ICES International Council for the Exploration of the Sea
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Theme Session Q

Interactions between Aquaculture and Wild Stocks: Comparative Experiences for Atlantic Cod and Atlantic Salmon

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The growing interest in gadoid culture in the North Atlantic has led to substantial increases in the production of farmed cod. Atlantic cod are present in sea cages in Norway, UK, Iceland, Canada and the U.S., and the potential exists for continued increases in cod production in each of these countries. On the other hand, Atlantic salmon have been reared in sea-cages for many years, and production of farmed salmon now exceeds the harvest of wild fish by more than 400 times. An ICES Theme Session on this topic is important as there is growing interest in fish culture as stocks of wild fish continue to decline, and there is potential for valuable transfer of knowledge between these two areas.

Interactions between wild and cultured Atlantic salmon have been well documented and there have been several dedicated symposia over the last two decades, but there has not previously been a scientific forum to address wild/cultured interactions for cod. This Theme Session therefore provided a valuable opportunity to share knowledge and experience between these fields. This is particularly timely, as the growth in cod farming is occurring as many wild cod stocks are undergoing serious declines and some are listed as threatened or endangered.

This successful Theme Session was comprised of 16 oral and 3 poster presentations with a brief summary of their findings and related comments summarized below.

Escape of farmed salmon into the wild can result in interbreeding and competition with wild salmon and can facilitate the spread of pathogens, thereby impacting wild populations negatively. Whole river experiments have documented evidence of an immediate depression in wild salmon population productivity, as well as a depression in fitness caused by interbreeding.

However, not all reports note severe negative effects. For Atlantic salmon, a molecular genetic study was conducted to assess the direct genetic impacts in a small river system in northwest Scotland containing a small wild stock. The study was based on an eclectic set of DNA sources and genetic data. The study found significant genetic differences between wild and farm salmon and that farm escapes appeared to contribute little to the genetic character of the current wild stock through interbreeding and introgression. However, some ecological interactions for food and space and of increased pathogen transfers cannot be ruled out.

In a Norwegian study on cod, release of tagged farmed and wild cod showed that wild fish are more resident than farmed after a release. Cod would spend two weeks around the cage site and then move off, wild fish tended to visit local

spawning areas more than farmed cod. Results differed between years such that escaped farmed cod would at times show attraction to a cod farm but in another year they tended to swim away. The potential to recapture escaped cod seems higher than for salmon. Recapture rates of escaped cod were 28-44% by fishermen in a fjord. Thus, attention may be given to develop recapture initiatives by fishermen shortly after the report of a cod escape.

Pacific salmon catches (much of it pink salmon) are of a record high, however landings in western Canada have declined dramatically. In the 1970s, Canada used to land 24% of all Pacific salmon but this has now declined to 1%. Production of farmed salmon increased as the wild declined and British Columbia is now the 4th largest area producing salmon in the world (80,000 tonnes). The value of farmed British Columbia salmon is more than the wild catch of Alaska. A major area of Atlantic salmon farming is the Brougthon archipelago and there exists good escapement of pink salmon swimming through this area. The record low sockeye salmon returns in the Fraser River have been perceived by some as related to salmon farms, in particular sea lice. After 5 years of research no strong evidence has been given to prove sea lice are a problem. However, more information on factors affecting early life history of salmon, and on sea lice ecology are needed.

Experiments have been conducted to assess the relative contribution of lice to mortality of juvenile pink salmon. Mortality only occurred at very high exposure levels (median 14.6 lice per g of fish to die). In samples of wild salmon, there is a reported decline of sea lice in the Brougthon archipelago from 2004 to 2008. Some of the decline may be related to the use of ivermectin as farmers are more vigil in their surveillance at farms to treat lice. More information is required to assess sub lethal effects of sea lice such as juvenile swimming speed and predator avoidance.

A Norwegian study showed that cod aquaculture overlaps with coastal cod stocks. Evidence shows that cod are ten times more likely to escape than salmon. Given this, there is a good possibility that escaped cod will encounter wild spawning fish. In laboratory experiments, it was reported that more male types (farmed and wild) courted farmed than wild females. Wild females rejected farmed males, whereas farmed females were more promiscuous. Using acoustic tags and automatic listening stations around a spawning shoal, it was shown that farmed males were not allowed to enter into the area where wild males existed, and this precluded the former from spawning opportunities with wild females. Farmed females were interacting more with wild males than expected by chance. In the event of an escape, it appears hydridization will occur primarily through farmed female and wild males.

In Canada, evidence exists for crosses between wild and farmed salmon. As farmed salmon do not do well at high river acidity, the act of introgression would lead to a reduction of the wild stock to cope with low pH. Adaptive variability among cod populations exists and it appears that growth rates are better for warm populations than cold, thus genetic variability exists among populations. Interbreeding would have a negative or nil effect on progeny performance. The degree of this is based on how frequent and how many spawning events actually occur compared to wild spawnings.

Evidence was given that more population structure exists for salmon than cod at neutral genetic markers. This may be expected as spawning site fidelity is

stronger for salmon than cod, given they return to natal rivers compared to spawning in shoals in the ocean. Farming results in selection for fast growth and late maturity, so interbreeding between escaped and wild fish will lead to genetic change.

In Norway, about 13,500 metric tonnes of cod were produced in 2008. The number of escaped cod ranged from 20,000 to 290,000 fish from 2004-2008. Using 9 microsatellites it was ascertained that escapees can be correctly genetically matched to net pens about 75% of the time. Broad genetic differentiation occurs among groups of cod grown in sea cages.

Using a genetic marker, Norwegian scientists noted that a significant fraction of yolk sac larvae were found originating from a cod net pen in the inner region of a fjord area (ranges from 10-20% up to 36%). Three years later, it was found that 8/283 fish survived to mature size and were caught by fishermen. The monitoring program is now expanding to collect better data on the fate of escaped cod embryos. In time, it is possible that offspring of escaped fish will be produced.

Photoperiod manipulation has often been used by fish farmers to control early puberty. Cod farmers have unsuccessfully halted sexual maturity, even when using 4 times the light intensity than used by salmon farmers. In some cases, extended daylength delayed spawning into the summer. In these cases, the embryos may be less suited to survive than those released by cod kept in cages under natural photoperiod. The end result is that cod farmers presently are having a difficult time to control sexual maturation with greater than 90% of fish in cages achieving puberty in a Canadian study. These fish thus represent a potential contributing source of gametes that if survival conditions are met could develop into mature individuals and interbreed with wild fish.

Triploidy has been successfully used to generate sterile fish, particularly females. This technique has been applied to both salmon and cod. Trials of triploid Atlantic salmon in Canada resulted in an overall yield of 91% compared to diploids and this was sufficiently poor to lead the abandonment of triploids by Canadian salmon farmers. However, the strain effects have never been properly evaluated. Consequently, research is recommended to ascertain whether triploidy could be used in a family breeding program to select elite families that perform well as triploids. Tasmania remains as the only location to use salmon triploids. Triploids are generally inferior with reduced tolerance to chronic stress and higher incidence of lower jaw deformities. Experience in Ireland showed that triploids could not handle lower water oxygen at time of treatment when water levels were reduced at slack tide.

Mating experiments of triploid and diploid farmed male Atlantic cod in Canada revealed they have the same capacity to spawn with farmed diploid females. Sperm motility patterns were similar among diploid and triploid males and this was reflected in equivalent potency in fertility trials. Consequently, if triploid male cod are raised and escape they may have the potential to spawn with wild cod. However, they would still need to outcompete wild males for access to wild females, plus their progeny would suffer from high mortality rates early in life (aneuploids).

Studies in Norway have shown that 16 species of fish were found aggregated around 4 cage sites. Saithe, cod and haddock are important. 2,000-40,000 saithe

were noted per cage, most of these within 10 m with the numbers dropping quickly as one moved away from the cage. Intentionally released, tagged saithe stayed around the cages at one site for 12 weeks, yet at another cage this pattern was not so obvious. Estimates showed that in a Norwegian fjord it is possible to have ~200,000 saithe move between cage sites in a single year. This can be accompanied by the spread of pathogens. Some of this could be minimized by more careful attention to feeding levels and reducing the amount of waste food.

A newly developed universal SNP chip (4,514 SNPs) is now available for Atlantic salmon. A set of 105 SNPs were identified as being highly diagnostic in identifying individual fish as of farm or wild origin, regardless of population or strain.

In a Danish led study using 98 gene-associated SNPs in populations of cod across the species distribution it was found that wild cod populations exhibit adaptive population divergence. Genome scan tests for selection revealed eight loci with very high support for a statistical model of local selection compared with a model of neutral population divergence. This finding may have a number of strong implications for future sustainable aquaculture management and conservation of adaptive genetic diversity with the species.

Closing remarks

In summary, Atlantic salmon and Atlantic cod are different species and there are different challenges connected to the impacts from aquaculture on wild stocks. For example, Atlantic cod will mature in net pens and release viable eggs to the environment without escaping from the rearing environment. For Atlantic salmon the aquaculture industry had already grown large, before research on effects on wild populations was initiated. Luckily, this is not the case for Atlantic cod, and for this species we can provide research based advice for management while the aquaculture production is still low.

There remain, however, major gaps in our understanding on how aquaculture interacts with wild populations, and continued persistence is needed in our research efforts to fill these gaps. It is recommended that an international meeting be planned in the near future for an update on new results and new fruitful discussions on this important topic.