker and J. Hargreaves, editors. Environmental best management practices for aquaculture. Blackwell Publishing, Ames, Iowa.

The BMPs for current net-pen technology have been published by national salmon producer associations as codes of practice to avoid or minimize environmental effects. North American programs have been less prescriptive regarding equipment specifications and more focused on equipment testing, preventive maintenance, and monitoring and improvement of standard operating protocols. Site characteristics—especially current patterns—will affect the efficiency of feed utilization (and therefore waste production) and the accumulation or dispersal of wastes. Adequate water velocities will disperse solid wastes, ensure good water quality, and reduce the probability that the local carrying capacity of the site is exceeded. Whether a site is depositional or erosional depends on current velocity, storm frequency and magnitude, hydrography, and local circulation patterns, among other factors. Bottom type and granulometry can be used to determine whether a site is depositional or erosional.

Fallowing on net-pen farms is a relatively new technique. Management practices that address the linkage between benthic and water-column environments are relatively new. Gear placement can significantly affect water circulation patterns on a site.

Chamberlain, J., and D. Stucchi. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. Aquaculture 179:127–140.

Models that simulate the input and fate of waste materials from marine cage finfish farms are considered valuable tools within management strategies for predicting environmental impacts. However, the overall utility of these models may be limited because of uncertainty regarding values used to parameterize and configure simulations, and variability in coupling predicted flux and benthic impacts. This study applies the aquaculture waste model DEPOMOD (Cromey, C.J., Nickell, T.D., Black, K.D. 2002a. DEPOMOD—modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214, 211–239.) at a marine finfish farm in British Columbia and examines i) the effect of uncertainty in three model parameters (percent waste feed, carbon concentration of feed and fecal material) and one process (resuspension) on model outputs; ii) the relative contribution of waste feed and fecal material to the predicted carbon flux distribution; and iii) the relationships between model outputs and high resolution field survey data collected at the site. Simulation of resuspension processes resulted in predictions that were considered unrealistic as 98% of the applied material was transported out with the model domain. When resuspension processes were not simulated, the applied waste feed value was the most significant contributing factor to the predicted range in model outputs up to ~ 100 m from the farm site. The waste feed component accounted for between 50% and 75% of the overall carbon deposition, dependent upon the applied carbon concentration of the particles, and potentially in excess of 80% of the predicted carbon flux at the cage edge. The effect of uncertainty in the applied carbon concentrations of fecal material to the overall range in predicted flux was minimal. Coupling of model outputs with field measurements indicated that, within the predicted envelope of uncertainty, significant alterations to the benthic community structure (H`, ITI) and sediment geochemistry ($S^{=}$) indicative of the transition between oxic and anoxic benthic zonation status occurred at predicted flux values of between ~ 1 and 5 $gC/m^2/d$.

Hargrave, B.T. 2003. A scientific review of the potential environmental effects of aquaculture in aquatic ecosystems, Volume 1. Fisheries and Oceans Canada, Canadian Technical Report of Fisheries and Aquatic Sciences 2450, Ottawa. Available online at: www.dfo-mpo. gc.ca/science/enviro/aquaculture/sok-edc/volume1/hargrave-eng.htm.

Sediment profile images (SPI) of cores collected by SCUBA diver were obtained using a modified Hargrave corer from fish farm sites in the Bay of Fundy, Canada and southeastern Tasmania, Australia. Shipboard and land-based photography were used to obtain the SPI with a tripod mounted digital camera and image analysis by commercially available software. Computer images were analyzed to determine the variables used by Nilsson and Rosenberg [Mar. Ecol., Prog. Ser. 197 (2000) 139], modified to account for non-equilibrium conditions, to assess successional stages of organic enrichment. To validate the method, they concurrently sampled macrofaunal species composition and abundance and measured profiles of redox potentials and total sulphides by ion analysis. In each case, the null hypothesis that sediments collected directly under an active salmon net-pen were indistinguishable from a nearby reference site was rejected. The SPI method can successfully detect organic enrichment where impacts occur in soft sediments in geographically diverse locations.

Hargrave, B., M. Holmer, and C. Newcombe. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin 56:810–824.

A nomogram is developed to show that pH, redox potentials (Eh_{NHE}) and measures of dissolved sulfides ($H_2S + HS^- + S^{2-}$)(total free S^{2-}) can be used to classify organic enrichment impacts in marine sediments. The biogeochemical cycle of sulfur in marine sediments is described to show that changes in macrobenthic infauna community structure associated with high levels of organic matter supply result from stress due to oxygen deficiency (hypoxia and anoxia) and toxic effects of S^{2-}. The changes reflect enhancement of microbial sulfate reduction under conditions of high organic matter sedimentation and the progressive formation of hypoxic–anoxic conditions measured by decreased Eh_{NHE} and increased concentrations of S^{2-}. The nomogram provides a basis for classification of the oxic status of marine sediments based on changes in inter-related biological and biogeochemical variables along an organic enrichment gradient.

Holmer, M., D. Wildish, and B. Hargrave. 2005. Organic enrichment from marine finfish aquaculture and effects on sediment biogeochemical processes. Pages 181–206 in B.T. Hargrave, editor. Handbook of environmental chemistry, Volume 5M, Springer Verlag, Berlin.

Organic enrichment of sediments underlying fish farms in temperate and tropical coastal zones is reviewed to identify similarities and important biogeochemical differences. Improvements in technology have allowed farms to move from depositional sites to more erosional offshore locations. However, low cost farms are still being located in sheltered areas, in particular in the tropics. Important differences in the response of sediment geochemical variables to organic enrichment are associated with finfish aquaculture located under highly diverse hydrographic and sedimentological conditions in different coastal areas. In temperate latitudes where farms are often located over soft bottom, organic enrichment increases sediment microbial activity and may alter benthic community structure. Enhanced anaerobic activity may lead to accumulation of sulfides with adverse effects on aerobic bacteria, plants and fauna due to progressive oxygen depletion. In warm temperate waters, such as the Mediterranean and tropical latitudes, many farms are located in more advective areas with coarse-grained carbonate-rich sediments. Effects of organic enrichment in these areas are less well described, but studies have also shown sulfide accumulation in sediments indicative of deteriorated benthic habitats.

Kalantzi, L., and L. Karakassis. 2006. Benthic impacts of fish farming: meta-analysis of community and geochemical data. Marine Pollution Bulletin 52:484–493

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.

Rooney, R.C. and C.L. Podemski. 2009. Effects of an experimental Rainbow Trout (*Oncorhynchus mykiss*) farm on invertebrate community composition. Canadian Journal of Fisheries and Aquatic Sciences, 66(11):1949-1964.

The authors examined the development of changes in the zoobenthos along a transect from an experimental Rainbow Trout farm in Lake 375, Experimental Lakes Area, northwestern Ontario, Canada. After 2 months, invertebrate abundance was reduced under the fish cage (2542 ± 569 individuals/m^2) compared with samples collected 45 m away ($16\,137 \pm 2624$ individuals/m^2). Taxa richness was also depressed, but changes in biomass were variable. Reductions in abundance and richness at high organic loading levels are consistent with earlier models developed for the marine environment of responses to organic loading in marine systems. After two production cycles, the significant principal components axis explaining 76% of total variance in abundance was correlated with distance from the cage (Spearman rank correlation, $r = -0.775$, $p = 0.014$) and with chemical variables recommended for freshwater aquaculture monitoring (Pearson's correlation coefficient, $r = 0.78$, 0.76, and 0.75 with $p = 0.013$, 0.018, and 0.020 for pore-water ammonia and sediment Cu and Zn, respectively). The effects of farming were localized, dissipating within 15 m of the cage edge. Invertebrate abundance demonstrated the most potential for incorporation into monitoring schemes at new farms. At established farms, richness may be a valuable monitoring metric.

USEPA (United States Environmental Protection Agency). 2010. Update to the biological evaluation submitted April 17 and August 6, 2008, regarding EPA action on Washington's marine finfish rearing facility provision contained in the Sediment Management Standards. Prepared for National Marine Fisheries Service, Seattle, WA. 80 p.

This Endangered Species Act analysis concluded that listed fish species that occur in Washington State waters are not likely to be affected by Washington's marine finfish rearing facility provision, WAC 173-204-412. The EPA also determined that there is No Effect for ESA-listed species (fish, mammals, turtles), under NOAA jurisdiction, analyzed for EPA's approval of Washington's marine finfish rearing facility provision, WAC 173-204-412.

Wellman, S., K.A. Kidd, C.L. Podemski, P.J. Blanchfield, and M.J. Paterson. 2017. Incorporation of wastes by native species during and after an experimental aquaculture operation. Freshwater Science 36(2): 387-401.

Freshwater aquaculture increases dissolved and particulate nutrients near fish cages, but the degree to which they are incorporated into tissues of native animals is uncertain. At the Experimental Lakes Area in northwestern Ontario, Canada, a cage culture of Rainbow Trout was operated seasonally for 5 y, and invertebrates and fishes were collected before, during, and after culturing from the experimental lake and a

reference lake to assess changes in stable isotopes of C and N in their tissues. The feed contained marine fishmeal and was higher in C and N isotope values ($\delta^{13}C$ and $\delta^{15}N$) than lake biota by ≥4‰ (all taxa) and 3‰ (all invertebrates), respectively. During the aquaculture operation, $\delta^{15}N$ of littoral and pelagic invertebrates, profundal chironomids, minnows, and Lake Trout (*Salvelinus namaycush*) increased by 2 to 5 ‰ relative to before aquaculture values. In the 1st and 2nd years after aquaculture, $\delta^{15}N$ of several invertebrate taxa and all fishes continued to increase 1 to 2 ‰/y. In contrast, during aquaculture, only minnows and trout had significant increases (up to 3 ‰) in $\delta^{13}C$. In the period after aquaculture, the $\delta^{13}C$ of fishes, plankton, and profundal chironomids declined to below values measured before or during aquaculture. Isotopic analysis of native biota can be used to monitor assimilation of cage culture wastes in freshwater ecosystems.

Woodcock, S.H., T. Strohmeier, Ø. Strand, S.A. Olsen, and R.J. Bannister. 2018. Mobile epibenthic fauna consume organic waste from coastal fin-fish aquaculture. Marine environmental research 137:16-23.

Organic waste released from fin-fish aquaculture is being dispersed further as industry growth has led to the expansion of open net cages in dynamic coastal locations. Here the authors investigate the response of three mobile epibenthic invertebrates (brittle stars, urchins and brown crabs), whose natural habitats overlap with large scale coastal salmon farming. Using fatty acids and stable isotopes, they found these organisms displayed decreases in δ13C and δ15N and elevated levels of C18 fatty acids reflective of terrestrial components of fin-fish feeds. Furthermore, they found these three species consume aquaculture organic waste not only directly adjacent to the farm vicinity (0-20 m from cage edge) but up to 1 km away in the case of brittle stars and brown crabs. As aquaculture feeds shift to contain more terrestrial ingredients, the biochemistry of fauna feeding on organic waste is also being shifted, the result of these changes is currently unclear.

ESCAPED STEELHEAD IMPRINTING/HOMING

Steelhead, like other anadromous salmonids have a strong tendency to home to their natal stream as they become sexually mature. Only a very small fraction (~2%) of triploid steelhead have the potential to become sexually mature. However, even these few pen-reared steelhead are likely to have a weak tendency to select a specific stream as they will have imprinted on a freshwater source far from their rearing location with no migratory experience between the two locations.

Home stream imprinting is the physiological process by which anadromous salmonids develop the capacity to recognize the odor of their natal stream. Imprinting commonly occurs at the time the juvenile salmonids undergo smoltification, the physiological development process during which they develop the capacity to reside in salt water. In the case of the triploid steelhead smoltification will occur at the initial freshwater rearing facility prior to transport to the salt water rearing site. Any escaped steelhead will not have experience a migratory path between their natal rearing location and their saltwater rearing site. Absent this experience during their smolting phase they are likely to have a weak attraction to any specific fresh water stream, further reducing the survival of the few sexually mature individuals to potentially mate with wild or hatchery steelhead.

Abadía-Cardoso, A., E.C. Anderson, D.E. Pearse, and J. Carlos Garza. 2013. Large-scale parentage analysis reveals reproductive patterns and heritability of spawn timing in a hatchery population of steelhead (*Oncorhynchus mykiss*). Molecular Ecology 22(18):4733-4746.

Understanding life history traits is an important first step in formulating effective conservation and management strategies. The use of artificial propagation and supplementation as such a strategy can have numerous effects on the supplemented natural populations and minimizing life history divergence is crucial in minimizing these effects. The authors used single nucleotide polymorphism (SNP) genotypes for large-scale parentage analysis and pedigree reconstruction in a hatchery population of steelhead, the anadromous form of rainbow trout. Nearly complete sampling of the brood stock for several consecutive years in two hatchery programs allowed inference about multiple aspects of life history. Reconstruction of cohort age distribution revealed a strong component of fish that spawn at two years of age, in contrast to program goals and distinct from naturally spawning steelhead in the region, which raises a significant conservation concern. The first estimates of variance in family size for steelhead in this region can be used to calculate effective population size and probabilities of inbreeding, and estimation of iteroparity rate indicates that it is reduced by hatchery production. Finally, correlations between family members in the day of spawning revealed for the first time a strongly heritable component to this important life history trait in steelhead and demonstrated the potential for selection to alter life history traits rapidly in response to changes in environmental conditions. Taken together, these results demonstrate the extraordinary promise of SNP-based pedigree reconstruction for providing biological inference in high-fecundity organisms that is not easily achievable with traditional physical tags.

Bett, N.N. and S.G. Hinch. 2016. Olfactory navigation during spawning migrations: a review and introduction of the Hierarchical Navigation Hypothesis. Biological Reviews 91(3):728-759.

Migrations are characterized by periods of movement that typically rely on orientation towards directional cues. Anadromous fish undergo several different forms of oriented movement during their spawning migration and provide some of the most well-studied examples of migratory behavior. During the freshwater phase of the migration, fish locate their spawning grounds *via* olfactory cues. The authors synthesize research that explores the role of olfaction during the spawning migration of anadromous fish, most of which focuses on two families: Salmonidae (salmonids) and Petromyzontidae (lampreys). They draw attention to limitations in this research, and highlight potential areas of investigation that will help fill

in current knowledge gaps. They use the information assembled from this review to formulate a new hypothesis for natal homing in salmonids. Their hypothesis posits that migrating adults rely on three types of cues in a hierarchical fashion: imprinted cues (primary), conspecific cues (secondary), and non-olfactory environmental cues (tertiary). They provide evidence from previous studies that support this hypothesis.

Bley, P.W. and J.R. Moring. 1988. Freshwater and ocean survival of Atlantic salmon and steelhead: a synopsis (No. FWS-88 (9)). Maine University at Orono.

Accurate values for survival of Atlantic Salmon (*Salmo salar*) are necessary for effective management of the species, particularly in areas with active restoration efforts. The steelhead (*Oncorhynchus mykiss*) is a species close to the Atlantic salmon, in both life history and taxonomy. Comparison of survival estimates at different life stages can be informative. The data available on survival in freshwater and saltwater is scattered among technical reports, scientific papers, and unpublished records. This report summarizes much of this material in a comparative synopsis by life stages. Though not intended to be a complete life history compendium, it presents the available information in a single report.

Bridger, C.J., R.K. Booth, R.S. McKinley, and D.A. Scruton. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. ICES Journal of Marine Science 58(2):510-516.

A combined acoustic and radio telemetry system was deployed within Bay d'Espoir. Newfoundland to determine whether cultured steelhead trout (*Oncorhynchus mykiss*) released in the vicinity of a commercial aquaculture site remain at the site (site fidelity) or disperse from it. Two sets of fish releases (summer and winter 1998) were performed to determine seasonal effects on movements in the wild. Simulated escapes in summer involved 68 fish released from the cage system and 66 fish released from a cage towed approximately 1 km away from the grow-out site. The winter releases involved three batches of 30 fish each one from the cage system and two off-site over the side of a boat (at 200 and 1,000 m distance) after transport on board with no cage towing involved. The results suggest site fidelity among steelhead released during the growing season. Fidelity was only slightly larger for on-sits releases than off-site releases. Off-site released steelhead make a rapid return to their rearing sites, suggesting homing behavior. During the winter, the movement to the overwintering release site was less directed with a higher degree of dispersal. Released steelhead eventually dispersed from the release site. and in both seasons displayed a directed movement to the hydroelectric spillway, which is also the location of the local salmonid hatchery. Implications of the results are discussed in light of the development of recapture methodologies for aquaculture salmonids.

Bridger, C.J. 2002. Movement and mitigation of domestic triploid steelhead trout (*Oncorhynchus mykiss*) escaped from aquaculture grow-out cages. Thesis, Memorial University of Newfoundland. 113 p.

Cultured fish may occur in the wild from intentional release for restocking and sea ranching purposes or aquaculture escapees from ocean grow-out facilities. Aquaculture facilities lose some individuals during the production cycle, especially when sea cages are used. In addition to economic loss incurred to the fish farmer from escapement, potential disease, ecological and genetic interactions between escapees and wild conspecifics are of concern. The author monitored escapee movement, by tracking transmitter-implanted domestic female triploid steelhead trout in the wild using sophisticated biotelemetry fixed data-logging and manual tracking techniques, in Bay d'Espoir, Newfoundland, Canada. Of the 68 triploid steelhead released on-site, in July 1998, 51 (75%) remained within a 500 m radius of the summer grow-out site 32 days after release. Similar to on-site released triploid steelhead, 17 of 66 (26%) triploid steelhead released approximately 1000 m outside of the summer grow-out site returned to the site within 4 h of release. Subsequent tracking found that an additional 26 triploid steelhead had returned to the summer grow-out two days after release, bringing the total number of off-site released triploid steelhead return to 65%.

Triploid steelhead trout released during the winter displayed lower fidelity than those released in summer. Dispersed triploid steelhead during summer were detected in the vicinity of other salmonid aquaculture sites throughout the bay. Summer and winter released triploid steelhead both displayed a directed movement upstream towards the hydroelectric spillway, also the location of the local salmonid hatchery. Results suggest escaped triploid steelhead trout may survive in the wild − moving between summer grow-out sites and the hydroelectric spillway, while feeding on excess farm feed during the summer season. A biotelemetry methodology was developed, and also described herein, to monitor and optimize potential recapture traps for the salmonid aquaculture industry. Recapturing escapees aggregating near aquaculture sites may help mitigate negative implications through removal of escapees from the wild.

Bridger, C.J., R.K. Booth, R.S. McKinley, and D.A. Scruton. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. ICES Journal of Marine Science 58(2):510-516.

A combined acoustic and radio telemetry system was deployed within Bay d'Espoir, Newfoundland, to determine whether cultured steelhead trout released in the vicinity of a commercial aquaculture site remain at the site (site fidelity) or disperse from it. Two sets of fish releases (summer and winter 1998) were performed to determine seasonal effects on movements in the wild. Simulated escapes in summer involved 68 fish released from the cage system and 66 fish released from a cage towed approximately 1 km away from the grow-out site. The winter releases involved three batches of 30 fish each, one from the cage system and two off-site over the side of a boat (at 200 and 1000 m distance) after transport on board, with no cage towing involved. The results suggest site fidelity among steelhead released during the growing season. Fidelity was only slightly greater for on-site releases than off-site releases. Off-site released steelhead make a rapid return to their rearing sites, suggesting homing behavior. During the winter, the movement to the overwintering release site was less directed with a higher degree of dispersal. Released steelhead eventually dispersed from the release site, and in both seasons displayed a directed movement to the hydroelectric spillway, which is also the location of the local salmonid hatchery. Implications of the results are discussed in light of the development of recapture methodologies for aquaculture salmonids.

Cooper, J.C. and A.T Scholz. 1976. Homing of artificially imprinted steelhead (Rainbow) trout, *Salmo Gardner*. Journal of the Fisheries Board of Canada 33(4):826-829.

Greater numbers of rainbow trout (*Oncorhynchus mykiss*) exposed to morpholine as fingerlings as compared to trout left unexposed to morpholine as fingerlings homed to a stream scented with this odor (174 vs. 16). In order to locate this stream, the imprinted fish are able to search a distance of at least 13 km. These data support the olfactory hypothesis of homing.

Goetz, F.A., E. Jeanes, M.E. Moore, and T.P. Quinn. 2015. Comparative migratory behavior and survival of wild and hatchery steelhead (*Oncorhynchus mykiss*) smolts in riverine, estuarine, and marine habitats of Puget Sound, Washington. Environmental Biology of Fishes 98(1):357-375.

Declines in the survival of steelhead (*Oncorhynchus mykiss*) populations in protected waters of Washington and British Columbia have drawn attention to the need for more information on migratory patterns and losses in river, estuary, and nearshore habitats. Accordingly, acoustic telemetry was used to quantify movements by wild and hatchery steelhead smolts released from 2006 to 2009 in the Green River, and tracked through Puget Sound, Washington. Survival varied by release group and migration segment but overall survival rates from release to the Strait of Juan de Fuca were 9.7% for wild and 3.6% for hatchery fish. These rates are low relative to similar studies on steelhead. Survival was higher for wild fish along all migration segments than hatchery-origin fish; the greatest loss for both groups coincided with the slowest travel rates as fish first entered the estuary and as they exited Puget Sound. Wild fish travelled faster than hatchery fish in the river (15.1 vs. 4.4 km/d) with the fastest travel in the lower river (41 vs. 20.2 km/d) and

slowest immediately after release (3.7 vs. 2.4 km/d). The travel rates of wild and hatchery fish became progressively more similar over time: 15.4 vs. 10.6 km/d in the estuary, and 10.3 vs. 9.3 km/d in nearshore areas. Movement was primarily nocturnal in the river, nearly equal between day and night in the upper estuary, and predominately diurnal in the lower estuary and nearshore waters, with no difference between wild and hatchery fish. The migration in marine water showed an early offshore movement and a strong northward and westward orientation, and all fish exited the Strait of Juan de Fuca rather than the Strait of Georgia. The findings support research suggesting that declines in wild and hatchery steelhead populations may be caused primarily by factors in the early marine period.

Hara, T.J., S. Macdonald, R.E. Evans, T. Marui, and S. Arai. 1984. Morpholine, bile acids and skin mucus as possible chemical cues in salmonid homing: electrophysiological re-evaluation. Pages 363-378 in Mechanisms of migration in fishes, Springer, Boston, MA.

The olfactory-imprinting and pheromone hypotheses of salmon homing recognize the involvement of olfaction in the recognition of the home stream. However, physiological basis for olfactory recognition and the nature of home stream odors have not yet been established. In this paper the state of knowledge and advances in the study of chemical cues relevant to salmonid homing are reviewed, with special emphasis on 1) imprinting to morpholine, 2) skin mucus as a chemical signal, and 3) chemoreceptor responses to bile acids. Although homing of salmonids artificially imprinted to morpholine appears evident from behavioral studies, the olfactory detection of morpholine has not been adequately demonstrated. The skin mucus has been shown to be a potent olfactory stimulus for salmonids. Chemical characterization revealed that free amino acids present in the mucus were primarily responsible for olfactory stimulation; a synthetic mucus, a mixture of amino acids based on the analysis data, induced olfactory response indistinguishable from that induced by the original mucus. Electrophysiological studies showed that bile acids, especially taurine conjugates, were not only potent olfactory stimulants, but also highly-specific taste stimuli for rainbow trout. The threshold concentration for taurolithocholic acid, the most potent bile acid tested, was estimated at 10-12 M, nearly 4 log units lower than that for L-proline, the most potent taste stimulant reported for this species. In the olfactory system bile acids were as stimulatory as amino acids, with the threshold being almost 1,000 times higher than those for trout taste receptors. Because high sensitivity of the salmonid gustatory system to certain chemicals has now been demonstrated, it is no longer appropriate to consider olfaction to be the sensory modality for chemical detection only on the basis of its high sensitivity. In the light of these findings some important issues for future study are discussed.

Hasler, A.D., A.T. Scholz, and R.M. Horrall. 1978. Olfactory imprinting and homing in Salmon: recent experiments in which salmon have been artificially imprinted to a synthetic chemical verify the olfactory hypothesis for salmon homing. American Scientist 66(3):347-355.

Describes nearly 30 y of laboratory and field experiments primarily concerned with the homing migration of the Coho Salmon (*Oncorhynchus kisutch*) and the Brown Trout (*Salmo trutta*). The use of olfaction for homing would require that each stream have a characteristic and persistent odor the fish can perceive, that the fish can discriminate between odors of different streams, and that they can retain an "odor memory" between downstream migration and homing migration. The results of the studies provide conclusive evidence for olfactory imprinting.

Hasler, A.D. and A.T. Scholz. 2012. Olfactory imprinting and homing in salmon: Investigations into the mechanism of the imprinting process (Vol. 14). Springer Science & Business Media.

A review of publications and research leading to our current understanding of salmonid imprinting and homing.

Keefer, M.L., and C.C. Caudill. 2012. A review of adult salmon and steelhead straying with an emphasis on Columbia River populations. Technical Report 2012-6, College of Natural Resources, University of Idaho. 86 p.

This literature review provides an overview of available information on the many inter-related mechanisms associated with juvenile imprinting and emigration and subsequent homing and straying behaviors by returning adults. The review includes a synthesis of published straying data from the Columbia River basin, with additional comparison data from representative studies outside of the Columbia system. Topics covered in the review and data synthesis were developed in consultation with U.S. Army Corps of Engineers (USACE) biologists as part of a coordinated effort to identify critical knowledge gaps and to provide a context for prioritizing research and management needs. In the review, we identified potentially important demographic and genetic factors affecting both donor populations (populations strayed from) and recipient populations (populations receiving strays).

Snake River steelhead straying model: This review also includes results from a Snake River modeling exercise that was developed in parallel with the literature review. The model estimates the number of adult steelhead strays for donor and recipient populations across a range of adult straying rates, smolt abundance at Lower Granite Dam, transportation rate from the Snake River, and smolt-to-adult returns (SARs) for hatchery, wild, in-river, and barged populations. Model outputs indicate that transported hatchery steelhead contribute the largest number of strays in most simulations. The absolute number of strays also tended to increase with smolt abundance, as SARs increased, and as transport proportion increased. As part of the modeling exercise, the authors developed a simple numerical model to show the proportion of strays in a wild recipient population (i.e., relative abundance) in relation to donor population size, recipient population size, and donor stray rate. This model shows that strays from large donor populations can numerically overwhelm native fish in small recipient populations, even at low (~1%) stray rates.

Key findings:

- Juvenile transportation can increase adult straying.
- Hatchery rearing contributes to adult straying.
- Adult straying is often associated with juvenile olfactory imprinting.
- Transportation of juvenile salmon and steelhead is commonly associated with adult straying.
- Most strays enter sites that are geographically close to natal streams.
- Strays can have positive, negative, or neutral effects on recipient populations.

Kenaston, K.R., R.B. Lindsay, and R.K. Schroeder. 2001. Effect of acclimation on the homing and survival of hatchery winter steelhead. North American Journal of Fisheries Management, 21(4):765-773.

The authors evaluated prerelease acclimation of hatchery winter steelhead *Oncorhynchus mykiss* in Whittaker Creek, a tributary of the Siuslaw River, Oregon, as a management strategy to attract returning adults to a release site where they could be removed. The objective was to reduce the number of hatchery fish in wild steelhead spawning areas while providing hatchery steelhead for recreational fisheries. They found no significant difference in homing rate or survival between hatchery steelhead acclimated for 30 d and those trucked from the hatchery and directly released. For the 1991–1993 broods, a mean of 92% of directly released fish and 97% of acclimated fish were accounted for in Whittaker Creek. In contrast, 15% of adults from hatchery smolts released at four traditional sites in the main-stem Siuslaw River were accounted for in Whittaker Creek. The spatial distribution of the catch in recreational fisheries was similar for the direct and acclimated groups; that catch, however, was nearer Whittaker Creek than the catch from traditional releases. The study shows that acclimation of juveniles is not necessary to achieve a high rate of homing of adult hatchery steelhead to a release site. Direct tributary releases combined with an adult

collection facility can be used as a management strategy to minimize effects of hatchery fish on wild stocks, yet still provide recreational harvest.

Lindberg, M., P. Rivinoja, L.O. Eriksson, and A. Alanärä. 2009. Post-release and pre-spawning behaviour of simulated escaped adult Rainbow Trout *Oncorhynchus mykiss* in Lake Övre Fryken, Sweden. Journal of Fish Biology, 74(3), pp. 691-698.

Using radio telemetry, they present study simulated the escape of 48 adult Rainbow Trout *Oncorhynchus mykiss* from a net-cage fish farm in the Lake Övre Fryken, Sweden. The post-release dispersal of *O. mykiss* was fast, showed long-range dispersal behavior, low winter survival and lacked the ability to find suitable spawning habitats. These results suggested that reproducing for the first time may be an obstacle to the establishment of escaped farmed *O. mykiss*.

Scholz, A.T., C.K. Gosse, J.C. Cooper, R.M. Horrall, A D. Hasler, R.I. Daly, and R.J. Poff. 1978. Homing of Rainbow Trout transplanted in Lake Michigan: a comparison of three procedures used for imprinting and stocking. Transactions of the American Fisheries Society 107(3):439-443.

The authors compared the homing ability of three groups of Rainbow Trout (*Oncorhynchus mykiss*) stocked in Lake Michigan by different procedures. One group of juvenile rainbow trout was imprinted to a synthetic chemical, morpholine, during the pre-smolt and smolt stages, and a second group was not imprinted. Both groups were stocked directly into Lake Michigan, 1 km north of the Little Manitowoc River. A third group of trout was retained in a pond on the Little Manitowoc River during the pre-smolt and smolt stages and then released into Lake Michigan at the same location as the other two groups. During the adult spawning migration, morpholine was metered into the Little Manitowoc River. This river and 16 other locations were monitored for returning fish. The morpholine-imprinted fish returned to the Little Manitowoc River in greater numbers and strayed less than did fish from the other two treatment groups. This result is a consequence of exposure to a unique odor cue at the critical period for imprinting.

Scholz, A.T., R.J. White, M. Muzi, and T. Smith. 1985. Uptake of radio-labelled triiodothyronine in the brain of steelhead trout (*Salmo gairdneri*) during parr-smolt transformation: implications for the mechanism of thyroid activation of olfactory imprinting. Aquaculture, 45(1-4):199-214.

Two groups of 13-month-old trout were treated with either TSH (induced smolts) or saline (parr) to examine for in vivo uptake of radio-labelled triiodothyronine (^{125}I-T_3) into brain nuclei. This was accomplished by injecting a tracer dose of ^{125}I-T_3 either alone or with a 1,000-fold excess of nonradioactive T_3 and measuring the amount of radioactivity that accumulated in isolated brain nuclei in each case. Uptake of ^{125}I-T_3 was reduced by 80–90% for both TSH and saline groups receiving nonradioactive T_3 when compared with their counterparts receiving radio-labelled T_3 only. This result is consistent with the suggestion that trout brain contains saturable nuclear receptors for T_3. Similar experiments indicate gill, integument and olfactory epithelium may also be target cells that contain T_3 receptors. In gut and muscle no difference in uptake of ^{125}I-T_3 was seen between fish with or without nonradioactive T_3, suggesting that these tissues do not contain T_3 receptors. All of the putative target tissues contained consistently more radioactivity and all nontarget tissues consistently less radioactivity in the TSH induced smolts than in the saline pre-smolts. This result is consistent with the conjecture that an ontogenetic change occurs in receptor binding kinetics during smolt transformation; i.e., T_3 receptor concentration and/or binding affinity may have increased in the target tissues of the TSH group so that less T_3 would be available for uptake by nontarget tissues.

Skilbrei, O.T. 2012. The importance of escaped farmed Rainbow Trout (*Oncorhynchus mykiss*) as a vector for the salmon louse (*Lepeophtheirus salmonis*) depends on the hydrological conditions in the fjord. Hydrobiologia *686*(1):287-297.

The objectives of the study were to see if escaped Rainbow Trout (*Oncorhynchus mykiss*) spread rapidly or not from fish farms, and to test whether the hydrological conditions in a fjord influence their vertical distribution and importance as vector for the salmon lice (*Lepeophtheirus salmonis*). Fifty farmed rainbow trout were tagged with acoustic transmitters including depth sensors and released from two of 11 fish farms in the fjord system. In addition, unintentionally escaped rainbow trout were recaptured for analysis of salmon lice and stomach content. Dispersal out of the fjord system was limited. Most fish stayed in the vicinity of and moved between the fish farms but fed primarily on a variety of indigestible items. They moved in the warm relatively fresh surface layer from late spring until early autumn where the risk of being infested with salmon lice was low. They swam gradually deeper and became much more infested with salmon lice as the surface layers cooled and salinity and temperature gradients became less distinct over the course of the winter. The observed post-escapement behavior may challenge the control of the spread of diseases and parasites between neighboring farms and to wild fish, but also increases opportunities for recapture.

Westley, P.A., T.P. Quinn, and A.H. Dittman. 2013. Rates of straying by hatchery-produced Pacific salmon (*Oncorhynchus* spp.) and steelhead (*Oncorhynchus mykiss*) differ among species, life history types, and populations. Canadian Journal of Fisheries and Aquatic Sciences 70(5):735-746.

The authors ask whether straying differs among species, life history types, and populations of adult hatchery-produced Pacific salmon and steelhead in the Columbia River basin. Previous estimates of straying have been confounded by various factors influencing the probability of individuals returning to non-natal sites (e.g., off-station releases), whereas analyses undertaken here of nearly a quarter million coded-wire tag recoveries control for these factors. Their results revealed large and generally consistent differences in the propensity to stray among species, life history types within species, and populations. Paired releases indicated that (i) Chinook Salmon (*Oncorhynchus tshawytscha*) strayed more (mean population range 0.11–34.6%) than Coho Salmon (*Oncorhynchus kisutch*) (0.08–0.94%); (ii) ocean-type Chinook (5.2–18.6%) strayed more than stream-type Chinook (0.11–10%); and Chinook salmon (0.90–54.9%) strayed more than steelhead (0.30–2.3%). They conclude these patterns are largely the result of species-specific behavioral and endocrine factors during the juvenile life stages, but analyses also suggest that environmental factors can influence straying during the adult upstream migration.

PARASITE ISSUES

Beamish, R., J. Wade, W. Pennell, E. Gordon, S. Jones, C. Neville, K. Lange, and R. Sweeting. 2009. A large, natural infection of sea lice on Pacific salmon in the Gulf island area of British Columbia, Canada. Aquaculture 297:31-37.

High levels of sea lice generally exceeding a prevalence of 60% were found on all species of juvenile Pacific salmon and on juvenile Pacific Herring in the Gulf Islands area within the Strait of Georgia, British Columbia. Virtually all sea lice were *Caligus clemensi* and most stages were maturing or mature. There are no active fish farms in this area, indicating that this is a naturally occurring epizootic of sea lice. It is possible that the infection was associated with Pacific Herring that spawned in the area in the spring, although the linkage between the spawning Pacific Herring and the infection on Pacific salmon was not determined.

Brauner, C.J., M. Sackville, Z. Gallagher, S. Tang, L. Nendick, and A.P. Farrell. 2012. Physiological consequences of the salmon louse (*Lepeophtheirus salmonis*) on juvenile Pink Salmon. Philosophical Transactions of the Royal Society B Biological Sciences 367(1596). https://doi.org/10.1098/rstb.2011.0423

Pink Salmon, *Oncorhynchus gorbuscha*, are the most abundant wild salmon species and are thought of as an indicator of ecosystem health. The salmon louse, *Lepeophtheirus salmonis*, is endemic to pink salmon habitat but these ectoparasites have been implicated in reducing local pink salmon populations in the Broughton Archipelago, British Columbia. This allegation arose largely because juvenile pink salmon migrate past commercial open net salmon farms, which are known to incubate the salmon louse. Juvenile pink salmon are thought to be especially sensitive to this ectoparasite because they enter the sea at such a small size (approx. 0.2 g). The authors describe how 'no effect' thresholds for salmon louse sublethal impacts on juvenile pink salmon were determined using physiological principles. These data were accepted by environmental managers and are being used to minimize the impact of salmon aquaculture on wild Pink Salmon populations.

Bricknell, I.R., Dalesman, S.J., O'Shea, B., Pert, C.C., and Luntz, A.J. 2006. Effect of environmental salinity on sea lice *(Lepeophtheirus salmonis)* settlement success. Diseases of Aquatic Organisms. 71(3):201-12.

This study looked at the infectivity and survival rates of sea lice copepodids to different salinities. Results showed lower salinities resulted in a reduced survival and infectivity of *Lepeophtheirus salmonis* copepodids on potential host species. The sea louse *Lepeophtheirus salmonis* (Krøyer, 1837) (Copepoda: Caligidae) is an ectoparasite of salmonid fish. It has earlier been proposed that the free-swimming infectious copepodid stage of L. salmonis gather at river mouths to infect wild Atlantic salmon *Salmo salar* and sea trout *S. trutta* smolts during their seaward migration. This study used aquarium-based methods to investigate the survival, infective ability and behavior of *L. salmonis* copepodids exposed to short periods of low salinity levels, such as those encountered at river mouths. Survival of free-swimming copepodids was found to be severely compromised at salinity levels below 29 parts per thousand (ppt). Attachment to an *S. salar* host did not aid copepodid survival during post-infection exposure to low salinity environment, and a reduction in salinity appears to reduce the ability of copepodids to remain attached to *S. salar* smolts. Pre-infection exposure of copepodids to reduced salinity levels reduced infection of *S. salar*. Infection levels at reduced salinity were lower than predicted from the free-swimming survival experiment, suggesting that low salinity compromises the copepodids' ability to sense or respond to the presence of a host. In salinity gradients, copepodids demonstrated avoidance of salinities below 27 ppt, by both altering their swimming behavior and changing the orientation of passive sinking. Avoidance of low salinity levels

may be due to their adverse effects on copepodid physiology, as suggested by the reduction in survival. Sinking rates were also faster in reduced salinity, suggesting that remaining in the water column would be more energetically demanding for the copepodids at reduced salinity. These results show that both survival and host infectivity of *L. salmonis* are severely compromised by short-term exposure to reduced salinity levels.

Godwin, S.C., L.M. Dill, M. Krkošek, M.H.H. Price, and J.D. Reynolds. 2017. Reduced growth in wild juvenile sockeye salmon *Oncorhynchus nerka* infected with sea lice. Journal of Fish Biology 91(1):41-57.

Daily growth rings were examined in the otoliths of wild juvenile Sockeye Salmon *Oncorhynchus nerka* to determine whether infection by ectoparasitic sea lice *Caligusc lemensi* and *Lepeophtheirus salmonis* was associated with reduced host body growth, an important determinant of survival. More than 98% of the sea lice proved to be *C. clemensi* and the fish that were highly infected grew more slowly than uninfected individuals. Larger fish also grew faster than smaller fish. Finally, there was evidence of an interaction between body size and infection status, indicating the potential for parasite-mediated growth divergence.

Krkošek, M., M. Lewis, and J.P. Volpe. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceedings of the Royal Society B. 272:689–693.

Marine salmon farming has been correlated with parasitic sea lice infestations and concurrent declines of wild salmonids. The authors report a quantitative analysis of how a single salmon farm altered the natural transmission dynamics of sea lice to juvenile Pacific salmon. They studied infections of sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) on juvenile Pink Salmon (*Oncorhynchus gorbuscha*) and Chum Salmon (*Oncorhynchus keta*) as they passed an isolated salmon farm during their seaward migration down two long and narrow corridors. Their calculations suggest the infection pressure imposed by the farm was four orders of magnitude greater than ambient levels, resulting in a maximum infection pressure near the farm that was 73 times greater than ambient levels and exceeded ambient levels for 30km along the two wild salmon migration corridors. The farm-produced cohort of lice parasitizing the wild juvenile hosts reached reproductive maturity and produced a second generation of lice that re-infected the juvenile salmon. This raises the infection pressure from the farm by an additional order of magnitude, with a composite infection pressure that exceeds ambient levels for 75km of the two migration routes. Amplified sea lice infestations due to salmon farms are a potential limiting factor to wild salmonid conservation.

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

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.

Morton, A.B., and R. Williams. 2003. First report of a sea louse, *Lepeophtheirus salmonis*, infestation on juvenile Pink Salmon, *Oncorhynchus gorbuscha*, in nearshore habitat." The Canadian Field-Naturalist 117(4):634-641.

High infestation rates of the Sea Louse (*Lepeophtheirus salmonis*) have been reported on juvenile salmonids in Europe since 1989; however, this species has not been reported on juvenile Pacific salmonids until now. Magnitude of Sea Lice infestation was examined in 2001 on juvenile Pink Salmon (*Oncorhynchus gorbuscha*) migrating through a British Columbia archipelago. On average, the 751 juvenile Pink Salmon sampled weighed 2.25 g (± 0.039 SE), were infected with 11.3 (± 0.41 SE) Sea Lice per fish and 6.1 (± 0.24SE) Sea Lice per gram host weight. Fully 75.0% of fish were infected at loads to or higher than the lethal limit reported for much larger Sea Trout (*Salmo trutta*) post-smolts. Abundance (Kruskal-Wallis statistic = 100.95, $p<0.0001$) and intensity (KW=70.05,$p<0.0001$) of lice, and mean number of lice/ghost weight(K-W=112.23,$p<0.0001$) were significantly higher in juvenile Pink Salmon in close proximity to salmon farms, than in Pink Salmon distant from salmon farms.

Morton, A., R.D. Routledge, and R. Williams. 2005. Temporal patterns of sea louse infestation on wild Pacific salmon in relation to the fallowing of Atlantic Salmon farms. North American Journal of Fisheries Management 25 (3):811-821.

The authors report on a 3-year study of the infestation rates of the sea louse, *Lepeophtheirus salmonis*, on wild juvenile Pink Salmon *Oncorhynchus gorbuscha* and Chum Salmon *O. keta* in the Broughton Archipelago, British Columbia. In 2002, the British Columbia Ministry of Agriculture, Fisheries, and Food ordered farm fallowing (i.e., the removal of farmed Atlantic Salmon *Salmo salar* from net-cages) along the presumed migration route of wild juvenile Pacific salmon in this area. The goal was to protect wild juvenile fish from sea louse infestation. We assessed the effectiveness of this decision by comparing sea louse infestation rates on wild juvenile salmon near three Atlantic Salmon farm sites prior to, during, and after fallowing. Overall, *l. salmonis* levels were significantly reduced ($P < 0.0001$) at the study sites during fallowing but returned to the original level after fallowing. The decline was age-specific. While the abundance of the earliest attached sea louse phase (the copepodid stage) declined by a factor of 42, the mean abundance of adult *L. salmonis* did not decline significantly. Changes in salinity and temperature could not account for the decline. This study provides evidence that the fallowing of Atlantic Salmon farms during spring juvenile salmon migrations can be an effective conservation and management tool for protecting wild salmon. While this correlation adds to the increasing weight of evidence linking Atlantic Salmon farms to increased parasite loads on wild salmon, greater cooperation between researchers and farmers will be necessary to isolate the causal mechanisms and provide safe seaward passage to wild juvenile salmon.

Morton, A., and R. Williams. 2006. Response of the sea louse *Lepeophtheirus salmonis* infestation levels on juvenile wild Pink, *Oncorhynchus gorbuscha*, and Chum, *O. keta*, Salmon to arrival of parasitized wild adult Pink Salmon. The Canadian Field-Naturalist 120(2):199-204.

Recent recurring infestations of Sea Lice, *Lepeophtheirus salmonis*, on juvenile Pacific salmon (*Oncorhynchus* spp.) and subsequent annual declines of these stocks have made it imperative to identify the source of Sea Lice. While several studies now identify farm salmon populations as sources of Sea Louse larvae, it is unclear to what extent wild salmonid hosts also contribute Sea Lice. The authors measured Sea Louse numbers on adult Pink Salmon (*Oncorhynchus gorbuscha*) migrating inshore. They also measured Sea Louse numbers on wild juvenile Pink and Chum Salmon (*Oncorhynchus keta*) migrating to sea before the adults returned, and as the two age cohorts mingled. Adult Pink Salmon carried an average of 9.89 (SE 0.90) gravid lice per fish and thus were capable of infecting the adjacent juveniles. Salinity and temperature remained favorable to Sea Louse reproduction throughout the study. However, all accepted measures of Sea Louse infestation failed to show significant increase on the juvenile salmon, either in overall abundance of Sea Lice or of the initial infective-stage juvenile lice, while the adult wild salmon were present in the study area. This study suggests that even during periods of peak interaction, wild adult salmon are not the primary source of the recent and unprecedented infestations of Sea Lice on juvenile Pacific Pink and Chum Salmon in the inshore waters of British Columbia.

Novales F.I., C. Gulbransen, M. Galbraith, and D. Stucchi. 2009. Monitoring and potential control of sea lice using an LED-based light trap. Canadian Journal of Fisheries and Aquatic Sciences 66(8):1371-1382.

Sea lice are ectoparasitic copepods that threaten salmon farming aquaculture and the viability of wild salmon populations. To control infestations on farmed salmon, several chemotherapeutants have been developed, but these are invasive (often causing fish stress and loss in production), costly, may induce parasite resistance over time, and their impact on the environment is a major social concern. The authors show that a light-emitting diode (LED)-based light trap can be used to monitor sea lice presence on fish and in the water. The performance of the light trap was tested in experimental tanks and in the ocean. Plankton net tows were also performed to compare catches with those from light traps. The light trap caught ~70% of salmon lice larval stages loaded onto a tank and ~24% of the adults. It also acted as a delousing agent by removing ~8% of adult salmon lice infective on Chinook Salmon (*Oncorhynchus tshawytscha*) smolts in tank experiments. In the ocean, the light trap caught 21 sea lice (10 *Lepeophtheirus salmonis* and 11 *Caligus clemensi*), comprising free-swimming and attached stages, while plankton net tows failed to capture any. They conclude that light traps constitute an effective, noninvasive, environmentally friendly method to monitor sea lice.

Orr, C. 2007. Estimated sea louse egg production from Marine Harvest Canada farmed Atlantic Salmon in the Broughton Archipelago, British Columbia, 2003–2004. North American Journal of Fisheries Management 27(1):187-97.

Recent infestations of sea lice *Lepeophtheirus salmonis* on wild juvenile Pink Salmon *Oncorhynchus gorbuscha* and subsequent declines in the number of returning adult Pink Salmon have raised concern for the health of wild fish relative to salmon farming activities in the Broughton Archipelago, British Columbia. He used available (but limited) industry data to estimate sea louse egg production from Atlantic Salmon *Salmo salar* farmed by Stolt Sea Farm (now Marine Harvest Canada, Inc., Campbell River, BC) in 2003 and 2004. The 12 active farms contained between 1 and 5 million Atlantic salmon during the 2 years and about 800,000 fewer mature salmon at the start of 2003 than in 2004. Sea louse egg production peaked during winter–spring in both years prior to the seaward migration period of the area's small and vulnerable juvenile pink salmon and chum salmon *O. keta*. Marine Harvest Canada salmon hosted over 6 million gravid sea lice that produced 1.6×10^9 eggs during 2 weeks in the winter of 2003–2004. Only half as many eggs were produced from the fewer hosts present during this period in 2003. Sea lice on farmed fish were further reduced to near zero each year through multiple uses of emamectin benzoate (Slice). Fewer farmed Atlantic Salmon and sea lice in 2003 coincided with lower abundance and prevalence of *L. salmonis* on juvenile Pink Salmon and Chum Salmon near farms. A recent agreement between industry and conservationists may help improve data quality, our understanding of the dynamics sea louse–salmon interactions, and our chances of conserving.

Poley, J.D., L.M. Braden, A.M. Messmer, O.O. Igboeli, S.K. Whyte, A. Macdonald, J. Rodriguez et al. 2018. High level efficacy of lufenuron against sea lice (*Lepeophtheirus salmonis*) linked to rapid impact on moulting processes. International Journal for Parasitology: Drugs and Drug Resistance 8(2):174-188.

Drug resistance in the salmon louse *Lepeophtheirus salmonis* is a global issue for Atlantic salmon aquaculture. Multiple resistance has been described across most available compound classes with the exception of the benzoylureas. To target this gap in effective management of *L. salmonis* and other species of sea lice (e.g. *Caligus* spp.), Elanco Animal Health is developing an in-feed treatment containing lufenuron (a benzoylurea) to be administered prior to seawater transfer of salmon smolts and to provide long-term protection of salmon against sea lice infestations. Benzoylureas disrupt chitin synthesis,

formation, and deposition during all molting events. However, the mechanism(s) of action are not yet fully understood and most research completed to date has focused on insects. The exposed the first parasitic stage of *L. salmonis* to 700 ppb lufenuron for three hours and observed over 90% reduction in survival to the chalimus II life stage on the host, as compared to vehicle controls. This agrees with a follow up in vivo administration study on the host, which showed >95% reduction by the chalimus I stage. Transcriptomic responses of salmon lice exposed to lufenuron included genes related to molting, epithelial differentiation, solute transport, and general developmental processes. Global metabolite profiles also suggest that membrane stability and fluidity is impacted in treated lice. These molecular signals are likely the underpinnings of an abnormal molting process and cuticle formation observed ultra-structurally using transmission electron microscopy. Treated nauplii-staged lice exhibited multiple abnormalities in the integument, suggesting that the coordinated assembly of the epi- and procuticle is impaired. In all cases, treatment with lufenuron had rapid impacts on *L. salmonis* development. They describe multiple experiments to characterize the efficacy of lufenuron on eggs, larvae, and parasitic stages of *L. salmonis*, and provide the most comprehensive assessment of the physiological responses of a marine arthropod to a benzoylurea chemical.

Price, M.H.H. 2003. Early marine ecology of Pacific salmon: interactions with sea lice. Thesis, University of Victoria, BC. 121 p.

Pacific salmon (*Oncorhynchus* spp.) are key elements of ecological systems, and play an important role in the cultural foundation of human societies. All species of wild salmon face multiple, simultaneous threats, with habitat degradation likely playing a key role in survival. Open net-pen salmon farms can degrade important nursery marine habitat for wild juvenile salmon by disrupting natural salmonid host-parasite dynamics. The first two chapters in this thesis examine louse parasitism of wild juvenile Chum (*Oncorhynchus keta*), Pink (*O. gorbuscha*), and Sockeye Salmon (*O. nerka*) in relation to their marine migration past salmon farms.

He compares sites of low and high exposure to salmon farms, and include two areas without farms on British Columbia's central and north coasts to assess baseline infection levels. Louse prevalence and abundance were lowest and most similar to natural baseline levels at low exposure sites, and highest at high exposure sites in all farm regions. A significantly greater proportion of the lice infecting juvenile chum and pink salmon were *Lepeophtheirus salmonis* at high exposure sites. *Caligus clemensi* was the principal louse species infecting all juveniles in areas without salmon farms, and at low exposure sites within salmon farm regions; *C. clemensi* was also the dominant louse to infect juvenile sockeye that migrated past farms. Mixed-effects modelling results showed that exposure to salmon farms was the most consistent factor to explain the variation in louse infection levels, and support my hypothesis that salmon farms are a major source of sea lice on juvenile wild salmon in regions with salmon farms.

He discovered that juvenile sockeye at one particular location within the Georgia Strait hosted unusually high lice levels; this location was situated at a distance from salmon farms, but near a farm salmon processing facility. He found live sea lice, *Lepeophtheirus salmonis*, mucus, and fish tissue in effluent discharged from the processing facility. Sea lice transmitted from this source may pose a threat to wild salmon populations, and the release of potentially untreated offal, including blood water, is of considerable concern.

Roberts, L.J., J. Taylor, and C. Garcia de Leaniz. 2011. Environmental enrichment reduces maladaptive risk-taking behavior in salmon reared for conservation. Biological Conservation 144(7):1972-1979.

Hatcheries often produce bold fish that are maladapted to survive in the wild, as absence of predators and selection for fast growth tend to favor risk-taking behaviors. Not surprisingly, losses of hatchery fish through predation can be high immediately after release and this may account for the failure of many *ex-*

situ fish conservation programs. For supportive-breeding to be useful, it is essential that released fish are able to display natural behaviors. They compared the performance of juvenile Atlantic Salmon reared in environmentally-enriched tanks receiving natural prey and subjected to simulated predator attacks with fish reared under standard hatchery conditions while keeping densities constant. No differences were detected between controls and environmentally enriched fish in survival, final size or nutritional status. Yet, changes in rearing conditions had rapid and marked effects on risk-taking behavior. Environmentally enriched fish were 2.1 times less willing, and took significantly longer to leave shelter, than controls within two weeks of enrichment. Their study indicates that it is possible through environmental enrichment to modify at least one component of fishes' behavior known to have clear adaptive implications, i.e., the propensity of hatchery-reared fish to take excessive risks. *Ex-situ* conservation could therefore benefit from rearing fish in naturalized, structurally complex environments with natural prey to promote the development of more natural behaviors.

Rust, M.B., K. H. Amos, A.L. Bagwill, W.W. Dickhoff, L.M. Juarez, C.S. Price, J.A. Morris Jr, and M.C. Rubino. 2014. Environmental performance of marine net-pen aquaculture in the United States. Fisheries 39(11):508-524.

Efforts to reduce escapes in salmon farming in Washington State and British Columbia, Canada, have been successful. From 1987 to 1996, the average annual escape rate was 3.7% of annual harvest, whereas more recently (2000–2009) escape rate averaged 0.3%. The primary concern of escaped fish is the potential for them to interbreed with wild conspecifics and reduce the long-term fitness of the wild population.

Saksida, S.M., D. Morrison, and C.W. Revie. 2010. The efficacy of emamectin benzoate against infestations of sea lice, *Lepeophtheirus salmonis*, on farmed Atlantic Salmon, *Salmo salar* L., in British Columbia. Journal of Fish Diseases 33:913–917. https://doi.org/10.1111/ j.1365-2761.2010.01192.x

Sea lice are a naturally-occurring ectoparasite of wild salmon (Nagasawa 2001; Beamish, Neville, Sweeting & Ambers 2005). There is also clear evidence that these parasites are seldom a production or fish health concern on farms in British Columbia (Saksida, Constantine, Karreman and Donald 2007), in direct contrast to most other salmon-producing regions. There are significant numbers of wild salmon in the Pacific Ocean, and the presence of these large untreated populations may reduce the selection pressures that appear to be at work in regions where there are fewer wild hosts. In addition, there is evidence of a genetic difference between the Atlantic and Pacific *L. salmonis*. Health implications associated with infection by the Pacific species appear to be more benign.

Skilbrei, O.T. 2012. The importance of escaped farmed rainbow trout (*Oncorhynchus mykiss*) as a vector for the salmon louse (*Lepeophtheirus salmonis*) depends on the hydrological conditions in the fjord. Hydrobiologia, 686(1):287-297.

The objectives of the study were to see if escaped Rainbow Trout spread rapidly or not from fish farms, and to test whether the hydrological conditions in a fjord influence their vertical distribution and importance as vector for the salmon lice. Fifty farmed rainbow trout were tagged with acoustic transmitters including depth sensors and released from two of 11 fish farms in the fjord system. In addition, unintentionally escaped Rainbow Trout were recaptured for analysis of salmon lice and stomach content. Dispersal out of the fjord system was limited. Most fish stayed in the vicinity of and moved between the fish farms but fed primarily on a variety of indigestible items. They moved in the warm relatively fresh surface layer from late spring until early autumn where the risk of being infested with salmon lice was low. They swam gradually deeper and became much more infested with salmon lice as the surface layers cooled and salinity and temperature gradients became less distinct over the course of the winter. The observed post-escapement

behavior may challenge the control of the spread of diseases and parasites between neighboring farms and to wild fish, but also increases opportunities for recapture.

Sutherland, B.J.G., J.M. Covello, S.E. Friend, J.D. Poley, K.W. Koczka, S.L. Purcell, T.L. MacLeod et al. 2017. Host–parasite transcriptomics during immune stimulant-enhanced rejection of salmon lice (*Lepeophtheirus salmonis*) by Atlantic Salmon (*Salmo salar*). FACETS 2(1): 477-495.

Salmon lice (*Lepeophtheirus salmonis*) are important ectoparasites of wild and farmed salmonids and cause major losses to the salmon farming industry throughout the Northern Hemisphere. With the emergence of resistance to several commonly used parasiticides, novel control strategies and integration of multiple treatment options are needed, including host immune stimulation. The authors investigate the effects of a functional feed containing a peptidoglycan and nucleotide formulation on *L salmonis* infection of Atlantic Salmon (*Salmo salar*) by characterizing lice infection levels, the expression of several host immune genes, and the parasite transcriptomic response to the immune stimulated host. Although initial infection intensities were low, the low dose (LD) immunostimulant diet reduced the total lice burden by 50% relative to controls. Immunostimulant fed hosts upregulated interleukin-1β in the skin and spleen. This gene has been implicated in successful responses of several salmonid species to salmon lice but is typically not observed in Atlantic Salmon, suggesting a favorable influence on the immune response. Lice infecting LD immune stimulated salmon overexpressed genes putatively involved in parasite immunity, including carboxylesterases, and expressed genes putatively involved in feeding (e.g., proteases). These lice response genes further improve the characterization of the transcriptome of the non-model parasite by identifying genes potentially involved in evading host immunity.

Sutherland, B.J., S.G. Jantzen, D.S. Sanderson, B F. Koop, and S.R. Jones. 2011. Differentiating size-dependent responses of juvenile Pink Salmon (*Oncorhynchus gorbuscha*) to sea lice (*Lepeophtheirus salmonis*) infections. Comparative Biochemistry and Physiology D 6:213–223. https://doi.org/10.1016/j.cbd.2011.04.001

Salmon infected with an ectoparasitic marine copepod, the salmon louse L *Epeophtheiru ssalmonis*, incur a wide variety of consequences depending upon host sensitivity. Juvenile Pink Salmon (*Oncorhynchus gorbuscha*) migrate from natal freshwater systems to the ocean at a young age relative to other Pacific salmon, and require rapid development of appropriate defenses against marine pathogens. The authors analyzed the early transcriptomic responses of naïve juvenile pink salmon of sizes 0.3 g (no scales), 0.7 g (mid-scale development) and 2.4 g (scales fully developed) six days after a low-level laboratory exposure to *l. salmonis* copepodids. All infected size groups exhibited unique transcriptional profiles. Inflammation and inhibition of cell proliferation was identified in the smallest size class (0.3 g), while increased glucose absorption and retention was identified in the middle size class (0.7 g). Tissue-remodeling genes were also up-regulated in both the 0.3 g and 0.7 g size groups. Profiles of the 2.4 g size class indicated cell-mediated immunity and possibly parasite-induced growth augmentation. Understanding a size-based threshold of resistance to *L. salmonis* is important for fisheries management. This work characterizes molecular responses reflecting the gradual development of innate immunity to *L. salmonis* between the susceptible (0.3 g) and refractory (2.4 g) Pink Salmon size classes.

Whyte, S.K., J.D. Poley, A. Mueller, C. Van Iderstine, K.E. Fitzpatrick, S.L. Purcell, B.F. Koop, S.C. Johnson, S. Wadsworth, and M.D. Fast. 2019. Avermectin treatment for *Lepeophtheirus salmonis*: Impacts on host (*Salmo salar*) and parasite immunophysiology. Aquaculture 501:488-501.

The avermectins, emamectin benzoate (EMB) and ivermectin (IVM) have been commonly used in North America over the last two decades to control the salmon louse, Lepeophtheirus salmonis, infections in farmed Atlantic Salmon. Emamectin benzoate, trade name SLICE ™, was used heavily in the Eastern Canadian industry between the years 2000–2008, due to its long-lasting protection and efficacy against all

parasitic life stages. However, over reliance on this drug soon resulted in reduced sensitivity in many *L. salmonis* populations, resulting more recently in uses of higher treatment dosages and switching to the use of IVM. For these reasons, we investigated the effects of different dosages of EMB and multiple IVM treatments on baseline immunophysiological indicators, anti-viral responses and protection against subsequent salmon lice exposure in salmon smolts. Different doses of EMB or repeated treatment with IVM did not affect feeding behavior in salmon, however by the end of the second IVM treatment, some neurotoxicity was observed. A single (1×) EMB dose (50 µg/Kg) administered for 7 consecutive days had no significant effect on I abundance and development, whereas triple the dosage (150 µg/Kg) significantly reduced lice development, thereby eliminating subsequent stress responses in salmon associated with lice development to pre-adult stages. Emamectin benzoate and IVM treatment did not significantly impact expression of resting antigen presentation molecules in salmon (MH class I or II), however they did inhibit short-term (6 h) induced responses to the ISA virus. The impact of gender, as previously shown, had the greatest effect on louse transcriptomic regulation, but avermectin treatment also caused perturbations in gene expression. Transcriptome differences between lice on control and 1× EMB treated fish were larger than those observed for IVM or 3× EMB. Nearly half of the transcripts differentially expressed by IVM were also affected by one of the EMB treatments. Transcriptomic results from the louse suggest a high degree of similarity and concordance within and across studies in avermectin treatment, with gender of louse and dosage of drug significantly impacting the outcomes.

Weir, L.K. and J.W. Grant. 2005. Effects of aquaculture on wild fish populations: a synthesis of data. Environmental Reviews 13(4):145-68.

The potential adverse environmental effects of aquaculture have been the subject of considerable attention in both the media and the scientific literature. The authors synthesize the published scientific literature, primarily concerning Atlantic Salmon (*Salmo salar*), to assess the current data available regarding these potential effects. No data are available to test for the direct effects of aquaculture organisms on the demographics of wild fish populations. However, seven studies show that escaped salmon in the wild have lower fitness, as measured by survival and reproductive success, than native salmon. Thirteen other studies, encompassing 91 different traits, provide strong evidence of phenotypic differences between farmed and wild salmon, presumably because of artificial selection in the aquaculture environment. An additional 10 studies have documented significant genetic differences between farmed salmon and the wild fish with which they will interact, or potentially interact.

GENETICS, INTERBREEDING ISSUES

Benfey, T.J. 2016. Effectiveness of triploidy as a management tool for reproductive containment of farmed fish: Atlantic Salmon (*Salmo salar*) as a case study. Reviews in Aquaculture 8(3):264-82.

Atlantic Salmon dominates aquaculture production in its native North Atlantic range, raising concerns about the impacts of escaped farmed fish on wild populations. While physical confinement and operational management practices have improved steadily with the development of this industry, some escapes are inevitable. In the absence of effective measures for the rapid recapture of escaped fish, the only practical method currently available to minimize their impacts on wild populations is to ensure that they are female triploids and therefore reproductively sterile. The technology for producing all-female triploid populations of Atlantic salmon is simple and easily applied on a commercial scale, and routinely results in populations that are entirely female and >98% triploid. Aside from sterility, there are no population-wide phenotypic effects of triploidy, although triploids do tend to perform less well than diploids with respect to commercial culture characteristics and are also less likely than escaped diploids to outcompete or displace native salmon. Some uncertainties exist with respect to their disease resistance and their potential to become reservoirs for the spread of pathogens to wild populations. If the spawning potential of escaped farmed Atlantic Salmon is deemed to pose an unacceptable risk to native populations, then all-female triploid populations could be used as an alternative to reduce risk. Research should continue to focus on improving triploid performance through breeding programmes and optimization of husbandry conditions (including nutrition, environmental conditions and fish health), with the goal of making triploids an attractive option for fish farmers.

Blanchfield, P.J., L.S. Tate, and C.L. Podemski. 2009. Survival and behaviour of Rainbow Trout (*Oncorhynchus mykiss*) released from an experimental aquaculture operation." Canadian Journal of Fisheries and Aquatic Sciences 66(11):1976-1988.

The potential for farmed fish that have escaped from open-cage aquaculture operations to affect native populations will depend on their survival and behavior in the wild. The authors used standard commercial practices to rear 10 tons of Rainbow Trout (*Oncorhynchus mykiss*) in a 23 ha lake at the Experimental Lakes Area (Ontario, Canada). Each fall (2003–2005) they released farmed Rainbow Trout (escapees) into the study lake and monitored their movements using automated positioning telemetry. Rainbow Trout experienced high annual mortality (~50%), with none surviving beyond 3 years. Farmed fish had narrowly defined pelagic distributions that comprised the upper few meters of the water column, even when at the cage site. Although released rainbow trout dispersed throughout the study lake, most spent significant portions of time at the cage site, especially during normal operation when commercial feed was available. Core use areas (50% Kernel) included the farm for half of the released fish. Surviving rainbow trout showed continued reliance upon the cage site in their second year. However, wide dispersal, high growth rate, and lack of reliance on the cage site by some escaped fish warrant further research to assess potential effects of open-cage aquaculture in the water bodies where the industry occurs.

Waples, R.S., K. Hindar, and J.J. Hard. 2012 Genetic risks associated with marine aquaculture. U.S. Dept. of Commerce. NOAA Tech. Memo. NMFS-NWFSC-119, 149 p.

This technical memorandum is intended to provide managers with a better understanding of the genetic effects of marine aquaculture on natural populations, so that these factors can be more effectively incorporated into informed decisions pertaining to federal marine aquaculture policy and regulatory decisions. The paper summarizes what has been learned over the past several decades from experience in three major arenas: salmon (Salmonidae) aquaculture and hatcheries, propagation of marine species, and agriculture. The paper characterizes risks and benefits of marine aquaculture and artificial propagation programs and strategies to minimize genetic risks. Specifically for marine aquaculture those strategies involve the following: Reduce opportunities for escapes and reduce opportunities for reproduction of escapes in the natural environment. Among those strategies discussed in detail are containment, recapture of escapes, the use of sterile fish stocks, and the use of highly domesticated populations in culture. Sterility of fish stocks raised in culture has the potential to significantly reduce risks from escaped individuals along with domestication of stocks that reduces probabilities of survival to maturity and successfully reproducing.

FISH DISEASE ISSUES

Amos, K.H., and J. Thomas. 2002. Disease interactions between wild and cultured fish: Observations and lessons learned in the Pacific Northwest. Bulletin of the European Association of Fish Pathologists 22:95-102.

The authors examine the interactions of selected endemic pathogens in fish stocks in the Pacific Northwest. In particular, case histories involving infectious hematopoietic necrosis virus (IHNV), and viral hemorrhagic septicemia virus (VHSV) is discussed. Field observations and epidemiological studies indicate the natural hosts and reservoir of infection are wild fish populations, both salmonid and non-salmonid marine species. Salmon recovery and restoration initiatives which re-introduce or significantly increase the number of returning adult salmon into streams and rivers supplying water for hatcheries increase the threat of exposure to the natural pathogen reservoirs. Additionally, spawned-out salmon carcasses obtained at hatcheries are being utilized for nutrient enhancement of aquatic ecosystems. For hatcheries to continue their success as a tool for salmon enhancement and restoration, strategies to maintain/improve the pathogen status of hatchery water supplies need to be pursued.

Amos, K.H., L. Gustafson, J. Warg, J. Whaley, M. Purcell, J. Rolland, J. Winton, K. Snekvik, T. Meyers, B. Stewart, J. Kerwin, M. Blair, J. Bader, and J. Evered. 2014. U.S. response to a report of infectious salmon anemia virus in western North America. Fisheries 39:501-506.

Federal, State, and tribal fishery managers, as well as the general public and their elected representatives in the United States, were concerned when infectious salmon anemia virus (ISAV) was suspected for the first time in free-ranging Pacific Salmon collected from the coastal areas of British Columbia, Canada. This article documents how national and regional fishery managers and fish health specialists of the U.S. worked together and planned and implemented actions in response to the reported finding of ISAV in British Columbia. To date, the reports by Simon Fraser University remain unconfirmed and preliminary results from collaborative U.S. surveillance indicate that there is no evidence of ISAV in U.S. populations of free-ranging or marine-farmed salmonids on the west coast of North America.

Chen, M.F., S.M. O'Neill, A.J. Carey, R.H. Conrad, B.A. Stewart, K.R. Snekvik, G.M. Ylitalo, and P.K. Hershberger. 2018. Infection by *Nanophyetus salmincola* and toxic contaminant exposure in out-migrating steelhead from Puget Sound, Washington: Implications for Early Marine Survival. Journal of Aquatic Animal Health 30(2):103-118.

Out-migrating steelhead *Oncorhynchus mykiss* from four Puget Sound rivers and associated marine basins of Puget Sound in Washington State were examined for the parasite, *Nanophyetus salmincola* in 2014 to determine whether recent trends in reduced marine survival are associated with the presence of this pathogen. A subset of steelhead from three of these river–marine basin combinations was analyzed for the presence of persistent organic pollutants (POPs) to assess whether exposure to these contaminants is a contributing factor to their reduced marine survival. The prevalence and parasite load of *N. salmincola* were significantly higher in fish from central and southern Puget Sound than in fish from river systems in northern Puget Sound. The proportion of steelhead samples with concentrations of POPs higher than adverse effects thresholds (AETs) or concentrations known to cause adverse effects was also greater in fish from the central and southern regions of Puget Sound than in those from the northern region. Polybrominated diphenyl ether concentrations associated with increased disease susceptibility were observed in 10 and 40% of the steelhead sampled from central and southern Puget Sound regions, respectively, but in none of the fish sampled from the northern region. The AET for polychlorinated biphenyls was exceeded in steelhead collected from marine habitats: 25% of the samples from the marine basins in the central and southern regions of Puget Sound and 17% of samples from northern Puget Sound

region. Both *N. salmincola* and POP levels suggest there are adverse health effects on out-migrating steelhead from one southern and one central Puget Sound river that have lower early marine survival than those from a river system in northern Puget Sound.

Nash, C.E., P.R. Burbridge, and J.K. Volkman. 2005. Guidelines for the ecological risk assessment of marine fish aquaculture. National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-NWFSC-71. Silver Spring, MD.

This report provides guidelines for assessing the ecological risks of marine fish aquaculture in a variety of marine ecosystems. Ten areas of substantive risk are identified in the interaction between marine fish aquaculture. The risks include: increased organic loading, increased inorganic loading, residual heavy metals, transmission of disease organisms, residual therapeutants, biological interaction of escapes with wild populations, physical interaction with marine wildlife, physical impact on marine habitat, using wild juveniles for grow-out, and harvesting industrial fisheries for aqua-feeds.

The chances of each risk occurring can differ greatly in accordance with the natural characteristics of the local ecosystem and its geographic location. Therefore, each assessment template contains a biological overview of its respective risk and briefly discusses factors that may enhance or mitigate the risk's occurrence.

Rust, M.B., K.H. Amos, A.L. Bagwill, W.W. Dickhoff, L.M. Juarez, C.S. Price, J.A. Morris Jr, and M.C. Rubino. 2014. Environmental performance of marine net-pen aquaculture in the United States. Fisheries 39(11):508-524.

Efforts to reduce escapes in salmon farming in Washington State and British Columbia, Canada, have been successful. From 1987 to 1996, the average annual escape rate was 3.7% of annual harvest, whereas more recently (2000–2009) escape rate averaged 0.3%. The primary concern of escaped fish is the potential for them to interbreed with wild conspecifics and reduce the long-term fitness of the wild population.

WILD FISH ATTRACTION

Callier, M.D., C.J. Byron, D.A. Bengtson, P.J. Cranford, S.F. Cross, U. Focken, H.M. Jansen et al. 2018. Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: a review. Reviews in Aquaculture 10(4):924-949.

Knowledge of aquaculture–environment interactions is essential for the development of a sustainable aquaculture industry and efficient marine spatial planning. The effects of fish and shellfish farming on sessile wild populations, particularly infauna, have been studied intensively. Mobile fauna, including crustaceans, fish, birds and marine mammals, also interact with aquaculture operations, but the interactions are more complex and these animals may be attracted to (attraction) or show an aversion to (repulsion) farm operations with various degrees of effects. This review outlines the main mechanisms and effects of attraction and repulsion of wild animals to/from marine finfish cage and bivalve aquaculture, with a focus on effects on fisheries-related species. Effects considered in this review include those related to the provision of physical structure (farm infrastructure acting as fish aggregating devices (FADs) or artificial reefs (ARs), the provision of food (e.g. farmed animals, waste feed and feces, fouling organisms associated with farm structures) and some farm activities (e.g. boating, cleaning). The reviews show that the distribution of mobile organisms associated with farming structures varies over various spatial (vertical and horizontal) and temporal scales (season, feeding time, day/night period). Attraction/repulsion mechanisms have a variety of direct and indirect effects on wild organisms at the level of individuals and populations and may have implication for the management of fisheries species and the ecosystem in the context of marine spatial planning. This review revealed considerable uncertainties regarding the long-term and ecosystem-wide consequences of these interactions. The use of modelling may help better understand consequences, but long-term studies are necessary to better elucidate effects.

Dempster, T., I. Uglem, P. Sanchez-Jerez, D. Fernandez-Jover, J.T. Bayle-Sempere, R. Nilsen, and P.A. Bjørn. 2009. Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect. Marine Ecology Progress Series 385:1–14.

Coastal aquaculture is a globally expanding enterprise. Currently, 1,200 salmon farms operate in coastal Norway, yet their capacity to aggregate and subsequently modify wild fish distributions is poorly known. Aggregations of wild fish at 9 farms and 9 control locations were counted on 3 separate days in June to August 2007. On each sampling occasion, 6 counts were made at 5 distinct depth-strata at each farm and control location. Wild fish were 1 to 3 orders of magnitude more abundant at farms than at control sites, depending on the location. Gadoid fish (*Pollachius virens, Gadus morhua* and *Melanogrammus aeglefinus*) dominated farm-associated assemblages and were present across a wide range of sizes, from juveniles to large adults. Estimated total farm aggregated wild fish biomass averaged 10.2 metric tonnes (t) per farm across the 9 farms (range: 600 kg to 41.6 t). Applied across the geographical range of Norway's 1200 salmon farms, their estimates indicate that salmon farms attract and aggregate over 12000 t of wild fish into a total of just 750 ha of coastal waters on any given day in summer. Possible consequences of these persistent, substantial aggregations of wild fishes at farms include a heightened potential for the transfer of pathogens from salmon farms to wild fish and among adjacent salmon farms, and altered availability of wild fish to fisheries. Restrictions on fishing in the immediate surrounds of salmon farms may avoid farms acting as ecological traps, particularly for species with depressed populations such as *G. morhua*, which are highly attracted to farms.

Fernandez-J.D., R.I. Martinez, P. Sanchez-Jerez, J.T. Bayle-Sempere, J.A.I. Jimenez, F.J.M. Lopez, P.A. Bjørn, I. Uglem, and T. Dempster. 2011. Waste feed from coastal fish farms: a trophic subsidy with compositional side-effects for wild gadoids. Estuarine, Coastal and Shelf Science, 91(4):559-568.

Aquaculture of carnivorous fish species in sea-cages typically uses artificial feeds, with a proportion of these feeds lost to the surrounding environment. This lost resource may provide a trophic subsidy to wild fish in the vicinity of fish farms, yet the physiological consequences of the consumption of waste feed by wild fish remain unclear. In two regions in Norway with intensive aquaculture, the authors tested whether wild Sithe (*Pollachius virens*) and Atlantic Cod (*Gadus morhua*) associated with fish farms (F_{assoc}), where waste feed is readily available, had modified diets, condition and fatty acid (FA) compositions in their muscle and liver tissues compared to unassociated (UA) with farms. Stomach content analyses revealed that both cod and saithe consumed waste feed in the vicinity of farms (6–96% of their diet was composed of food pellets). This translated into elevated body and liver condition compared to fish caught distant from farms for cod at both locations and elevated body condition for Sithe at one of the locations. As a consequence of a modified diet, they detected significantly increased concentrations of terrestrial-derived fatty acids (FAs) such as linoleic (18:2ω6) and oleic (18:1ω9) acids and decreased concentrations of DHA (22:6ω3) in the muscle and/or liver of F_{assoc} cod and saithe when compared with UA fish. In addition, the ω3:ω6 ratio clearly differed between F_{assoc} and UA fish. Linear discriminant analysis (LDA) correctly classified 97% of fish into F_{assoc} or UA origin for both cod and saithe based on the FA composition of liver tissues, and 89% of cod and 86% of saithe into F_{assoc} or UA origin based on the FA composition of muscle. Thus, LDA appears a useful tool for detecting the influence of fish farms on the FA composition of wild fish. Ready availability of waste feed with high protein and fat content provides a clear trophic subsidy to wild fish in coastal waters, yet whether the accompanying side-effect of altered fatty acid compositions affects physiological performance or reproductive potential requires further research.

Sanchez-Jerez, P., D. Fernandez-Jover, I. Uglem, P. Arechavala-Lopez, T. Dempster, J.T. Bayle-Sempere, C. Valle Pérez, D. Izquierdo, P.A. Bjørn, and R. Nilsen. 2011. Coastal fish farms as fish aggregation devices (FADs). Artificial Reefs in Fishery Management. CRC Press. Taylor & Francis Group pages 187-208.

This review documents increased densities of native fishes it the locations of at least some of the numerous aquaculture facilities in various European countries.