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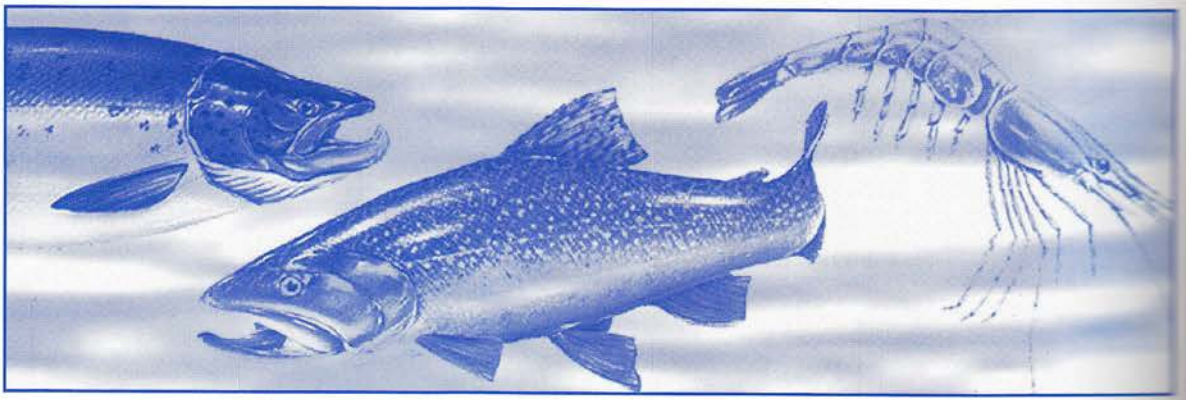

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Pacific halibut were also maintained in net-pens for several months at the Manchester, Washington, laboratory of the National Marine Fisheries Service.

Attempts were made to put solid bottoms in net-pens and we even thought about developing a net-pen with its bottom in contact with the sediments at all stages of the tide. As a result of serendipity, a scientific breakthrough was made. Someone accidentally placed an adult halibut in an unmodified net-pen with several large Atlantic salmon rather than in one of the modified net-pens. That fish survived and seemed content. Some 20 halibut were ultimately placed in an unmodified net-pen and were held for over three years without difficulty. Long-term survival of adult halibut in circular tanks has also been high.[7,8]

Male Pacific halibut are generally quite small and those used through 1992 were about 90 cm total length (males used in 1995 were over 110 cm long). Females become much larger than males, but we have elected to work with fish no longer than about 120 cm.[2] It is necessary to maintain newly captured adults in captivity for several months before the spawning season. Fish collected in the late summer or early fall will not spawn during their first winter in captivity. Keeping adults in the dark to mimic offshore conditions and help induce spawning was found to be unnecessary,[2] though the fish avoid bright light and will move to shaded locations in the tank. Broodstock holding tanks are covered — at least with netting — and are located indoors. Covers are also important to prevent adults from jumping out of the tanks.

Examination of the external characteristics of adult halibut vents provides a means, though not totally reliable, by which the fish can be sexed.[2] Fish can be accurately sexed by analyzing the levels of steroid hormones in the blood — presence of estradiol, for example, is confirmation that the fish is a female.[3] Females, as well as males, contain androgens and females in which the levels of the two hormones do not reach or exceed 0.5 ng/mL cannot be expected to spawn.

Pacific halibut are multiple spawners. Spawning is facilitated when the broodfish are anaesthetized; effective levels of anaesthesia can be produced by placing the fish in water containing MS-222 at 35 mg/L or in a mixture of 15 mg/L MS-222 and 5.0 mg/L quinaldine.[2]

From 1987 through 1989, when only one male was being held in captivity, spermiation began prior to the availability of ripe eggs, so the spawning season of the sexes did not overlap. Thereafter, when several males were being held, milt was available throughout the period when

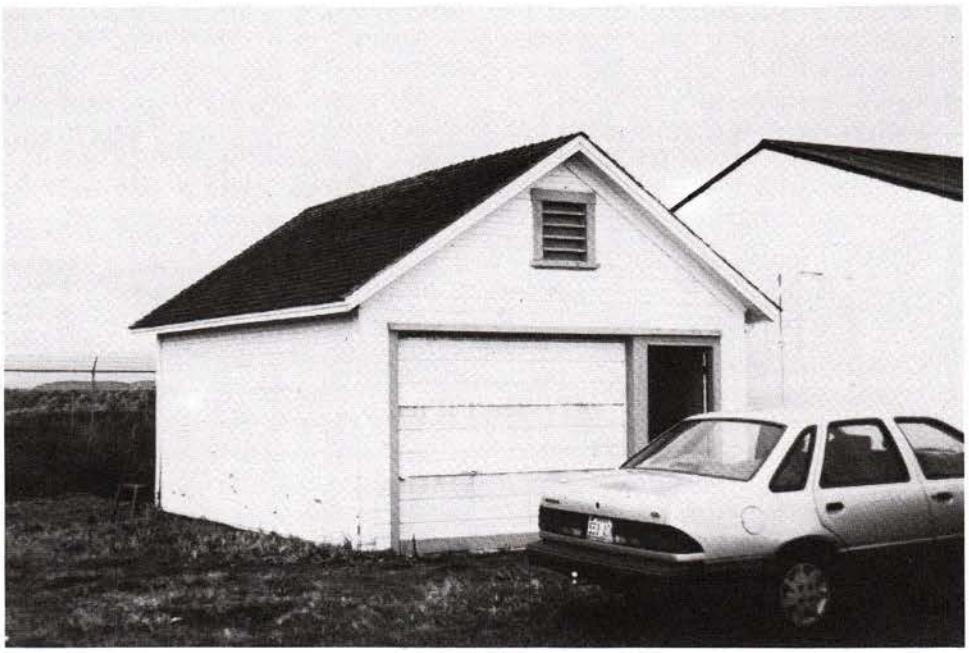

Figure 1. Garage building at the U.S. Fish and Wildlife Service Marrowstone laboratory which served as the first halibut hatchery used in the research program.

Figure 2. The new Marrowstone, Washington, wet laboratory of the U.S. Fish and Wildlife Service which contains two halibut broodstock tanks and the hatchery and larval rearing laboratory.

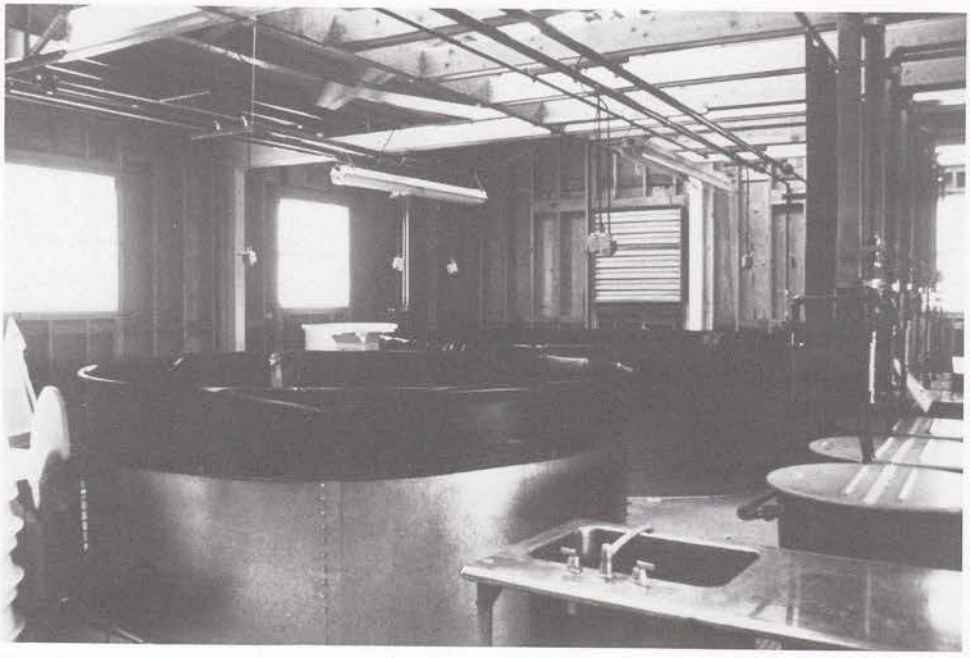

Figure. 3. Interior of a portion of the new Marrowstone laboratory showing the broodstock tanks.

eggs were being taken. In instances when milt may not be obtainable late in the spawning season (end of March or in April), eggs can be fertilized by using cryopreserved sperm. Properly cryopreserved sperm can be used effectively two weeks or more after having been frozen in liquid nitrogen.[2]

Methods of obtaining gametes and fertilizing them have been provided by Liu.[2] In brief, the method involves placing approximately 400 mL of unfertilized eggs in a dry 8-L bucket. After mixing 1 mL of milt and 20 mL of seawater (33 ppt salinity) for 3 seconds, the sperm solution is added to the eggs, after which 4 L of seawater are added. A second batch of sperm, diluted as above, is then added and the solution is gently mixed. An additional 2 L of seawater are added. The bucket is allowed to stand for 5 minutes after which floating (viable) eggs are removed and the remaining eggs are discarded. The retained eggs are washed three times with seawater and then placed in incubation tanks.

The effects of temperature, salinity, and light on egg hatching and larval development,[5] descriptions of early larval development,[4] and the salinity of neutral buoyancy of eggs and larvae[5] have all been studied in detail. Incubators have been designed to maintain the eggs and larvae in static or nearly static water. It is also important to keep the eggs in the dark, though the larvae can stand exposures to light of the proper quality and quantity.[2,6]

Egg development requires about 15 days, depending on temperature,[2] with the optimum being from 6 to 8°C.[6] The extremely fragile and weak larvae must be maintained for another 30 to 40 days before they begin feeding.[2] While few Pacific halibut have been reared that long, a few have been provided with rotifers (*Brachionus plicatilis*) and have accepted them as food items. No postlarvae have been produced. It has been estimated the time from first-feeding to metamorphosis will be about 85 days.[2]

Accomplishments in 1994-95

Broodstock were moved from a net-pen in Port Angeles to Marrowstone during the summer of 1994. Some of the fish had been held for four years in the net-pen. Those fish were supplemented with new broodstock obtained at sea by the IPHC in the fall of 1994. Because the fish had been either relocated or had not been previously held in captivity, they were not expected to spawn. However, some of the net-pen fish did develop, so a hatchery was quickly assembled in anticipation of spawning and egg collection.

Figure 4. Adult female halibut being examined for ripeness. Note the light colored monogenetic trematode parasites on the surface of the fish.

Three females ultimately spawned. A total of 12 L of eggs (about 500,000) were obtained, though most were of poor quality. Running ripe males were available as well, so each batch of eggs was fertilized. Fertilization rates ranged from 0 to 60%, but most of the fertilized eggs died within 3 days. A total of 12,000 larvae hatched, but the majority of the larvae did not survive beyond 3 days. The last of the fish died on April 7 at the age of 21 days, before first-feeding had been reached.

Since there had been no expectation of obtaining eggs during the 1995 spawning season, the modest success achieved was significant in that it provided more experience and the opportunity to test the new hatchery. Other accomplishments included the establishment of 3 broodfish tanks, all of which are under roof; the setting up of an incubation system in which light and temperature are controlled; and the design and construction of a new type of incubator. Broodfish were trained to accept prepared feed for the first time, though they continue to prefer herring (frozen or live).

In an attempt to condition broodstock to spawn within their first year of captivity, another fishing expedition was conducted in May 1995. That trip added 7 males and 17 females to the broodfish population. The females were smaller than desired and may not mature prior to the 1996 spawning season. However, they will be good subjects for feeding experiments.

Plans for the future

While awaiting the onset of the 1996 spawning season, studies on adult feeding have been initiated. Several commercial feeds have been obtained and are being evaluated to determine if they will be accepted by adult halibut. Texture seems to be an important aspect of palatability and will be the focus of additional study. Much of what is learned about food preferences of adults (not only nutrient content but also physical characteristics) should be useful when we begin developing prepared feeds for juveniles.

Attractants of various types will be provided to broodfish to determine if substances can be found to make prepared feed more palatable. Once that has been accomplished, we will evaluate the nutritional requirements of adult halibut and determine if diet modification can be used to enhance egg quality.

Past success in keeping a few larvae alive to reach first-feeding has provided us with some information as to the type of live food that should be supplied. Employment of the green water technique (providing zooplankton as food in the presence of algae) appears to be desirable and will be studied in more detail as will the potential for weaning larval halibut from live to prepared feeds prior to metamorphosis.

One of the first goals of the research, to produce postlarval Pacific halibut, has yet to be achieved. Postlarvae are routinely being produced in Norway with Atlantic halibut, and since the two species are similar in all other respects,[8] we remain optimistic about the possibility of producing postlarval Pacific halibut.

We acknowledge the support of the International Pacific Halibut Commission, the Canadian Department of Fisheries and Oceans, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service. Support for much of the work was obtained from the National Oceanic and Atmospheric Administration through a Saltonstall-Kennedy grant.

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The future of salmon enhancement in British Columbia

Ted Perry

Salmon enhancement in British Columbia is comprised of a wide range of projects and activities intended to help rebuild and maintain stocks or to increase catch. Hatcheries, spawning channels and lake enrichment projects produce about 8 million salmon annually of which some 5 million are harvested in Canadian fisheries. Much of the effort of the Salmonid Enhancement Program (SEP) is directed to conservation of stocks through small-scale production, habitat restoration, education, and public awareness and involvement activities.

Throughout its 18 year history SEP has been a discrete organizational unit within the Department of Fisheries and Oceans (DFO). Last month this changed. SEP amalgamated with Habitat Management Branch forming a new Habitat and Enhancement Branch with responsibility for protection of habitat for all fish species and for production of both wild and enhanced stocks of salmon.

Future role of enhancement in stock conservation will be determined by the factors causing conservation concerns. Habitat restoration will be the most widespread activity.

Conservation, and development and sustained utilization are the DFO salmon stock management goals. The new Habitat and Enhancement Branch will play a central role in achieving these goals. Rapid population growth in British Columbia is putting more pressure on fish habitat and salmon stocks. At the same time, fisheries management budgets are dropping. For example, the annual SEP budget has declined from a peak of $38 million to $27 million during the past five years, and further reductions are expected. Consequently our ability to develop new projects has been reduced, the number of staff has been reduced and several hatcheries and lake enrichment projects have been discontinued. In addition we need to remain flexible and able to respond to critical stock situations such as those facing salmon stocks on the west coast of Vancouver Island. We will have to use our financial resources more efficiently and to find new ways to get the job done in the future. We hope to minimize the impact of further budget reductions through user-pay cost recovery mechanisms. We also plan to expand upon existing partnerships with fishers, private industry including aquaculture, the public and other government agencies.

Conservation of the more than 9,000 salmon stocks in British Columbia and fishery development will require integrated habitat, harvest and enhancement management. Integrated planning is in progress for the Fraser River watershed through the Green Plan initiative; however planning has been sporadic elsewhere. It is intended to develop salmon stock management plans for the entire region based on natural production capacity, sustainable harvest objectives and enhancement where appropriate. I envision a plan which designates some regions to be managed solely

for wild stocks and others where production may be increased using enhancement technologies. Habitat protection and restoration will be a priority in all areas. Fisheries will be managed at rates sustainable by wild stocks with higher harvest rates in terminal fisheries on enhanced stocks. Many of our fisheries are already managed in this manner, but there is inconsistency and some stocks are not at full capacity. The plans will consider scientific knowledge about limits to production in fresh and marine waters, as well as the concerns of fishers and the public.

The future role of enhancement in salmon stock conservation will be determined by what factors are causing a conservation concern. Habitat restoration will be the most widespread activity. Hatcheries and other technologies may be used for short periods of time or on an ongoing basis as necessary. Examples of long-term and short-term applications are described below.

Long-term fish production will be required if fish habitat is lost. For example, the Capilano Hatchery in Vancouver maintains coho and steelhead stocks which were historically spawned and reared upstream of an impassable dam constructed for water storage. Long-term production may also be required to maintain small stocks with exceptionally low rates of productivity. Coho salmon stocks in the Strait of Georgia serve to illustrate this point. There are hundreds of coho stocks in this area all of which mix in the ocean and are harvested together in the commercial and recreational fisheries. Wild Strait of Georgia coho are declining in abundance and a plan has been developed to rebuild them. Reduced harvest to get more spawners in the rivers is the first step. The new harvest rates are intended to conserve virtually all the stocks, but it is probable that some stocks will not rebuild because of naturally low productivity (in terms of adult progeny produced per spawner). Failure of a large number of stocks to rebuild will result in further harvest reduction or other measures, but not expanded hatchery production. If only a few stocks do not rebuild after two cycles, hatchery production will be considered to maintain the stocks. Hatchery releases will be limited to levels that produce an escapement equal to 50 percent of the natural spawning target in order to maintain genetic integrity. In this case, hatchery production may be necessary for the foreseeable future. This plan is a great improvement over the way we have managed Strait of Georgia coho since the 1970s. During this twenty year period, permitted harvest rates were too high and a substantial amount of coho habitat was degraded. At the same time we started producing coho in hatcheries. The bottom line is that catch of Strait of Georgia coho has been relatively constant but it appears, superficially at least, that we have simply replaced wild fish with hatchery fish. The new plan is intended to restore the wild fish abundance, with the existing hatchery production providing additional fish.

Increased fish production for harvest purposes may also emerge as an important goal during the next few years.

Short-term hatchery production may be required to help stocks survive crises. West coast Vancouver Island chinook salmon provide an example. Spawning returns are expected to be very low in 1995 and 1996 due to extremely high rates of predation by mackerel on the smolts in 1992 and 1993. The unusual abundance of mackerel has been linked to warm ocean conditions as a result of El Niño events. Many of the wild chinook stocks which normally have hundreds of spawners may be reduced to tens of spawners. This raises concerns not only for the immediate survival of stocks but also for their long-term viability, considering the impacts of inbreeding on genetic diversity. Geneticists advise that in order to minimize inbreeding effects the numbers of spawners should be increased as quickly as possible and that hatchery production would be a beneficial supplement to accelerate rebuilding. The

Quickstart concept described by M. Mulholland in this issue of the *AAC Bulletin* could be an integral component of the enhancement plan implemented to assist these chinook stocks.

Increased fish production for harvest purposes may also emerge as an important goal during the next few years. There has been a major effort during the past two decades to rebuild wild stocks through harvest management in order to increase and stabilize catches. In fact, since SEP started in 1977, annual catch of salmon in British Columbia increased from approximately 70,000 tonnes to over 90,000 tonnes in the early 1990s. The increase was related about equally to natural production increases and to enhancement. Since the mid-1980s there has been relatively little investment in enhancement projects large enough to have a significant impact on catch. This could change for a number of reasons including aboriginal fisheries development, terminal commercial or recreational fishery development, or simply to take advantage of opportunities to expand existing fisheries or establish new ones.

The essential requirement for any new large-scale salmon enhancement project will be that it provides additional catch without negative effects on wild salmon stocks. That is so harvest can occur with little or no by-catch of other stocks. Nitinat hatchery and Long Lake fertilization projects are described below to illustrate this type of production project.

Nitinat hatchery is on the west coast of Vancouver Island. Prior to hatchery operation in 1980, the chum salmon run was large enough to sustain a fishery once or twice each decade and the escapement target was met only sporadically. Since hatchery returns started, there has been a fishery every year with catch averaging about 700,000 chum and the escapement target has been met every year. The fact that wild chum stocks elsewhere on the west coast of Vancouver Island remain at low levels of abundance despite very low harvest rates confirms the contribution of the hatchery in maintaining the Nitinat stock at high levels.

Central coast sockeye provide another example of this type of fishery development. Long Lake has been fertilized to promote the growth and survival of sockeye salmon fry since 1977. Since then the stock has doubled in size and has sustained a terminal fishery. Over the same period of time unenhanced sockeye in Rivers Inlet just north of Long Lake have declined. This suggests that lake fertilization may be responsible for maintaining and increasing the Long Lake sockeye abundance.

There are opportunities for terminal fishery development of all species of salmon elsewhere along the British Columbia coast similar to the Nitinat and Long Lake examples.

Successfully achieving our goal of the long-term viability of salmon stocks clearly depends on conservative harvest management and maintenance of fish habitat. Enhancement projects can help achieve this goal if they are integrated with harvest and habitat management, and with scientific knowledge on production capacity and biological interactions in freshwater and marine environments. Salmon enhancement activities directed toward stock conservation will likely expand in the future, with increased involvement by other government and non-government parties. New production to maintain or increase catch or angling opportunities is also probable but implementation is expected to depend on investment by those who benefit directly.

Long-term viability of salmon stocks clearly depends on conservative harvest management and maintenance of fish habitat. Enhancement projects can help achieve this goal.

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Abalone stock enhancement: a review of rationale and techniques

Murray Rudd[1]

Market demand for abalone has soared over the past decade in Asia and, as a result, wild abalone stocks worldwide have come under increasingly heavy fishing pressure. Landings in several regions have declined to as low as 10% of peak landing levels. In British Columbia, where there had been commercial, sport, and native food fisheries, a ban on all types of harvesting was imposed in 1990 due to government concerns over declining stock levels. This ban, which remains in effect, has prompted increased interest in abalone enhancement in British Columbia. There are several potential enhancement methods available for use on abalone, each of which addresses different factors that can limit production. Available techniques include: transplants of adult and/or juvenile abalone from populated to unpopulated areas; habitat modification or addition of artificial shelters in regions with limited rearing space; and restocking of larval and/or juvenile abalone in regions with insufficient natural recruitment. Severe stock depletion in British Columbia makes active restocking programs the only real option for enhancement of local abalone stocks. Abalone restocking programs can utilize either larvae or juveniles. This paper briefly reviews some of the advantages and disadvantages of each strategy given the unique biological aspects of abalone. In either case, development of an effective enhancement program would be a long-term effort requiring substantial work on a site-by-site basis.

Introduction

Abalone are marine gastropods highly valued for the delicately flavoured meat of their foot muscle. Concentrations of abalone tend to occur in regions with abundant kelp resources upon which they feed. Australia is currently the largest abalone producer with annual landings from the wild fishery in excess of 4,700 tonnes. Australia has seen a moderate decrease in production over the last decade while landings in Japan, British Columbia, California, and Mexico have dropped drastically. Supply of farmed abalone to international markets is minimal to date.

In Asia, abalone is a historic and prestigious food for both Chinese and Japanese consumers. Rapidly increasing income levels of consumers have caused soaring market demand. Rising demand and falling supply have driven market prices for abalone to extreme levels — Japanese landings command prices equivalent to over Cdn $100 per kilogram. Due to the high profit potential, abalone stocks worldwide have come under heavy pressure from legitimate commercial fisheries and from highly organized and lucrative poaching operations.

In British Columbia, there is one naturally occurring species of abalone, the pinto or northern abalone (*Haliotis kamtschatkana*). A fishery for the pinto abalone developed in British Columbia in the early 1970s and rapidly expanded, reaching a peak in the late 1970s. The Department of Fisheries and Oceans imposed landing quotas and other restrictions on the fishery but, despite the restrictions, the abundance of indicator stocks monitored by government biolo-

gists declined severely in the mid- to late-1980s. In 1990 a total ban on abalone fishing, affecting commercial, sport and native food fishery sectors, was imposed for conservation reasons. The indicator abalone stocks in British Columbia have shown no signs of recovery since 1990 and as a result the fishery closure has been extended indefinitely. This closure has stimulated interest in both restocking programs and commercial farming operations in British Columbia.

In this paper, I will briefly review some unusual biological characteristics of abalone that influence stock rehabilitation and examine some of the techniques available for enhancement programs.

Biological characteristics impacting rehabilitation programs

There are three main biological factors that will influence the chances for stock rehabilitation and/or viability of enhancement programs in British Columbia: slow growth rates, the tendency of adult abalone to aggregate, and the limited dispersion of larvae.

Growth of abalone in the cool waters of British Columbia is slow — they take from 5 to 9 years to reach market size (10 cm shell length), depending on local conditions. The main difficulties caused by the slow growth are related to biological and economic assessments of rehabilitation programs.

Abalone tend to aggregate into densely populated beds in areas of prime rearing habitat. This behaviour increases the chances for successful reproduction as abalone are broadcast spawners. However, this same behaviour makes abalone easy to target in a commercial fishery or poaching operation and has resulted in many stocks being virtually stripped of large adults that contribute the bulk of the stock's reproductive effort. Recruitment is irregular for abalone in temperate climates at the best of times, but once egg production declines to levels less than 40% of that of unfished stock, the ability of the stock to sustain itself is in question. In general, it appears likely that stocks that have been severely depleted are incapable of recovery on their own. In British Columbia, virtually all abalone stocks appear to have been reduced far below the 40% egg production threshold and a problem in any rehabilitation program will be how to rebuild stocks to such a density that they become self-sustaining.

The third biological factor that has a major impact on stock recovery or rehabilitation is the limited distribution of abalone during their brief planktonic larval stage. The larval period for pinto abalone is short, being typically up to 12 days at water temperatures common during the spawning period. Australian studies have shown experimentally that abalone larvae have very limited dispersion — in the range of 10's to 100's of meters.[3] While species differences do exist, it is probable that pinto abalone spend at least a portion of their larval period in gravel and cobble very close to the spawning site. Abalone larvae are very selective with regard to habitat for settlement. They respond to chemical cues from coralline red algaes, so successful settlement is highly dependent on local microhabitat. The combination of short larval period, larval behaviour, local topography, and microhabitat requirements for settlement all combine to strictly limit stock rehabilitation potential for abalone. The end result is that even if sufficient adult abalone are preserved in pockets of marine reserves, there is little chance that larval dispersion would be widespread enough to rehabilitate stocks outside the immediate region.

Other biological factors will also affect rehabilitation programs. Of particular interest for British Columbia restocking programs is the fact that the coast has a relatively low level of abalone predators compared to California and Japan; this could prove a long-term competitive advantage for British Columbia production.

Enhancement methods

There are a number of potential techniques that could be used in abalone enhancement programs, including: broodstock and/or juvenile transplants; habitat modification; and active restocking of young abalone.

Transplants of wild adults and juveniles have been used extensively in Japanese stock development programs. Experimental transplants of stunted "surf" abalone (which never reach the legal 4–inch (10–cm) harvest size due to the harsh environment in which they live) to more sheltered locations have also been conducted in British Columbia in the past.[2] Transplants are, however, unlikely to be a factor in any future enhancement programs simply because of the lack of available animals in remaining natural stocks. Japanese work has shown that continual long-term stocking efforts are needed to have

any lasting impact on fishery production.

Habitat modification measures (e.g., addition of artificial rearing shelters, removal of predator species, kelp afforestation) are also used extensively in Japan, but are unlikely to be important in British Columbia. The first reason for this is that there is an abundance of suitable local habitat. In addition, intensive habitat modification can have adverse effects on other species; in Japan, local fishery cooperatives have almost exclusive control over coastal areas and manipulate the environment to a degree which would not be permitted in British Columbia.

Restocking of young abalone is the most promising option for stock enhancement in British Columbia. Abalone can be released to the wild at either the larval or juvenile stage. Larval restocking involves releasing large numbers of larvae to regions with suitable micro-habitat for settlement just at the time they are competent to settle. Juvenile restocking involves the use of intensive hatchery production of juvenile abalone as "mini-seed" less than 7-mm in shell length (i.e., prior to the stage at which juvenile abalone are weaned from a diet of diatoms and other micro algae to kelps), or as juveniles of 10 mm to 40 mm shell size. Larval reseeding programs would require only minimal seasonal hatchery facilities for broodstock holding, spawning and larval rearing. Production of juvenile abalone would require more sophisticated facilities with water treatment, diatom culture, and juvenile rearing equipment.

There are two potential advantages as well as some disadvantages with larval restocking programs. The first advantage is that up-front costs are low because of limited capital investment and seasonal labour requirements. Biologically, the adult abalone resulting from larval restocking programs would be more "natural" than those from hatchery juvenile stocking programs. Biological and economic assessment of larval restocking programs may be problematic however. More importantly, the success of a larval restocking program would be highly dependent on proper selection of stocking sites. There would have to be a very good understanding of local topography, current patterns, and ecology; it should be expected that successful enhancement efforts would be "hit-and-miss" for some time and that variability between enhancement sites would limit the ability to develop a standardized enhancement protocol.

Systematic examination of larval abalone restocking has been conducted in New Zealand. The first larval restocking experiments during the mid-1980s showed high levels of enhancement resulting in 68 versus 8 juveniles per square meter in experimental and control sites, respectively.[5] However, subsequent work did not live up to the initial promise: larvae stocked at 20,000 per square metre in underwater tents (to limit dispersion) resulted in only 10% settlement rates and 1% survival to the 4- to 5-month stage.[4] Research on enhancement of abalone has been reduced and efforts are being focused on farming activities. New Zealand government personnel do feel that larval restocking is technically feasible if sites are carefully selected and that economic feasibility could be improved by stocking larvae at levels much lower than the 20,000 per square meter used in previous experiments.

Restocking of juvenile abalone would be much easier to monitor and assess than stocking larvae, but costs for hatchery development and operation would be high. There has been some evidence that hatchery-reared juveniles are not able to cope well after release to the wild; this has been particularly evident with relatively new commercially-oriented hatcheries in California, where post-release predation has been a problem, and in a pilot-hatchery in New Zealand, where it was shown that the stress of an extra year of hatchery rearing outweighed the benefits of the larger release size.

In Japan, where juvenile restocking programs have been in place for decades, juvenile quality seems to be much less an issue while optimization of production, by manipulation of timing and size at release, is a primary focus. Hatchery protocol is particularly well-developed for *Haliotis discus hannai*. Japanese juvenile abalone are usually moved from hatchery to ocean long-line facilities for intermediate holding before release on the fishing grounds at a shell size of 20- to 40-mm.

Juvenile restocking programs in Japan place almost 30 million juvenile abalone onto commercial fishing grounds each year and hatchery-based production accounts for approximately 10% of overall Japanese production.[6] For some regions, hatchery-based production exceeds 50% of overall production. Recovery rates for hatchery seed are typically 10% to 30%, but in some cases reach 65% over the 1- to 3-year growout period.

Despite the large national restocking program,

overall Japanese production has been falling and now stands at less than 50% of the level of landings only a decade ago. Most of the drop in production has occurred in northern Japan where the restocking efforts are concentrated. There is speculation that shifts in major ocean currents, resulting in cooler than normal winter water temperatures, have been inhibiting survival of juvenile abalone.

The economics of Japanese enhancement is impossible to assess due to government subsidies of hatchery seed and in-kind contributions of feed and labour by fishery cooperatives. One report[4] about the Tarou Fishery Cooperative implied a production cost of Cdn $0.92 per 30-mm juvenile and an overall cost of production of $58 per kg for landed hatchery-origin abalone. The cooperative received a market price of $98 per kg (all prices converted at 1992 exchange rates) making enhancement under Japanese conditions look viable. Experiments in New Zealand resulted in preliminary cost-of-production estimates of Cdn $18 to $33 per kg (more than market value for the New Zealand species at the time).

Conclusions

There is no reason to believe that abalone stocks in British Columbia will naturally rehabilitate in the immediate future. Even if serious enhancement efforts were to begin immediately, it would be a number of years before the effort could be adequately evaluated and even longer before there could be any significant impact on abalone stocks. Results will be highly influenced by local conditions down to the micro-level and on-going intensive management at the local-scale will be needed to maximize the chances of success. Almost by definition, this sort of program would require major changes to the tenure system in British Columbia and to existing government fishery policy.

Larval restocking programs are attractive due to the low "up-front" costs. A larval enhancement program would also allow the development of the knowledge-base necessary to further develop juvenile restocking programs in the future. In British Columbia, we must realize that we are now decades behind Japan and at least 10 years behind New Zealand in enhancement experimentation. There will be no quick fixes for the abalone fishery in British Columbia through enhancement programs. However in the long-term, enhancement may be an important tool that fishery managers can use, in combination with effective management and enforcement measures, to aid in rehabilitating a devastated fishery.

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Overview of the QUICKSTART captive broodstock program for Pacific salmon

Mike Mulholland

QUICKSTART is a private initiative sponsored by the Sport Fishing Institute of British Columbia on behalf of a number of salmon fisheries stakeholders — sport fishers, commercial fishers, First Nations, salmon farmers, coastal communities and government. The program is unique in its formation and goals, providing coordination and funding for the maintenance of captive broodstock whose progeny will be used to supplement natural populations. The primary objective of the program is to restore stocks by ensuring that existing genetic bases are sufficiently preserved to allow the stock to sustain itself naturally in the future. The use of captive broodstock is an attractive concept because of the potential to rapidly rebuild depleted populations.

Introduction

Over the past years, the media has focused public attention on the decline of natural populations of Pacific salmon. The existence of many of the wild coho and chinook runs in British Columbia coastal streams is threatened as the number of returning adults is lower than the minimum necessary to sustain the runs. Salmon stocks are vulnerable to habitat degradation, predation, natural disasters, disease, and direct and indirect incidental over-harvesting.

The clock is ticking as the genetic diversity of the stock is eroding and moving it closer to extinction. If no action is taken, then Pacific salmon stocks in British Columbia may well follow the disturbing patterns experienced in the lower Columbia River salmon stocks and in the East Coast cod fishery. Corrective action must involve all the fisheries management tools at our disposal, including habitat management, habitat restoration, habitat preservation, salmon enhancement and exploitation management.

This report will focus on salmon enhancement and more specifically the use of captive broodstock as a tool to complement other enhancement techniques. In addition, I will describe the establishment of strategic alliances between private interests and government to provide funding for these types of programs. With public pressure on governments to eliminate the debt and reduce spending, there has been no choice but to cut government programs. Reductions have occurred everywhere, from health care to salmon enhancement. Therefore, if we want to continue to produce fish, we cannot rely solely on the government. More and more private initiative programs will have to be used, in concert with government, to meet our needs.

What is QUICKSTART?

QUICKSTART is a private initiative program sponsored by the Sport Fishing Institute of British Columbia on behalf of a group of fisheries stakeholders. This strategic alliance is made up of sport fishers, commercial fishers, First Nations, salmon farmers, coastal communities and government. QUICKSTART focuses on the use of captive broodstock for one run cycle to provide a large boost — or "jump-start" — of offspring to a system.

What does the program do?

QUICKSTART is a tool to complement standard fisheries management practices. It provides funding and coordination for the maintenance

of captive broodstock. The large potential boost in smolt production requires that the program be part of an integrated fisheries management plan including:

1. Assessment,
2. Habitat Management,
3. Salmon Enhancement,
4. Harvest Management.

Program objectives

The objective of QUICKSTART is to restore salmon stocks for future generations by ensuring that the existing genetic base is preserved in sufficient numbers to allow the stock to sustain itself naturally in the future. In order to do this, it is necessary to:

- determine the reasons for the decline in the stock;
- preserve a living gene bank through captive broodstock;
- eliminate the cause of the decline; and
- outplant the offspring boost to match the capacity of the system.

For the program to be successful and to obtain return on the investment in broodstock, the problem must be corrected, whether it is habitat restoration or harvest rate reduction. The focus of the program is to supplement production for one cycle, allowing enough adults to subsequently return to spawn naturally and increase the population in the future. If the problem or cause of the decline has not been corrected, then stock enhancement will only delay the final outcome. When the enhancemment program is finished, then the population will decline again.

The use of hatcheries to supplement salmon runs has a long history in the Pacific Northwest. They have been used over the past 100 years with some success to support runs that have declined due to overfishing, installation of dams and loss of habitat. Hatcheries are attractive because the egg to smolt survival is much higher than in the wild. and they provide a large survival advantage for the early stages with the potential to result in an increase in the return of adults to a system.

Lately there has been a focus on the restoration of natural or wild runs with supplementation. In this case, a small portion of the population is reared in the hatchery and is then used to supplement the wild population. This approach in turn can be supported by a captive broodstock program, where the returning hatchery progeny mate with the wild population and the increase is sustained in the future.

Background on captive broodstock programs

The aquaculture industry is based solely on the maintenance and breeding of broodstock in captivity to supply egg requirements. In British Columbia, the technology has progressed significantly since the early days and programs involving the Cowichan/Koksilah River chinook, Nanaimo River chinook and the Marble River chinook have been used to supplement these runs. In the United States, programs are in place to aid in the restoration of the Sacramento River chinook and the Snake River sockeye runs.

Captive broodstock process

The use of captive broodstock involves:

1. Capturing wild broodstock and stripping milt and eggs;
2. Mating fish 1 to 1 or using a factorial mating plan to increase the genetic variance;
3. Incubating eggs in a hatchery, keeping the families separated;
4. Taking a small sample of eyed eggs (30-100) from each family;
5. Using the remaining eggs in the ongoing enhancement program;
6. Pooling the broodstock eggs, rearing them until they smolt and then transferring them to sea pens;
7. Rearing the smolts to maturity and then stripping them;
8. Fertilizing captive eggs with new wild milt, stored milt or captive milt;
9. Outplanting offspring as eyed eggs, fry or smolts in native streams.

The final number of offspring and their use must be determined prior to the start of the program. The number of offspring released must be matched with the natural population and the carrying capacity of the system.

QUICKSTART applications

The maintenance of captive broodstock is expensive and will rely on the infrastructure of the aquaculture industry for support. Therefore,

there are very specific applications for QUICKSTART:

1. ***Smolt limited habitat:*** If a stream has a history of supporting a large production of salmon and has the necessary habitat to support much higher numbers of smolt production, the system is being under utilized because of reduced escapement to the system. QUICKSTART will allow production to be boosted quickly to fully utilize the available rearing habitat.
2. ***Habitat restoration:*** Presently the stream is not smolt limited but, with habitat restoration work, much more habitat will become available and increased numbers of fry will be needed to utilize this new area. This is typical of many streams in southwestern British Columbia where upper reaches of streams have been degraded and side channels have been cut off or made inaccessible by development.
3. ***Inaccessible habitat:*** The system has extensive habitat that is suitable for fish rearing but due to some impediment access to the habitat is blocked. QUICKSTART will allow the production of this habitat through colonization. However in this situation, the increase in returning adults will have to provide smolts for an ongoing routine of colonization.
4. ***Preservation of a living gene bank:*** In some instances there may be a recent history of only a few adults returning each year. The objective is to preserve the existing genetic material and to supplement the natural run with additions from the captive broodstock to bring the run back to its full production potential.
5. ***Fail safe:*** An important, valuable run may be at risk of being subjected to over exploitation by predators, pollution spills or mixed stock fisheries. The possible result is that insufficient numbers are returning to seed the system and sustain fish production. In this case, broodstock may be kept as a back-up to ensure that the run is maintained. If sufficient numbers return naturally, then the broodstock are not used and are harvested. If there are insufficient numbers returning, then the broodstock is used to supplement the run. Examples of this type of system could be the Vancouver Island chinook stocks in the Puntledge River which are under stress from seal predation and those in Robertson Creek which are depleted due to mackerel predation.
6. ***Colonization or transplants:*** The historic run to the system has been destroyed and, in order to restore the run, a program of colonization is required. To be successful, experience has shown that a large number of offspring must be transplanted

Developing a captive broodstock program

If the system falls in one of the above categories, there are other factors that must be addressed in developing the plan and program:

1. Cause of the weak stock;
2. Corrections for the cause;
3. How the eggs will be used;
4. Size of the natural population (maintaining genetic diversity);
5. Where the captive eggs will be reared;
6. How the offspring will be outplanted;
7. Program evaluation and marking.

Timing of one run cycle for coho and chinook

The duration of a captive broodstock program is important as it will determine the cumulative increase in the potential for inbreeding in the population. However, simulations have shown that if captive broodstock are used for only one run cycle then the change in the level of inbreeding will be slight. If the population size remains large in subsequent generations following the end of the program, then the cumulative level of inbreeding will actually be less than it would have been without supplementation. However,

if the population size declines back to its original size then the inbreeding level will be considerably higher.

Selective marked fishery

If the objective of the program is to provide more fish for harvest and draw pressure away from the wild stock, then a working program of the hatchery fish can be implemented and the outcome will be growth in the wild component.

Advantages of the use of captive broodstock

- Provides the potential to rebuild depleted stocks quickly because of the high fecundity of salmon combined with the increased survival of the initial broodstock reared in captivity.
- Reduces the need to rely on taking fish from the wild. In many cases, limited numbers of fish may be coming back to a system. Because of the logistics and difficulty in capturing broodstock in some systems, fish are often killed and lost without ever spawning their eggs.
- Provides an insurance policy that can be accessed in case of a problem such as predation. If the returns are healthy and adequate in subsequent years, then the captive brood stock can be harvested.
- Provides a surplus source of eggs and fry that can be used for colonizing new habitat created by restoration projects.
- Provides the opportunity to bring together a number of conflicting user groups to focus on a common goal. This may be the most important aspect of the QUICKSTART Program.

Issues and concerns

The use of captive broodstock for supplementing natural populations is still rather new, even though it has been used in a number of situations. There are issues that will have to be addressed as we develop these programs:

1. ***Expense:*** It is expensive to keep fish until maturity. The saltwater rearing phase of the program will initially rely heavily on the infrastructure of the aquaculture industry.
2. ***Masking of real problems:*** The maintenance of broodstock must be combined with measures to correct the cause of the decline. All efforts must be made to ensure that the population increase is sustained. The presence of captive broodstock cannot be used as a justification for ongoing poor management practices.
3. ***Genetic bottleneck:*** The plan must address the maximization of the genetic variability and limiting of the potential for inbreeding. Topics such as program duration, age structure of the stock, mating design, sib avoidance, and effective population size must be considered to minimize this.
4. ***Maintaining of increased populations:*** This will be determined largely by whether the factors responsible for the population decline have been adequately addressed.
5. ***Differing selective pressures:*** There will be different selection processes between the wild offspring and the captive offspring. How will this affect subsequent generations of fish? This will have to be evaluated over time, but using only one run cycle will allow natural selection to take place in the following generations.

Summary

It is the goal of QUICKSTART to make this program an example of how those with a stake and interest in the fishery resource can work together to promote stock restoration and habitat management. By focusing on restoration and preservation of a world famous fishery, this program would be a first in North America. In closing, it must be emphasized that the success of a captive broodstock program in meeting its objectives is related to how successful managers have been in correcting the cause of the decline.

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What do changes in the frequency of resistance to oxytetracycline in the sediments under salmon farms mean?

Peter Smith

Quantification of the impact of antimicrobial agents on the "frequency of resistance" in environmental microflora presents major theoretical and practical problems that present difficulties for the interpretation of the meaning and significance of data that is, and may become, available. Quantification has normally been achieved by differential plate counts — methods only capable of investigating the properties of a very small fraction of the viable bacteria. Issues of choice of media and selection agent concentration have not been resolved and will not be easy to resolve. Equally, the issue of the causal relationship between the presence of antimicrobial agents and changes detected in the "frequency of resistance" is complex. The nature of the mechanisms underlying increases in "frequency of resistance" in a population have rarely been investigated but the assumption that specific resistance genes on transferable plasmids are centrally involved is naive and unjustified by the evidence available. Bacterial strains may also be inherently insensitive to an agent, may manifest presistence mechanisms or may be resistant as a result of chromosomal mutation. In theory, the emergence of resistant bacteria in aquatic sediments could represent a risk for the use of these agents in human or veterinary medicine. The size of the risk is rarely addressed and, as a series of events would be required for such a risk to manifest, in all probablity is miniscule. There is only one consequence of the use of antimicrobial agents in fish farming for which there is compelling evidence — the increased frequency of clinically significant resistance in fish pathogens. The only species demonstrably at risk is the financially solvent fish farmer.

Introduction

A number of investigations have reported increases in the frequency of oxytetracycline resistance in the microflora under fish cages in marine farms[9,10,17,18,22] and Weston[23] has summarized the data. This short paper is a commentary on the probable meaning of the data. *Meaning* is not an objective property of data, it is context dependent. The meaning and validity of data can only be assessed by reference to the uses to which they are to be applied. Three aspects of the meaning will be considered: the first is the extent to which the available data provide an adequate picture of the changes that occur in the microbial populations of the sediments; the second is the extent that it is reasonable to infer that the changes in frequencies of resistance are a result of the therapeutic use of oxytetracycline by the farms; the third is the extent to which the available data allow an estimation of the potential risks associated with the use of oxytetracycline in fish farms, for its continued value as a therapeutant in human and animal medicine. We addressed these issues in a previous review[20] and although some degree of repetition is inevitable, this paper will concentrate on more recent developments.

In the presence of fish feed, marine sediments and sea water, but in the absence of oxytetracycline, frequencies of oxytetracycline resistance will rise from approximately 1% to 35% as anaerobic decomposition develops.

Changes in natural microflora

The majority of studies of oxytetracycline resistance in under-cage sediments have relied on differential plating methods. In these methods, samples of sediment are plated on an agar medium, with and without oxytetracycline, incubated for a period of time and the number of colonies on the two media are compared. A number of decisions must be made in designing such an experiment, including which media and incubation conditions to use, and what concentration of oxytetracycline to add.

The media should support the growth of the largest number of organisms from the environment under study. However, agar culture methods so far developed have a poor ability in this regard and it is unlikely that any support the growth of more than 1% of the viable microflora.[4] The problem is compounded by the aerobic incubation conditions that have been employed to investigate sediments that are frequently hypoxic or anoxic. The media used by Norwegian workers is based on Tryptone Soya formulations (TSCA),[3,5,6,17,18,22] American workers based their media on Mueller-Hinton agar 23, whilst in Ireland Zobell's 2216V marine heterotroph media (ZV) has been used.[9,10] This presents obvious difficulties in comparing the results generated in each country. Kerry[8] compared results from TSCA with ZV and found that total counts and frequencies of resistance varied with the nature of the sample material being analysed.

The issue of what concentration of oxytetracycline to use is of obvious importance and its significance is discussed below. Most authors have used a concentration of 25 µg/mL — the same as used in studies of plasmid ecology in terrestrial environments.[20] In order to maximise the total counts obtained, most investigators have included some seawater salts in the media. However, the ionic components of seawater interact with and reduce the biological activity of oxytetracycline.[14] Norwegian investigators compensated for this seawater ionic effect by adding citrate ions to their media, the Americans increased the concentration of oxytetracycline and in Ireland concentration in ZV in sea water was considered low and no compensations were made. There is clearly a problem in determining the actual concentrations of biologically active oxytetracycline in these various media. Sandaa et al.[18] suggest that 25 µg/mL in TSCA has biological activity equivalent to 5 µg/mL. In a recent comparison of the biological activity of oxytetracycline in TSCA and ZV, we have shown that the biological activity is not only a function of the medium but also of the test organism. It is therefore impossible to define the biological activity of oxytetracycline in any of these media with respect to an unknown organism isolated from a marine sediment.

In summary, the differential plate count methods used to determine the frequency of resistance in the microflora of marine sediments have major defects. They examine a very small and variable fraction of the viable flora and the activity of oxytetracycline to which they select resistance is unknown. It is far from clear that the data produced by different groups using different methods on samples of different environments are in any way comparable. On the more optimistic side it is possible to argue that the changes detected over time by the application of one method may be more meaningful. It is interesting that studies in our laboratory where TSCA and ZV media were used on the same samples generated different total counts and frequencies of resistance, but the pattern of changes over time were similar.

The causal role of oxytetracycline

The majority, but not all, of the studies of under-cage sediments have reported elevated frequencies of resistance to oxytetracycline fol-

Table 1. A general classification of mechanisms by which environmental bacteria may attain the ability to form colonies on media containing antimicrobial agents.

Group	Major Properties
Innate	Bacteria are structurally sensitive. Can be selected by any change in the environment.
Non-specific	Frequently membrane mediated. Multiply resistant and can be selected by a wide variety of inhibitory agents. Mechanism may be genetic or phenotypic. Variants may be transient or persistent in the environment.
Specific	Genetically encoded mechanism and phenotype is persistent. May be encoded on chromosomes or plasmids. If plasmid encoded, may be transferrable. Selected by agent itself or by other agents to which the bacterium is resistant.

lowing periods of therapy. In many cases the interpretation of these observations is limited by the lack of data collected on the background frequencies of resistance to be expected in unpolluted sediments.[6,21] Smith et al.[20] following the initial observation of Samuelsen et al.[17] noted there is little evidence of correlation between the frequencies of resistance and the concentrations of oxytetracycline that have been reported. Two factors may have contributed to this.

Firstly, the biological activity of oxytetracycline in marine sediments cannot be estimated by the HPLC techniques that have been used in the majority of studies. The concentrations of divalent ions in seawater are known to dramatically increase the minimum inhibitory concentration (MIC) values of oxytetracycline activity.[14] Sediments themselves also increase MIC's.[16,24] Recent experiments in our laboratory have suggested that these two factors act synergistically so that the resultant bioactivity is very severely reduced. This increase in MIC's must be interpreted with caution. The frequency of resistant forms in a growing population of microorganisms may be influenced by a concentration which retards, rather than inhibits, the growth of sensitive cells. Thus, as has been shown in chemostat studies,[12] concentrations well below the MIC may have an effect on resistance frequencies.

The second set of reasons that may underlie this lack of correlation are related to the nature of oxytetracycline resistance itself and to the differential plating methods used to detect resistant frequencies. Table 1 outlines the major types of mechanisms that might underlie the ability of an organism to grow on agar media containing oxytetracycline. Some organisms are resistant to oxytetracycline because they possess a gene specifically encoding this property. Others may be innately resistant. This property has been attributed, for example, to *Pseudomonas aeruginosa*.[11] Thus, changes in the species distribution colonising an environment might produce an increase in resistance frequency. This might explain our unpublished observation that harrowing an under-cage sediment can result in a four-fold increase in resistance frequency in the absence of oxytetracycline. A third group of organisms may form colonies in the presence of oxytetracycline because they possess non-specific mechanisms that reduce their sensitivity to a number of inhibitory agents. It is probable that these non-specific mechanisms may involve low level resistance achieved by alterations in membrane function. Importantly for the arguments presented here, these mechanisms have not been associated with plasmids and therefore there is no evidence that they are transferable. To the extent that they resemble the persistence mecha-

The therapeutic use of oxytetracycline in the Norwegian farms may, therefore, have had no connection to the presence and persistence of these bacteria in the sediments. In these farms the resistance frequencies may be more related to poor feed administration methods than to any therapies employed.

nisms discussed by Bryan,[1] it is possible that the maintenance, in a population, of strains with nonspecific resistance may be dependent on the continued presence of a selective pressure. Confusingly, the presence of such "persister" cells may be transitory. Recent work has suggested that strains possessing nonspecific resistance mechanisms, selected by factors other than the presence of oxytetracycline, may have played a significant role in the elevated frequencies detected under fish cages. Kapetanaki et al.[7] have demonstrated that in the presence of fish feed, marine sediments and sea water, but in the absence of oxytetracycline, frequencies of oxytetracycline resistance will rise from approximately 1% to 35% as anaerobic decomposition develops. Shirley Vaughan, in our laboratory, has demonstrated high frequencies (up to 40%) of resistance to oxytetracycline in areas of a fresh water farm effluent system subject to feed accummulation. This farm had not used oxytetracycline for three years prior to the investigation.

The results of studies on the frequency of oxytetracycline resistance under fish cages can be broadly divided into two groups. One group working in Norway, reported high levels of resistance that persisted over a long time.[17,22] Samuelsen et al.[17] who detected no correlation between resistance frequencies and oxytetracycline concentration, recorded up to 50 cm of anaerobically decomposing feed under the cages they studied.

The other group[9,10,23] reported low frequencies and short persistence times. The sediments studied by Kerry et al.,[9] who reported that the resistance frequencies declined rapidly (half-life 26 days) and in parallel with the decline in oxytetracycline concentration,[2] were hypoxic shell sand with little feed accumulation. It is tempting to postulate that the strains detected as oxytetracycline resistant in the Norwegian studies were able to form colonies on media containing oxytetracycline because they possessed nonspecific mechanisms which provided them with resistance to the conditions generated in decomposing feed and simultaneously to oxytetracycline.

Risks to humans from oxytetracycline use on fish farms

The use of oxytetracycline in marine fish farms can represent a risk to the use of this agent in humans via two separate mechanisms. The first is via the direct selection of resistant variants of human pathogens in the environment of the farm. The size of this risk has been debated elsewhere[20] and it was concluded that it was probably very small. The second mechanism would be via the selection, in the farm environment, of bacteria possessing transferable resistance genes encoding specific resistance to oxytetracycline. If these genes were then transferred to human pathogens they might compromise therapy of human disease. Again a detailed analysis of the possibility has been presented.[20] The issue to be discussed here is the meaning of the data that has been generated in studies of resistance frequencies in under-cage sediments.

Table 1 illustrates that at least three groups of mechanisms can underlie the ability of marine sediment bacteria to grow on media containing oxytetracycline. Only those in the third group are of any significance. In theory, specific resistance genes can be encoded on either bacterial chromosomes or on plasmids. In practice, genes encoding specific resistance to tetracyclines are most frequently encoded on plasmids.[13] There is clear evidence that bacteria possessing plasmid mediated oxytetracycline resistance can be isolated from[18] and transfer their resistance in[19] marine sediments under fish farms. What has yet to be established is the extent to which bacteria of this type contribute to the resistant

flora that have been enumerated. The arguments presented above, however, suggest that it is entirely probable that members of the other two groups (Table 1) also contribute to the frequencies of resistance detected. These considerations strongly suggest that data generated by current differential plating methods have only limited relevance to arguments about potential risks to human medicine.

Conclusions

There is an urgent requirement for improvement in the methods used to investigate the impacts of the therapeutic use of oxytetracycline in marine fish farms. Current methods provide an inadequate understanding of the changes in the microflora of under-cage sediments. The results they have generated have failed to distinguish between the consequences of oxytetracycline use and those resultant on other changes in the sediment environment. The use of currently available data as a basis for considerations of the potential risks for human health is not justified.

The results fail to distinguish between the consequences of oxytetracycline use and those resultant from other changes in the sediment environment. The use of currently available data as a basis for considerations of the potential risks for human health is not justified.

The work and ideas presented in this paper are the product of inputs from many members and associates of the Fish Disease Group past and present. In alphabetical order these members are; Dave Cazabon, Rosie Coyne, Deirdre Gilroy, Maura Hiney, Maria Kapetanaki, Joe Kerry, Saoirse nicGabhainn, Gearóid O'Tuathaigh, Lisa Pursell, Sinéad Rudden, and Shirley Vaughan. The friendship and openness of Ole Bent Samuelsen also played a major part in the development of the concepts represented here.

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Sea lice and possible interactions with wild fishes

R. Cusack

Sea lice are crustacean ectoparasites of wild marine fishes. The two parasites of most concern to farmers of fish are *Lepeophtheirus salmonis* and *Caligus elongatus*. Mortality as a result of infestations of these parasites has been reported under both wild and culture circumstances. The primary pathology results from the parasite's feeding activity on the skin with the resulting excavation of mucus, epidermis and dermis, with final exposure of the underlying muscle. The ulcerative lesion created by the parasite is further extended by secondary colonization by necrotizing bacteria. Ulcerative lesions allow for the influx of salt ions into the circulatory system resulting in impaired osmoregulatory function which in turn results in poor performance or mortality. The skin lesions may also allow for the passage of other micro-organisms resulting in systemic infections. The relationship between the wild fish host and sea lice varies based on a series of factors that influence the host's ability to deal with the infection and the growth and reproductive rate of the parasite. It was as early as 1940 that wild fish were reported as being severely affected by sea lice in Nova Scotia. This paper will focus on many of the factors that influence the dynamics of sea lice infections.

Sea lice are a large group of crustacean ectoparasites from the family of Caligidae. There are over 300 species in two genera, *Caligus* and *Lepeophtheirus*.The caligids are easily distinguished microscopically from lepeophtheirids by the presence of paired lunules on the cranial aspect of the cephalothorax. Adults of these parasites measure 5 to 15 mm inclusive of elongated paired egg sacs.

Planktonic nauplii are released from the egg sacs of gravid females. These phototactic, weak swimmers moult twice into a copepodid form. Copepodids are strong swimmers and are chemotactic and highly phototactic. Finding a host, they attach to the skin by the use of a frontal filament. This stage measures about 1.2 mm in size and grows while still firmly attached to the host through a series of four moults (chalimus I to IV). Unattached pre-adults and adults freely move about the surface of the fish using muscularly controlled suctioning of the cephalothorax and walking legs. The life cycle takes about 6 weeks at 9°C.

Pathology resulting from infections can be quite severe. Lepeophtheirids feed on skin mucous, epithelial and other skin cells, as well as fish blood. Caligids are primarily mucous feeders. The breakdown of the integument barrier results in an influx of salt ions with resulting osmoregulatory dysfunction and possible death. Skin lesions are often exacerbated by secondary bacterial colonization. Bacterial action furthers wound development with resulting skin ulceration to the level of the muscle, cartilage, and bone. Systemic bacterial infections may also ensue. Furthermore, it is hypothesized that lice may act as vectors for other primary microbial pathogens of fish.

The interaction of sea lice with wild fish is well documented. In 1940, White[1] reported a sea lice epizootic in wild run Atlantic salmon from Nova Scotia. Templeman[2] found that Atlantic salmon off the coast of Newfoundland and Lab-

rador had a 70 to 80% prevalence of infection with a 1 to 8 level of intensity. Atlantic salmon off Greenland have been infected with up to 20 adult lice per fish with 100% prevalence. Infections of feral Atlantic salmon have also been reported from Ireland[3] and Norway.[4] Various Pacific salmon have lice, the most heavily infected species being pink and chum salmon.[5,6]

Several variables will affect sea lice infections on wild fish including water temperature, current speed and direction, host availability, predators, host condition, salinity, and migratory patterns of the fish.

Water temperature is one of the most significant variables in lice infections. Increased temperatures will shorten the louse's generation, time resulting in an increased number of copepodids to infect host fish. There is anecdotal evidence from the east coast of Canada that increases in lice intensity and prevalence occurs in years of warmer water temperatures. The cold weather associated with winter and spring correlates well with significantly lower lice numbers.

Although nauplii may swim, their distribution is determined to a large extent by water current, speed and direction. Stationary populations in low current water will therefore be more susceptible to infection. Newly released infective stages will be separated from their host in migrating fish or in areas of high current speeds.

In general, disease transmission is enhanced by the number and proximity of available hosts. Wild populations will likely be subject to increased levels of sea lice when stock numbers are highest and schools of fish are tight. In this type of scenario it should be expected that the level of infection will fluctuate depending on the size of the host population. Reciprocally, host numbers may be affected by the level of parasites.

Cleaner wrasse are successful predators of sea lice.[7] Salmonids also may consume lice. This natural delousing mechanism will have a role in the interaction of wild fish and sea lice. Natural and other pressures that interfere with the population dynamics of predator species will affect the success of the parasite and, in turn, growth and survival of wild salmon.

In farmed fish, poorly performing weak fish are more intensely parasitized relative to "healthy" members of the cohort. Nutritionally deprived or poorly performing wild fish will likely be more heavily parasitized. Johnson and Albright[8] used cortisol implants to mimic stressed fish and were able to show, conclusively, that healthy salmonids could mount a significant non-specific immune response to infections of *L. salmonis*. Alternately, those fish whose immune system was suppressed using cortisol lacked the response of the control fish.

The rate of infection in wild fish will be determined in part by water salinity. The lower optimal salinity level is about 16 ppt. During the freshwater phase of the anadromous fish's migration, the parasite's ability to reproduce will be inhibited and the parasites will dislodge.

Migratory patterns may play a role in determining the intensity of infections. In 1940 Smith[1] suggested that lice levels became high on wild fish because the migratory pattern was altered. In that year, the river's water level was very low and it was hypothesized this forced migrating salmon to spend an increased amount of time in the estuary waiting for water levels to rise. During that period, lice numbers rose to levels deleterious to the fish.

Sea lice do interact with wild fish. Mortalities due to sea lice infection may occur in the wild. The prevalence, intensity, and pathology of infections are likely related to water temperature, current speed and direction, host availability, predators, host condition, salinity, and host migration patterns.

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Stress, immune function and disease resistance in juvenile salmonids

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Several experiments were performed to determine the effects of various stressors on the non-specific immune system and disease resistance of juvenile salmonids. Phagocytosis and superoxide production of anterior kidney phagocytes, plasma cortisol, glucose and lysozyme concentrations were measured in chinook salmon (*Oncorhynchus tshawytscha*) subjected to confinement stress, as well as chinook salmon implanted with cortisol. Phagocytosis was measured in coho salmon (*O. kisutch*) injected with cortisol. In addition, the effects of daily stress on disease resistance was investigated in cutthroat trout (*O. clarki clarki*). Finally, the acute stress response was compared in three strains of coho salmon with predetermined differences in disease resistance. Confinement stress was found to have a significant effect on phagocyte function in chinook salmon. Phagocytosis decreased after three days while superoxide production increased. Injection of the stress hormone cortisol was found to significantly decrease phagocytosis in coho salmon. In contrast, cortisol implantation significantly increased phagocytosis in chinook salmon. The increase in plasma cortisol and glucose concentrations following handling did not correlate to differences in disease resistance in three strains of coho salmon. Cutthroat trout stressed daily were found to have lower mortality following the disease challenge. These results indicate that the relationship between stress, immune function, and disease resistance is complex, and requires the measurement of as many aspects of immune function as possible.

Introduction

The effect of stress on fish is valuable information in managing fish populations, both in aquaculture and in the wild. Stress in aquaculture can result from crowding or handling, poor water quality and social interactions. In the wild, potential stressors include contaminants, poor water quality, changes in temperature, migration and social interactions. The effects of stress on the physiology of fish are well documented.[2] Although the stress response is adaptive, there are detrimental effects of severe or chronic stress. Of these, the decrease in immune function and disease resistance is one of the most serious. Several studies have demonstrated that stress can cause changes in immune function and decrease disease resistance.[3-7] Others have shown that the stress hormone cortisol can suppress immune function.[4,8] From such data, the conclusion is often drawn that immunosuppression and decreased disease resistance is a general consequence of stress and elevated plasma cortisol concentrations. However, this may be an oversimplification as it is unlikely that all stressors result in the fish becoming more susceptible to disease.

There are many techniques available for studying the immune system in fish.[9,10] Assays of non-specific immune function are very relevant to fish health, because non-specific immunity represents one of the first lines of defense

against invading microorganisms. In addition non-specific immunity is thought to be more important than specific immunity at low temperatures and during the early life stages.[11,12] Phagocytes play a complex role in the immune system. They include such cells as monocytes, macrophages, and neutrophils, and are involved in the non-specific immune system through phagocytosis (uptake), killing of microorganisms (superoxide production), and lysozyme production (a bacteriolytic enzyme). Phagocytes also play a role in the specific immune system through antigen presentation and cytokine production. Factors affecting phagocyte function can therefore have a serious impact on immune competence.

This paper describes a series of experiments examining the effects of stress and the stress hormone cortisol on non-specific immune function and disease resistance. In the first experiment, the effects of confinement stress on three aspects of non-specific immune function — phagocytosis, superoxide production by anterior kidney phagocytes, and plasma lysozyme concentrations — were measured in chinook salmon (*Oncorhynchus tshawytscha*) and compared to plasma cortisol and glucose concentrations. The effects of the stress hormone cortisol were studied using cortisol injection to simulate acute stress in coho salmon (*O. kisutch*). Cortisol implantation was used to simulate chronic stress in chinook salmon. The stress response was measured in three strains of coho salmon and compared to differences in disease resistance found previously by Balfry and Iwama.[13] Disease resistance was also studied in cutthroat trout (*O. clarki clarki*) stressed daily for 9 weeks.

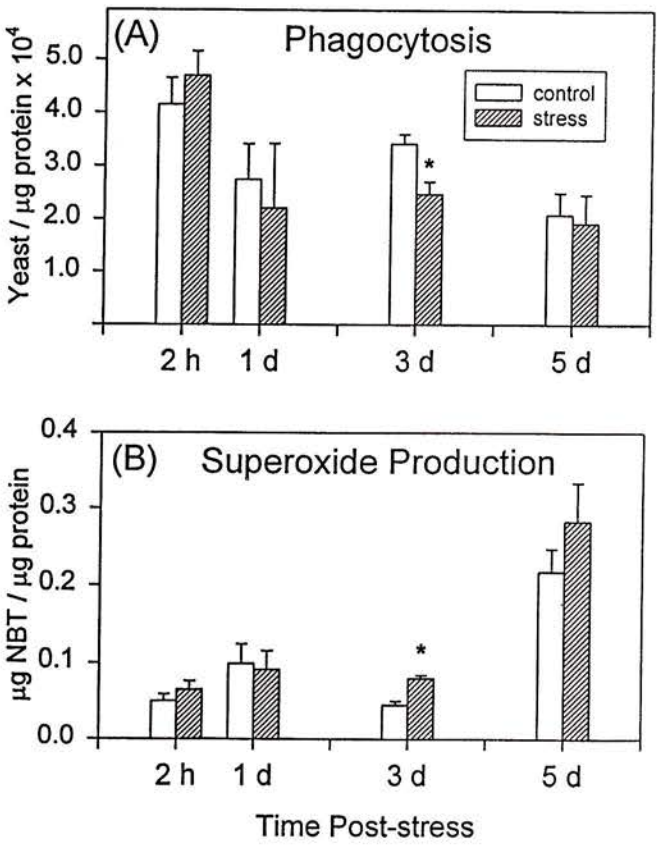

Figure 1. Effects of confinement stress (5 fish in 10 L of water in a 25-L bucket with aeration) on (A) phagocytosis and (B) superoxide production (NBT reduction) of adherent phagocytes from the anterior kidney of juvenile chinook salmon, *Oncorhynchus tshawytscha*, over time (n=4). * Significantly different from control at $p < 0.05$).

Materials and methods

Phagocyte Collection

Fish were killed with an overdose of MS 222 (tricaine methanesulphonate) and the anterior kidney was aseptically dissected out and placed in 5-mL L-15 tissue culture media (Leibovitz, Gibco/BRL) containing 10 units/mL heparin and 100 units penicillin–100 µg streptomycin/mL on ice. A cell suspension was prepared by teasing the tissue through 80 µm nylon mesh. The cell suspension was then layered onto a 34%/51% discontinuous percoll gradient and centrifuged for 20 min at 400 x g.[14] The

interface layer was collected and washed once in L-15 then resuspended in L-15 containing 0.1% fetal bovine serum.[14] One million cells were then seeded into microplate wells and allowed to adhere for 30 min at 37°C after which time the non-adherent cells were washed away.

Assays of Phagocyte Function

Microplates were divided into three sections for the determination of phagocytosis, superoxide production, and protein of adherent phagocytes for each fish. Duplicate or triplicate wells were measured for all three assays. Phagocytosis was determined by a microplate adaptation of a method described by Seeley *et al.*[15] Phagocytes were incubated with yeast (prestained with congo red) for 2 h. Unphagocytized yeast were then washed away, the phagocytes were lysed by overnight incubation with trypsin, and the red colour was measured at 525 nm with a microplate reader against trypsin blanks and standards. Superoxide production was measured by the reduction of NBT (nitro blue tetrazolium) and the resulting turquoise blue colour was read at 620 nm with standards using a microplate reader.[14] The protein content of the adherent phagocytes was determined using a BCA (bicinchininic acid) protein assay[16] read at 550 nm. The results of the phagocytosis and NBT assays were corrected for the number of phagocytes present by dividing by the amount of protein so that results were expressed per µg of protein.

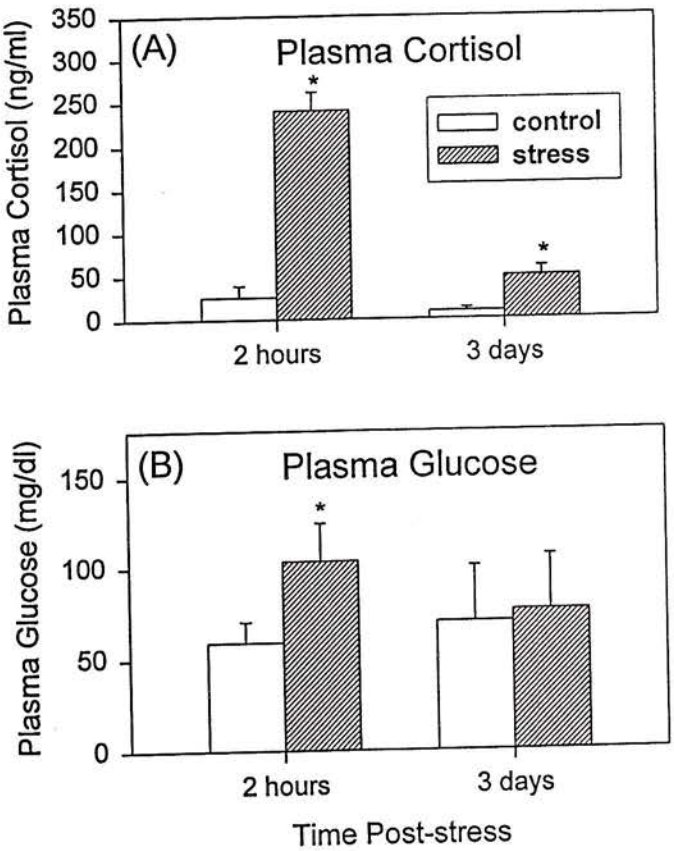

Figure 2. Effects of confinement stress (5 fish in 10 L of water in a 25-L bucket with aeration) on (A) plasma cortisol and (B) plasma glucose concentration in juvenile chinook salmon, *Oncorhynchus tshawytscha*, over time (n=4). * Significantly different from control at $p < 0.05$.

Blood Sampling

Blood was taken from the caudal vessels with a heparinized syringe immediately after the fish were killed with an overdose of MS 222. The blood was centrifuged immediately and the plasma stored at -50°C. Plasma cortisol concentration was determined with a radioimmune assay (Coat-a-count, Diagnostic Products Corp., Los Angeles), and plasma glucose concentration was determined with a microplate assay using the Trinder method (Sigma Chemical Co.). Plasma lysozyme concentration was measured using the lysoplate method.[17,18]

Confinement Stress

Juvenile chinook salmon (average 30 g) were maintained in dechlorinated Vancouver city water and fed a commercial salmon diet 3 to 4

times per week. Fish were transferred to 25-L buckets with aeration and 4 fish were sampled after 2 hours, 1, 3, and 5 days to measure phagocyte function, plasma cortisol, glucose, and lysozyme concentration. Control fish were kept in 170-L tanks.

Cortisol Injection

Juvenile coho salmon (average 22 g) were maintained in Cultus Lake water and fed a commercial salmon diet 3 to 4 times per week. Fish were injected with Prednisolone (a cortisol analog, 20 µg/g fish weight into the dorsal sinus) or saline (controls) and kept in 75-L aquariums. Four fish from each group were sampled after 2 hours, and 2, 4, 7, and 14 days to measure phagocytosis. Isolated phagocytes were incubated in chamber slides with yeast for 2 h after which nonadherent cells and unphagocytized yeast were washed away. The slides were dried, stained with Diff Quik, and the percentage of phagocytes that contained yeast cells were counted under a microscope.

Cortisol Implantation

Juvenile chinook salmon (average 30 g) were maintained in dechlorinated Vancouver city water and fed a commercial salmon diet 3 to 4 times per week. Cortisol (hydrocortisone) was dissolved in a mixture of 50% coconut oil and 50% vegetable oil, at two concentrations, and injected into the peritoneal cavity to give final doses of 50 and 100 µg/g fish weight.[19] Control fish were injected with implants without cortisol. Fish were kept in 70-L tanks and 4 fish per treatment were sampled after 1, 2, 3, 5, and 7 days to measure phagocyte function and plasma cortisol, glucose, and lysozyme concentrations.

Stress Responses of Coho Strains

Three strains of coho salmon with predetermined differences in disease resistance[13] were compared for differences in their stress response. The strains, Quinsam River, Kitimat River, and Robertson Creek (average 80 g), were raised communally in dechlorinated Vancouver city water on a commercial salmon diet. Eight fish per strain were sampled before a 30-second net stress, and then at 2 and 4 hours post-stress. Plasma concentrations of cortisol, glucose, and lysozyme were measured.

Daily Stress and Disease Resistance

Juvenile sea run cutthroat trout (average 50 g) were raised from eggs in dechlorinated Vancouver city water on a commercial salmon diet. Two 170-L tanks of cutthroat trout were stressed for 2 minutes daily for 9 weeks by chasing them with a dip net. Two tanks of control fish were left undisturbed. At the end of 8 weeks, the four tanks with 30 fish per tank were submitted to a disease challenge by immersion with *Vibrio anguillarum* in 4-L peptone saline aerated and warmed to 15°C. The resulting mortalities were recorded for the next 5 weeks. Mortalities that occurred within 48 hours after the disease challenge were defined as handling mortalities,

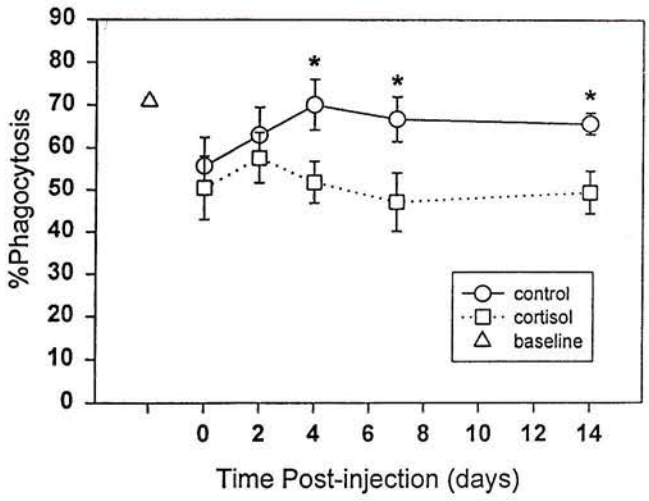

Figure 3. Effect of a single cortisol injection (prednisolone 20 µg/g) in the dorsal sinus of juvenile coho salmon, *Oncorhynchus kitsuch,* on percent phagocytosis of glass adherent phagocytes isolated from the anterior kidney over time (n=4). * Significantly different from control at $p < 0.05$.

while those occurring later were defined as mortalities due to vibriosis and were confirmed by culturing the pathogen.

Statistical Analysis

For the confinement stress experiment, Student's t-tests were used to compare means for each day. For the cortisol injection experiment, two way analysis of variance (ANOVA) was used on arcsin square root transformed proportion data and Student-Newman-Keuls tests were used to determine which groups were different. In the cortisol implantation and coho strain comparison, a two way ANOVA was used to compare groups and Student-Newmann-Kuels tests were used to determine which groups were different. Mortality data were compared in the cutthroat daily stress experiment using chi-squared tests. Significance level for all experiments was $p < 0.05$ and all data were presented as means ± standard errors.

Results

Confinement stress resulted in no difference in phagocytosis or superoxide production after 2 hours, 1 day, or 5 days, but there was a significant decrease in phagocytosis (Fig. 1A) and a significant increase in superoxide production at 3 days (Fig. 1B). Plasma lysozyme concentrations in confinement stressed fish were not significantly different from the controls (data not presented). Plasma cortisol concentrations were significantly higher than controls in confinement stressed chinook both after 2 hours and after 3 days (Fig. 2A), while plasma concentrations of glucose were only higher than controls after 2 hours (Fig. 2B).

Initial suppression of phagocytic activity was seen both in the cortisol and saline injected fish on days 0 and 2. However by day 4 saline injected coho had returned to baseline while cortisol injected fish showed significantly lower phagocytic activity on days 4, 7, and 14 (Fig. 3).

Two way analysis of variance showed a significant effect of both time and dose in the cortisol implantation experiment. Overall, cortisol implanted fish showed significantly higher phagocytosis than sham injected fish. However there was no difference between the two doses, or on individual days (Fig. 4A). Superoxide production was not significantly different in cortisol implanted fish than in sham implanted fish (Fig. 4B). Plasma lysozyme concentrations of cortisol implanted fish were not significantly different from sham im-

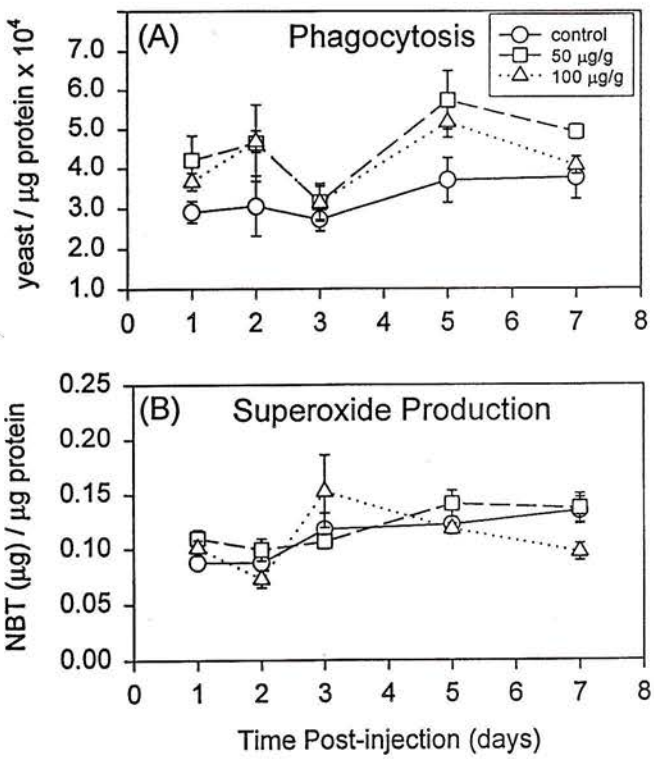

Figure 4. Effects of two doses of cortisol implants (50 and 100 µg/g) and sham implants on (A) phagocytosis and (B) superoxide production of adherent anterior kidney phagocytes isolated from juvenile chinook salmon, *Oncorhynchus tshawytscha* (n=4).

planted fish (data not presented). Plasma cortisol concentrations remained elevated over controls in the high physiological stress range for the duration of the experiment for both doses (Fig. 5A). Plasma glucose was higher in cortisol implanted fish than sham injected fish overall, however there was no difference between the two doses, or on individual days (Fig. 5B).

There were no strain differences in plasma cortisol concentration pre-stress or 4 hours post-stress, however the Kitimat coho showed a much higher increase in plasma cortisol concentration than the more disease resistant Robertson Creek coho and the less disease resistant Quinsam coho[13] at 2 h after stress (Fig. 6A). There were no strain differences in plasma glucose concentrations (Fig. 6B) or plasma lysozyme concentrations (data not presented).

The daily stressed cutthroat trout showed significantly higher survival in the *Vibrio anguillarum* challenge. Mortalities attributed to the handling and temperature effects of the challenge procedure were significantly lower in the stressed group (Fig. 7).

Discussion

The results presented here indicate that stress and the resulting increase in plasma cortisol concentration can have both suppressive and stimulatory effects on the immune system. Although confinement stress decreased phagocytosis after 3 d, superoxide production was increased at the same time. This may indicate that while fewer phagocytes were actively phagocytizing microorganisms, the killing activity of the active phagocytes was enhanced to compensate.

Cortisol appeared to have the opposite effect on phagocytosis when injected into coho salmon (suppression) than when implanted into chinook salmon (stimulation). There are many possible reasons for this observed difference including: the methods used to measure phagocytosis; the dose, method of administering, and type of cortisol (prednisolone acetate vs hydrocortisone); and species related differences. The two phagocytosis assays used in this study actually measure phagocytosis slightly differently. The slide assay of phagocytosis measures the percentage of phagocytes that are actively engulfing yeast cells (the number of yeast per cell can also be measured) while the microplate assay measures the total amount of yeast cells engulfed by a population of phagocytes, but does not measure the proportion of

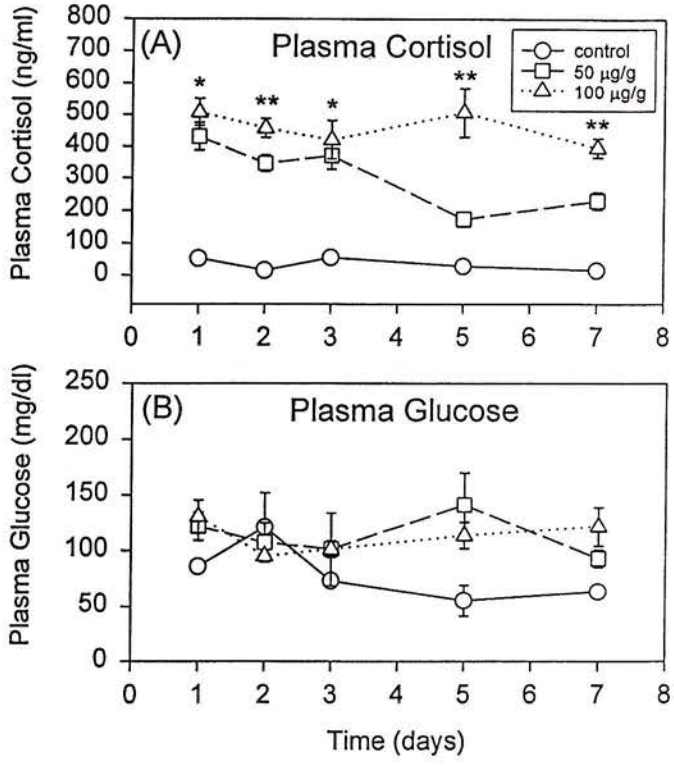

Figure 5. Effects of two doses of cortisol implants (50 and 100 µg/g) on (A) plasma cortisol and (B) glucose concentrations in juvenile chinook salmon, *Oncorhynchus tshawytscha* (n=4). * Both doses significantly different from control, ** both doses significantly different from control and from each other at p<0.05.

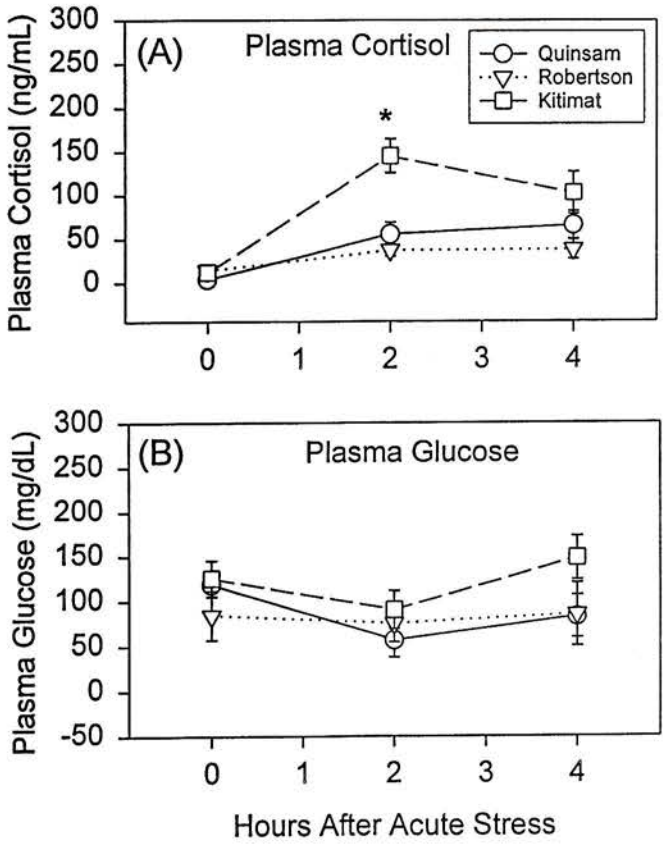

Figure 6. Effects of a 30 second handling stress on plasma cortisol and glucose concentrations in three strains of coho salmon, *Oncorhynchus kitsuch* (n=8). * Significant strain difference at p<0.05.

phagocytes that have engulfed yeast cells or the number of yeast cells engulfed per phagocyte. It is possible that although fewer phagocytes are actively engulfing yeast cells, they are engulfing more yeast per phagocyte so that the overall number of yeast engulfed is higher. These results demonstrate the importance of choosing the appropriate method of measuring phagocyte function.

Since a disease challenge involves both a handling and a confinement stress, any differences in the stress response may affect the results. The three strains of coho salmon used in this experiment have been shown to have differences in disease resistance.[13] These differences did not correlate with changes in plasma cortisol and glucose concentrations following a 30 sec netting stress, indicating differences in the stress response are probably not the most important factor affecting the differences in disease resistance among the three strains.

The results from the cutthroat daily stress experiment indicate that daily stress may not have negative effects on disease resistance. The fish that had been stressed daily demonstrated higher survival following a disease challenge than unstressed fish. Although phagocyte function was not measured in these fish, this type of stressor may have caused a stimulation of immune function similar to the increase in superoxide production observed in the confinement stressed fish and the increase in phagocytosis observed in the cortisol implanted fish. Acclimation may also have played an important role in this experiment. The fish that had been disturbed daily may have acclimated to the regular disturbance so that the handling and confinement of the disease challenge was less stressful than for the fish that had been left undisturbed for 9 wk. This disease challenge was more stressful than most since the water used was 10°C higher than the water in which they were maintained.

The results presented here show that the relationship between stress, immune function, and disease resistance is not simple. Decreases in some aspects of immune function, such as phagocytosis, may be compensated for by increases in other aspects, such as superoxide production, and different conclusions may be reached depending on what is measured. The nature, severity, and duration of stressors may have completely different effects on disease resistance (e.g., daily stressed cutthroat trout showing increased disease resistance compared to the decreased disease resistance due to stress

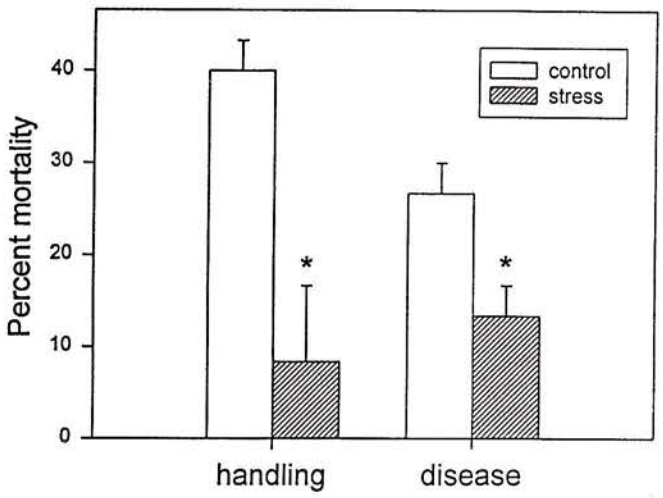

Figure 7. Effect of 9 weeks of stress (daily disturbance) on mortality following an immersion challenge with *Vibrio anguillarum* in aerated peptone saline at 15°C. Handling mortalities were those that occurred within 48 hours after the disease challenge and disease mortalities were confirmed as vibriosis by culture. * Significant at $p < 0.05$.

found by other authors).[3] These results demonstrate the importance of measuring as many aspects of immune function as possible. Caution should be taken when extrapolating results of a single assay of immune function to immune competence and subsequent disease resistance.

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Salmon farming in British Columbia — regional economic impacts

Greg D'Avignon

Speech given to open the session on Aquaculture Development

It is always difficult being the first speaker after lunch — many times after a large meal I have struggled to stay awake and listen to a speaker try in vain to hold my attention. You are probably thinking from the size of me that I have some experience with this post-meal attention theory. Well, you are right. Many times after a large meal my wife has asked, "Greg, are you paying attention to me?" Although I can't invoke marital privilege on you today, I do promise to provide you with some compelling information on how our industry—specifically salmon farming—in British Columbia is providing the families of coastal communities with the opportunity for secure year-round employment. In addition, I will touch on the potential we could have if governments support what I believe is the most exciting environmentally sustainable industry in our country today.

But first some background. Many of you know the salmon farming industry in British Columbia has grown from a $1 million business in 1980 to over a $160 million, 20,000 tonne business today. We export 85% of that production, mainly to the United States and Japan, which brings "new money" into the provincial economy. Because of the growth and success of the industry, salmon is now British Columbia's largest agricultural export product — larger than fruit, feed, beverages, animals, vegetables, grains, meat, flowers and dairy products.

We are a year-round producer of high quality fresh product that accounts for 6% of the world's farmed salmon production. The prospects for growth are excellent as world demand for seafood continues to climb, driven by increased population and changing consumer trends toward healthy, low-fat, fresh protein sources.

In the United States, annual per capita salmon consumption just topped one pound per person according to a recent survey. At the very time demand is surging, conservation of stocks — not consumer demand — determines the supply of wild salmon and seafood available.

Today, one in every three salmon consumed is farmed, a figure that will increase because of the concerns and pressures on wild stocks and increased demand from more people eating salmon and people eating more salmon.

But what does all this mean for us and the economies of coastal communities such as Campbell River, Tofino, Port Hardy, Courtney and Port McNeil? It means economic diversification, new business starts, business growth, increases in retail sales, new community facilities and, most importantly, it means jobs — skilled jobs, secure year-round employment, career potential and self esteem. It also means additional jobs, when employment created by new business start-ups and expansion needed to meet the demands of the industry are considered. Jobs in transportation, processing, retail, and manufacturing. Jobs and businesses that diversify an economy.

In 1993, salmon farming created over 2,000 person-years of employment in British Columbia with salaries, wages and benefits totaling $67 million dollars — 92% of those jobs were in communities outside greater Vancouver and Victoria. In contrast, over half of all forest in-

dustry jobs are in Vancouver and over 40% of commercial fishing jobs are in the lower mainland.

If the industry can add just 10 farm sites per year for the next ten years, by the year 2005 an additional 2,530 people will be employed. That's the equivalent to the total population of Tofino and Ucluelet combined.

Salmon farming provides year-round jobs in communities that are experiencing a difficult economic transition as their traditional employers in the forestry, mining and commercial fishing sectors reduce their workforce providing less security and fewer opportunities.Those industries are still active and are great contributors to the economy they just aren't providing as many people with the same chance to provide for their families as they once did.

In Tofino, salmon farming currently supports 14% of the work force. On average, each salmon farm produces 25.3 direct and indirect year-round jobs. The salmon farming industry in British Columbia just received approval on paper for its first new licenses in almost three years. If three of these were given to companies in the Tofino area, there would be a 12 per cent increase in the labor force. Unemployment in the Tofino/Clayoquot region is at 11.6% — you do the math.

To put it in perspective: salmon farming in the Tofino/Clayoquot area occupies about 0.02% of the total surface area of the water in the Sound, but produces close to two hundred jobs and generates over $40 million dollars.Those jobs make a difference to the families in our coastal communities.

I could go on about multipliers of 1.2 and 1.6 and inter-regional feedback effects, but put simply, our industry if given the opportunity can create wealth and year-round skilled jobs. It's doing it now! Recently I received word that North Island College through the support of government has been given approval to initiate a *Salmon Farm Production Skills Certificate Program* aimed at better equipping the work force to meet the increasingly technical demands of their job. The College, along with industry and the First Nations, will work to develop the program to ensure that it is relevant to the needs of industry.

It is but one indication of our commitment to providing the industry and our people with the skills necessary to take advantage of global opportunities. It is also speaks to the tangible ways government can support growth of our industries and I commend them on this initiative.

We need to do more as an industry to educate the public on our little secret, to ensure technology and scientific research is focused on enhancing our production capabilities. To work as partners with governments to allow them to embrace and promote our business. And perhaps most importantly, we have to do this by being responsible stewards of the environment, ensuring that we are truly sustainable.

I look forward to the future of our industry and the potential it holds for coastal communities and their economies, but most importantly I look forward to the opportunity for families in small coastal communities to work, have a secure job, and contribute to the economy.

Greg D'Avignon is Executive Director of the B.C. Salmon Farmers Association, #506 – 1200 West Pender Street, Vancouver, B.C. V6E 2S9 (telephone 1-800-661-7256)

Farmed Atlantic salmon in the Pacific Northwest

Ted Needham

I am an ecorealist. And as a realist I believe that salmon farming is the best thing that has ever happened to wild salmon. It has changed world salmon markets out of all recognition and is forcing rethinking on how wild salmon should be used and conserved. There are now as many pen–reared salmon harvested in the world as there are wild salmon captured in Alaska.

Salmon farming is the best thing that has ever happened to wild salmon. In Europe the Atlantic salmon has been saved by commercial salmon farming.

Look what has happened in Japan — a nation which consumes about 1/3 of the world's salmon. According to the U.S. Fisheries economist Mark Herrmann,[2] future Japanese demand for wild salmon from Alaska and Canada could be confined to sockeye and chinook, with requirements for Alaskan and Canadian chum salmon dying out. Low cost pinks will come from the Russian Far East and wild coho will increasingly be replaced by farmed coho from Chile. Ultimately, fresh farmed Atlantics could substitute for much of the wild chinook just as farmed rainbow trout from Chile are substituting for wild sockeye.

This should be music to the ears of those wanting to save British Columbia's beleaguered Georgia Strait coho. Not only are wild coho being replaced by farmed coho from Chile, they have been edged out entirely from European markets.

I repeat, salmon farming is the best thing that has ever happened to the wild salmon. It may not be the best thing that has even happened to commercial fishermen, but we must not confuse the interests of those who use the resource with the best interests of the resource itself.

In no case in British Columbia has commercial aquaculture been associated with any adverse impacts on wild salmon. Take away commercial aquaculture and there will be more pressure to overharvest wild fish and nothing will have been solved. The real causes of salmon stock extinctions, depletions, and loss of biodiversity are:

- fishing;
- poaching;
- hydroelectric dam construction;
- logging impacts;
- habitat destruction;
- excessive enhancement releases;
- illegal high seas drift netting;
- El Niño and climate change;
- sewage and industrial pollution.

In Europe, the Atlantic salmon has been saved by commercial salmon farming. According to Andrew Barbour in his recent book on the Atlantic salmon[1], it is now possible for sport fishing interests to buy out high seas fisheries in

the Atlantic Ocean because farmed salmon have edged wild salmon almost entirely out of European markets. Abundant year–round supplies of fresh farmed fish have depressed prices for the seasonal wild product and made the high seas fisheries less valuable and therefore easier to terminate. Furthermore, coastal netting stations around Britain have been bought out and shut down by angling interests. As a result, 1995 returns of wild salmon to the great rivers of Scotland are reported to be at a 30-year high — environmentalists and sports fishermen are delighted.

Looked at from the point of view of the wild salmon, salmon farming has to be a good thing. Yet salmon farming appears to be a convenient scapegoat for those who feel impotent to tackle the real problems.

Salmon farming concerns

Salmon farming can interact with the environment in a number of ways:

- through waste products;
- through disease contracted from wild fish;
- through possible impacts of escaped fish.

The first two topics have been exhaustively researched and have generated a large scientific literature. Suffice it to say that compared with any other resource-based industry on this coast the waste products of aquaculture are temporary and benign. Furthermore farmed salmon are under considerable threat from disease in wild fish. In contrast nobody has demonstrated that wild fish in British Columbia are at any risk whatsoever from disease in farmed salmon. After all, every disease detected so far on salmon farms in British Columbia has its origin in B.C. In addition, wild salmon bear a far greater number of parasite species than farmed fish.

It is the third concern, the possible impact of escaped Atlantic salmon, that needs to be addressed. This topic gives rise to the most ill-informed comment. For example, when some farmed Atlantic salmon fry escaped into a fresh water lake on Vancouver Island in November 1994, the incident was likened to a form of industrial pollution by a past president of B.C.'s Steelhead Society. Yet the lake in question has no natural runs of Pacific salmon and relies on both the provincial and federal government's stocking efforts for its fish. This was a wonderful opportunity to determine once and for all whether escaped Atlantic salomon were a true threat. As it happens, only 13 fry have been captured in the lake so far this spring. Most of the Atlantics, far from competing effectively, seem to have ended up in the stomachs of cutthroat trout.

It is difficult to see how escaped, hatchery–reared Atlantic salmon are a form of industrial pollution, yet planted brown trout — a less desirable sporting fish and known predator — are regarded as a positive thing.

Atlantic salmon introductions to Britsh Columbia

Looking more closely at Atlantic salmon, it is easy to understand why the accidental stocking of a fresh water lake last November was such a failure. First, sea-run populations of Atlantic salmon have never been established outside their normal range in the northern Atlantic despite considerable effort in some 20 countries over many years. Pacific salmon introductions have been more successful — they have flourished in the Great Lakes and there are returning populations of coho, chinook, and possibly chum salmon in Chile; chinook salmon are established in the rivers of South Island, New Zealand. Clearly Pacific salmon are more robust and adaptable to new environments. Yet self sustaining lake populations of Atlantic salmon

are rare outside the North Atlantic region, probably existing only in New Zealand and the Argentine. Elsewhere, in places like Australia and the western United States, they have to be maintained with hatchery programs.

Make no mistake, the Atlantic salmon is an extremely desirable species for sport fishermen. This is why in British Columbia there have been some 200 attempts to create Atlantic salmon runs in over 50 rivers using imports of about 6 million eggs in the first 35 years of this century. Much of this effort was concentrated on the Cowichan River where there were 40 releases of eyed ova and fry. Like similar large scale attempts to introduce runs of Atlantic salmon in Washington State over the last 20 years, these stocking programs have been a complete failure.

To those of us who have worked with Atlantic salmon in Europe and eastern North America, this failure is not surprising. All attempts to re-establish Atlantic salmon within their native range are fraught with difficultly. Atlantic salmon require substantial hatchery programs to sustain the species in rivers where they were once abundant like the Thames in England and the Penobscot in Maine.

In 1949, the eminent Canadian government biologist Neave maintained that Atlantic salmon never became established in Vancouver Island's Cowichan River because they faced overwhelming competition from the many fish species in the river, in particular the steelhead.

It is important to understand that in southcoast English rivers like the Hampshire Avon, introduced rainbows and steelhead outcompete Atlantic salmon. They are major predators and are regarded by Atlantic salmon purists as undesirable pests of little sporting interest. In Scotland, this niche is occupied by the brown trout and efforts are made to remove the species from the upper reaches of major salmon rivers with electrofishing.

I am not surprised that the many introductions of the more aggressive brown trout have succeeded where similar introductions of the more highly regarded Atlantic salmon have failed. This is particularly true in British Columbia where, according to the Provincial Ministry of the Environment, there are now self-sustaining populations of brown trout in the Cowichan River. Surprisingly, the provincial government is now transplanting this exotic fish further afield, as far north as the Adam river on Vancouver Island. It is difficult to see how escaped. hatchery–reared Atlantics are a form of industrial pollution, yet planted brown trout, a less desirable sporting fish and known predator, is somehow regarded as a positive thing.

Let us see from our critics a reasoned analysis of the risks Atlantic salmon pose to our native biodiversity.

Risks of escaped farmed Atlantics

What are the chances of escaped farmed Atlantic salmon establishing self-sustaining breeding populations in British Columbia and displacing native stocks? All the scientific evidence points to Atlantic salmon being uncompetitive with the diverse range of species occupying British Columbia's rivers. The brown trout has a better chance — the Atlantic salmon, it appears, has none.

According to a CBC radio program broadcast from Vancouver on 2 May 1995, 64,000 Atlantic salmon escaped in B.C. in 1994, an increase over the 10,000 reported in 1993. Four fisheries biologists employed by the Ministry of the Environment swam over 37 streams in search of these fish during the 1994 spawning season. They found only two Atlantic salmon amongst the returning Pacific salmon.

I am not surprised. Farmed salmon feed on pellets and escaped Atlantic salmon caught in commercial nets are generally in a starved and emaciated condition. Atlantics grown in cages become accustomed to light and overhead movement. As such they are easy prey to the huge populations of harbour seals in British Columbia, just as salmon fry in fresh water are prey to cutthroat and steelhead trout.

Most important of all, the few Atlantic salmon that make it to fresh water will so as a purely random process rather than as a response to a

migratory urge driving them inexorably towards a particular river system. This is because nearly all the Atlantic salmon raised in British Columbia are imprinted to ground water hatchery supplies.

Once on the spawning beds, farmed salmon are known to perform less effectively than their wild counterparts. Attempts to spawn with species other than brown trout are likely to be rejected simply because behavior cues do not match. Artificial crosses between the genera *Salmo* and *Onchoryncus*, the Atlantic and Pacific species, do not appear to be viable.

Should farmed Atlantic salmon successfully spawn in British Columbia creeds, it is unlikely to be in numbers that could successfully displace Pacific species from the spawning redds. The resulting fry would be at the mercy of the more aggressive resident species and as likely as not would end up by being eaten.

Where do we go from here?

As an ecorealist I believe in cooperation rather than confrontation. As salmon farmers we owe it to ourselves and to the environment in which we work to minimize risk. We must continue to do all we can to prevent escapes. Every lost fish has cost us dearly. We are like dairy farmers who cannot afford to have their cows wander off into the forest to be consumed by wolves, cougars, and bears. As a responsible industry we are working hard and spending a lot of money to see if single sex Atlantic salmon are not only technically possible but economically viable.

On the other hand, our detractors owe it to us to state their case in clear scientific terms. We need to know why there are not similar concerns about the brown trout, another exotic import from Europe that unlike Atlantic salmon has proven fish–eating habits in fresh water.

Perhaps we should have a controlled release of Atlantic salmon on a system like the Keogh River on northern Vancouver Island where any fish that return could be trapped. This is an experiment that should take place.

Above all, let us have less parochialism. Not far from here, in Washington State, the authorities prefer farmers to grow Atlantic salmon because they are considered to be far less of a threat to endangered Pacific salmon stocks than farmed Pacific species.

Elsewhere in the world there is an increasing recognition that salmon farming has helped alleviate the plight of the wild salmon. Salmon farming is a truly sustainable industry. It has helped to save the wild Atlantic salmon in Europe. Some commentators want to see salmon farming in Alaska[2] to provide year–round supplies of product and much needed support to the failing wild salmon business. Just as cattle farming in North America saved the few remaining bison from being hunted to extinction, salmon farming will be seen to save the wild resource here in British Columbia also.

In Washington State, the authorities prefer farmers to grow Atlantic salmon because they are considered to be far less of a threat to endangered Pacific salmon stocks than farmed Pacific species.

References

1. Barbour A. 1992. *Atlantic salmon, and illustrated history.* Cannongate Press PLC, 14 Frederick St., Edinburgh EH2 2HB ISBN 0 86241 3729. 95 pp.
2. Herrmann M. 1994. *J. Aquat. Food Prod. Technol.* 3(3):5-21.

Dr. Ted Needham is Director of Aquaculture Operations, British Columbia Packers Limited, 128-2270 Cliffe Avenue, Courtenay, B.C. Canada V9N 2L4

Calendar

•**Aquatech 96**, 5-7 May 1996, Hotel Newfoundland, St. John's. Annual conference to foster interactions and collaborations among industry, business and government sectors. Information: Seabright Corporation Ltd., Spencer Hall Memorial University, St. John's, Newfoundland, Canada A1C 5S7 (tel 709 737 4527; fax 709 737 4029).

•**Open-Ocean Aquaculture,** 8-10 May 1996, Portland, Maine, USA. Topics: developments in cage design for high-energy environments; suitability of species; economic feasibility; regulatory and environmental considerations; lessons from existing offshore operations in Israel and Norway. Information: Rollie Barnaby, University of New Hampshire, 113 North Road, Brentwood, NH USA (tel 603 679-5616; fax 603 679-8070; e-mail rollie.barnaby@unh.edu)

•**Aquaculture Canada 96,** 2-5 June 1996, Holiday Inn, Byward Market, Ottawa, Canada. Sessions: Sea urchin culture and enhancement, Government-industry relations, Therapeutants, Bottlenecks in juvenile production, Federal Aquaculture Strategy Review, Regulatory issues, Human resource issues. Abstract deadline 1 April. Information: Aquaculture Association of Canada, Box 1987, St. Andrews, NB Canada EOG 2XO (tel 506 529-4766; fax 506 529-4609; e-mail AAC@WOLVES.STA. DFO.CA).

•**Atlantic Aquaculture Exposition, Conference and Fair,** 20-23 June 1996, St. Andrews, NB Canada. Theme: *Diversifying Our Future.* Industry sessions on 20 June will be divided by species group. Special feature will be a mid-day lunch featuring the various species under discussion. Peter Redmayne, editor of Seafood Leader, will be the guest speaker. Information: Dayle Chambers at telephone 506 529-4578. Atlantic Aquaculture Fair, P.O. Box 89, St. Andrews, NB Canada E0G 2X0

•**Fisch 96 & Seafood Europe,** the continent's biggest dedicated fish and seafood trade fair, 7-10 June 1996, Bremen, Germany. Information: Karin Sundmaker, MGH Bremen GmbH, Bischofsnadel 1-2, 28195 Bremen, Germany (tel +49 421 36305; fax +49 421 321485).

•**International Congress on the Biology of Fishes**, 14-18 July 1996, San Francisco State University, USA. Organized by the Physiology Section of the American Fisheries Society. Combines several meetings: GUTSHOP, Amazonian Fishes, High Performance Fish, Pacific Biotech, Smolt Workshop, Fish Larvae/Eggs, Anadromous & Catadromous Fish, Fish Stress) and more. Information: Don MacKinlay, DFO, 555 West Hastings Street, Vancouver BC Canada V6B 5G3 Canada (fax 604-666-3450).

•**Successes and Failures in Commercial Recirculating Aquaculture,** 19-21 July 1996, Roanoke, Virginia, USA. Topics: successes and failures of recirculating systems, fish health and welfare, economics and farm management, product quality and safety, waste management and by-product recovery, system design and management, business plans and farm management, shellfish production in recirculating aquaculture systems. Contact: Constance Meck, 110 Shenandoah Avenue NE, Roanoke, VA USA 24016 (tel 540 857-6055).

•**Second World Fisheries Congress,** 28 July–2 August 1996, Brisbane, Australia. Theme: Developing and sustaining World Fisheries Resources, the state of science and management. Hosted by the Australian Society for Fish Biology. Information: Second World Fisheries Congress, P.O. Box 1280, Milton, Queensland 4064, Australia [fax 617 369 1512].

•**International Astacology Association,** 11th Symposium, 11-16 August 1996, Lakehead University, Thunder Bay, Canada. Includes sessions on all aspects of crayfish science and field trips to crayfish habitats. Information contact: Dr. W. Momot, Dept. Biology, Lakehead University, 955 Oliver Road, Thunder Bay, Ontario P7B 5E1 Canada (tel 807 343-8277; fax 807 343 8023; e-mail Walter.Momot@lakeheadu.ca).

•**Coastal Zone Canada 96,** 12-17 August 1996, Université du Québec, Rimouski, Canada. Theme: *Integrated Management and Sustainable Development in Coastal Zones.* Papers and case study presentations are invited from national and international coastal zones stakeholders, community-based organizations, scientists and engineers, governments and primary resource users, industry and business. Information: Prof. Mohammed El-Sabh, Groupe de recherche en environnement côtier, Université du Québec, 310 allée des Ursulines, Rimouski, Québec, Canada G5L 3A1.

•**2nd International Fullfat Soya Conference,** 21-24 August, 1996, Budapest, Hungary. Organized by the American Soybean Association. Agenda: processing techniques, quality control, utilization in poultry, swine, dairy, aquaculture and human nutrition, practical applications in feed manufacturing and on-farm mixing. Information: American Soybean Association, Gattersburggase 18/2/3a, 1190 Vienna, Austria (tel (43-1) 369-8218; fax (43-1) 369-82184).

•**125th Annual Meeting of the American Fisheries Society**, 25-29 August 1996, Hyatt Regency Hotel, Dearborn, Michigan, USA. American Fisheries Society, 5410 Grosvenor Lane, Suite 110, Bethesda, MD 20814 USA.

•**International Conference on Aquaculture Development in Eastern Europe,** 1-5 September 1996, University of Budapest, Hungary. Information: EAS, Coupure Rechts 168, B-9000 Gent, Belgium (tel 32 9 223 77 22; fax 32 9 223 76 04).

•**British Trout Farming Conference,** 4-6 September 1996, Sparsholt College, England. Main focus is on the papers presented, but a small trade show is held as well. Information: Shaun Leonard, Department of Fish, Game and Wildlife Management, Sparsholt College, Winchester, Hampshire S021 2NF (fax 01962 776587).

•**5th Canadian Workshop on Harmful Marine Algae,** 11-13 September 1996, St. John's, Newfoundland. To promote exchange of new and unreported information and to plan for future research. Program includes oral and poster presentations, review of relevant work by different agencies, and workshop sessions, including one on harmful marine algae and aquaculture site management. No registration fee. Information: M.A. Paranjape, Ocean Ecology Division, DFO, Box 5667, St. John's, NF Canada A1C 5X1 (tel 709 772-6184; fax 709 772-3207; e-mail mparanjape@ nflorc.nwafc. nf.ca)

•**Aquaculture Nutrition and Feed Management Short Course,** 15-20 September 1996, Corpus Christi. Outline: Nutrition of warm and cold water species: shrimp, catfish, tilapia, redfish, salmon and trout; Feeds formulation; Feeding and management practices; Tours of research, hatchery, production and processing facilities. Contact: Ed Lusas, Food protein R&D Center; College Station, Texas USA 77843 (tel 409 845-2741; fax 409 845-2744).

•**Sea Fare International 96,** Las Vegas, 26-27 September 1996. Information: Sea Fare Expositions, Inc., 5305 Shilshole Ave. NW, Suite 200, Seattle, WA USA 98107 (tel 206 789-6506; fax 206 789-9193).

•**Marketing and Shipping Live Aquatic Animals and Plants, Industry Conference and Exposition,** 13-15 October 1996, Seattle, Washington USA. Aimed at individuals, companies and agencies involved in the growth, harvesting, processing, regulating and shipping of live aquatics. Oral and poster presentations and commercial displays of products and services. Information: Nor'Westerly Food Technology Services, 2743 56th Avenue SW, Seattle, WA USA (tel 206 938-0676; fax 206 933-7937; e-mail 103243.675@compuserve.com).

•**The Health of Coastal Ecosystems through Shellfish Restoration — An International Conference**, 20-23 November 1996, Crystal Sands Crowne Plaza Resort, Hilton Head Island, South Carolina. Themes: Remediation/Pollution Abatement; Habitat Restoration; and Stock Enhancement/Aquaculture. Program will consist of invited oral presentations and contributed posters. Information: Elaine Knight, S.C. Sea Grant Consortium, 287 Meeting Street, Charleston, SC (tel 803 727-6406; fax 803 727-2080; e-mail knightel@musc.edu).

•**Aquaculture Canada 97,** the 14th annual meeting of the Aquaculture Association of Canada, 10-13 June 1997, Radisson Hotel, Quebec City, Canada. Information: AAC, Box 1987, St. Andrews, NB Canada EOG 2XO (tel 506 529-4766; fax 506 529-4609).

Book Review

Cold-Water aquaculture in Atlantic Canada (2nd edition)

Edited by Andrew D. Boghen,

Published by The Canadian Institute for Research on Regional Development

The latest edition of this book is more than an informative tour of aquaculture on Canada's East Coast. Beyond its focus on the development of aquaculture in eastern Canada, it has the makings of a good text on aquaculture. In addition to a historical perspective of Canadian aquaculture, Dr. Boghen introduces this book with a description of aquaculture which makes it clear that aquaculture is a fisheries activity that has to perform within a particular set of social and economic strictures. Some of the paradigms he uses to introduce aquaculture should be standard teaching tools for any course introducing aquaculture to students or professionals.

I am often disappointed by the narrow view of aquaculture presented in many books. Frequently they offer the reader either an overview that lacks a generalizable structure upon which the reader can build with future readings or they delve into technical (usually biological) research in such detail that the breadth and complexity of aquaculture as a bio-socio-economic endeavor is completely overlooked. This book avoids both those pitfalls.

The bulk of this book is divided into two parts. The first half of the book examines the range of species under culture in eastern Canada. That spans from culture of the seaweed, Irish moss, through several species of bivalves, American lobster and on to the culture of salmonid species. There is an additional chapter on 13 additional species that are under investigation for their potential as aquaculture species in Canada. Chapters on individual species follow a common template including material on the biology of the species, cultivation methods, site selection and constraints on development. Many of these chapters are well thought out and include sections on economics and marketing. I particularly like the focus on site selection within each of these chapters. However, I am disappointed more mention is not made of the Canadian and international work done on quantitative methods of estimating growth potential or carrying capacity of various environments. Even so, I feel the point is made that siting is one of the earliest and most critical decisions to be made in starting an aquaculture business.

The really outstanding aspect of this book, however, occupies its last 278 pages. This is the first book I have come across to which I would give even a passable mark for its treatment of aquaculture as a socio-economic practice.

Interactions between aquaculture and the environment are topical these days. While discussion of this subject can easily occupy volumes, Chapter 11 is a very good and broad introduction to the area. The chapters on economics, the legal framework for aquaculture activities and conflict resolution give an excellent introduction to important socio-economic aspects that have major impacts on aquaculture operations everywhere.

In the past I have been frustrated and at times amused, by texts which purport to examine economic or operational aspects of aquaculture, yet which omit or gloss over the importance of marketing. Rod Harris' chapter on marketing gives a clear and structured overview of how marketing functions in business in general and in aquaculture in particular. He makes it clear that while promotion or merchandising may be an important part of that skill set, it is only a part of the marketing skills needed to guide an aquaculture business to long term success. By the end of the chapter it is clear why, in today's highly competitive marketplace, successful aquaculture relies on good marketing skills in addition to good technical know-how.

This book belongs in the library of aquaculture educators and business people with a desire to understand the dynamics and constraints acting on the development of aquaculture everywhere.

—Ed Black, BCMAFF, Victoria

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