Module : Introduction to Marine Biology

Assignment : Coursework – Essay in Mariculture

Title : The temperature’s role in salmon farming

Introduction

Within the last three decades, world’s aquaculture production has increased exponentially, contributing to what some refer to as the “blue revolution” (Lien, 2007). Mariculture, with a production of 36.1 million tonnes and a value of US$37.9 billion of sea products (FAO, 2012), accounts for about one-half of total aquaculture production by weight. Therefore, it is crucial to gain a deeper understanding regarding how the habitats of natural populations can be stimulated, changed for convenience of harvest, or enhanced to increase yields.

This paper is going to discuss the influence of the water temperature in salmon (*Salmonidae*) farming, how climate change is affecting the wild stock’s productivity and suggests that sex manipulation might be a valuable aspect to increase productivity cost-effectively (Figure 1.

Image credit: Patrick Pleul/DPA via ZUMA Press.

Figure 1. Salmon cage farming facilities in Norway’s fjords. Although, wild stocks of Atlantic salmon have been caught since ancient times, the ongrowing in sea water takes place today exclusively in cage systems.

Figure 2. Both Atlantic salmon (*Salmo salar*) and sockeye salmon (*Oncorhynchus nerka*) are in most cases anadromus (FAO, 2015); that is, they undergo migration from their natal freshwater river or lake out to the sea, they only return to their freshwater origins to breed. As the salmon begin their migration to spawn, they start to display some sexual dimorphic characteristics such as large humps and hooked jaws, they can go through radical colour changes, like the sockeye salmon.

Salmon farming briefly

Commercial salmon aquaculture and mariculture, unlike wild-capture fisheries, uses technology to minimize unpredictable natural factors in raising fish. Salmon farmers fertilize, incubate, and hatch eggs in a controlled hatchery environment. There the juvenile fish develop into smolts, which are ready to live in salt water (Figure 3.). In North America especially, trout and other cold water species are grown in raceway shallows, rectangular pools tilted to create stream like conditions (Weber, 1997). From this point onward we are talking about mariculture, due to the smolts are moved to net pens or cages suspended in coastal marine waters, where they grow to market size and where are harvested before they reaching sexual maturity. Salmon farmers attempt to shorten production times by using a variety of technologies and husbandry techniques. Then the photoperiod and water temperature in the hatchery is manipulated, feeding diets are formulated for specific life stages and their breeding is selective to reproduce desired performance characteristics.

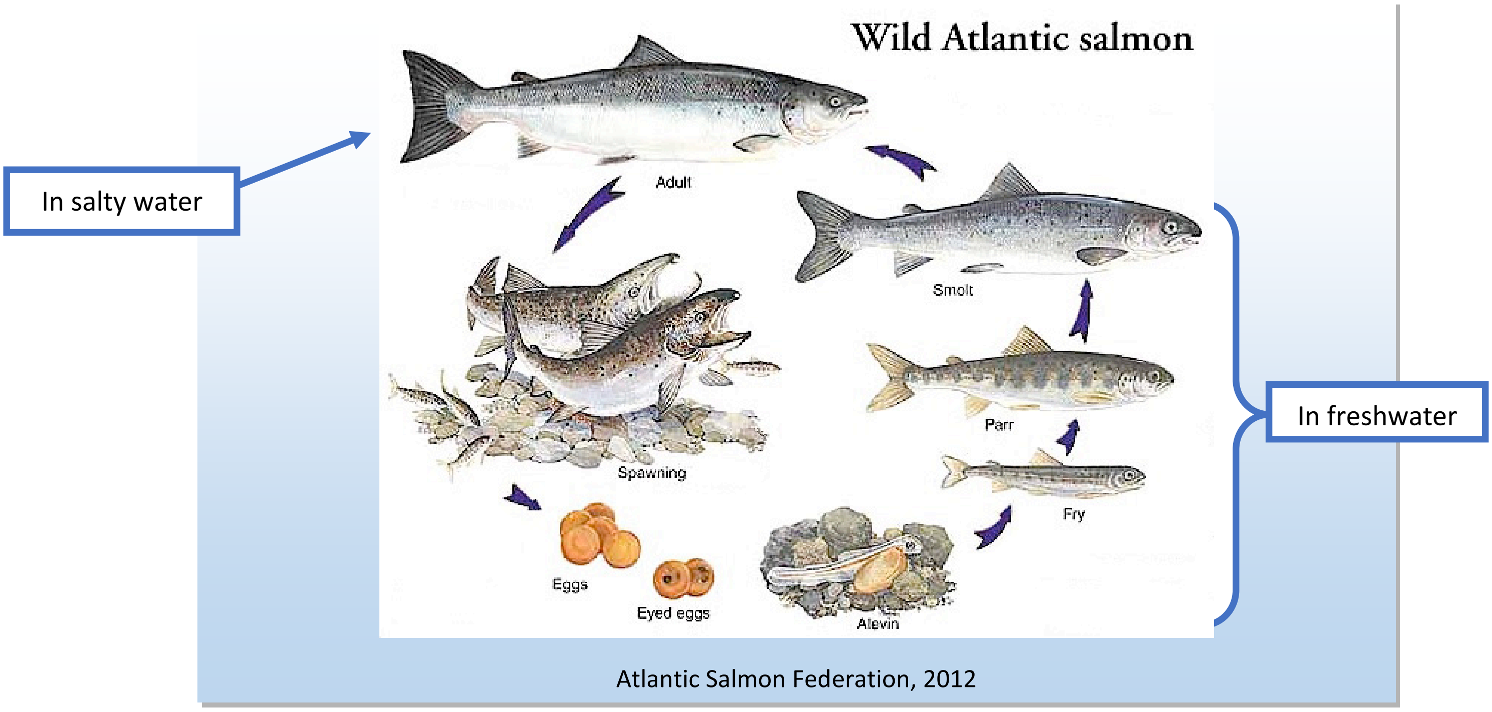

Figure 3. The Atlantic salmon's life cycle. After embryos have well-developed eyes, about 20 days later they will begin to hatch. The alevin do not need to eat while they still have their yolk sac, but once they use that up. When the fry enter the brackish water, the smoltification process begins to adopt to living in seawater, so they begin to transform into smolts (Wittouckm, 2002).

Temperature-dependent sex determination in fish

In fishes, sex determination does not appear to be strictly bound to the sex chromosomes, whereas control over sex determination associated with the sex chromosomes is relatively strict within the higher vertebrates (Devlin and Nagahama, 2002). Environmental sex determination (ESD) is said to occur when gender is irreversibly influenced by the environment during development (Figure 4.). The majority of studies on temperature effects on sex determination have focused on reptiles and amphibians. However, thermo sensitivity of gonadal sex determination in fishes has also been discovered in an increasing number of species since the first finding of temperature-dependent sex determination in Atlantic silverside, *Menidia menidia* (Conover and Kynard, 1981). Although only a very few environmental factors have been analysed, temperature appears to be the main environmental determinant of sex in most sensitive species (Baroiller and D'Cotta, 2001).

Three main types of response to temperature have been reported in fish. In most of the thermosensitive species, the male to female ratio increases with temperature and/or ovarian differentiation is included by low temperatures (i.e. *Menidia menidia*, Cichlids). Conversely, in some rare species (i.e. the channel catfish, *Ictalurus punctatus*), high temperatures may produce female-biased sex ratios and/or low temperatures promote male-biased populations (Patino, 1996). The third type induces monosex male popluations both at high and low temperatures while intermediate temperatures cause a 1:1 sex ratio (i.e. *Paralichthys olivaceus*).

Which sex is preferred in salmonid farming?

When it comes to sex manipulation the main question is which sex carries more potential to increase effectiveness and the predominant advantage is growth superiority.
Under artificial rearing conditions, sockeye salmon females can grow to a large size desired by consumers before sexual maturation starts (Azuma et al., 2004). Meanwhile, most males are sexually mature 1 year earlier than females before attaining market size. Females, therefore, are preferred since there is no degradation of fish meat by sexual maturation.

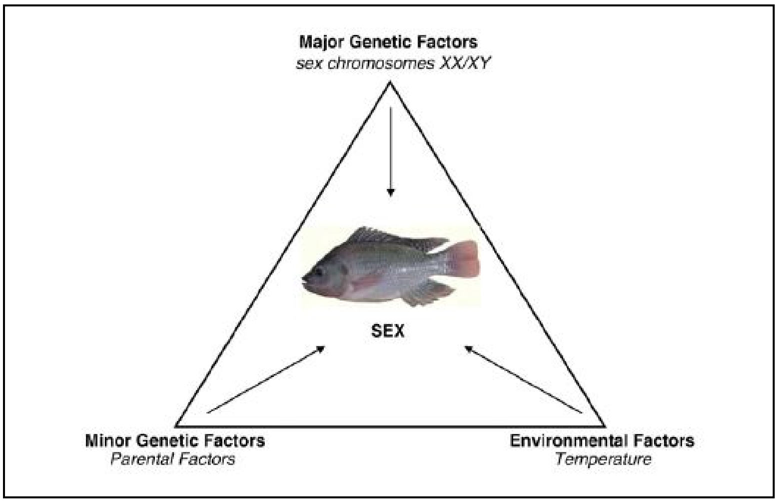

Figure. 4. Schematic triangle representing the complexity of tilapia sex determination showing the three factors influencing sex: the genetic sex determination carried by the XX/XY sex chromosomes, the minor genetic factors which are parental, and temperature, the environmental factor (Baroiller et al., 2008).

In addition, to obtain the offspring, only a small number of males, a fourth or a fifth of the number of females, are necessary for artificial fertilization (Devlin & Nagahama., 2002). Also, artificially sex-reversed males from genetic females are needed to ensure all-female production in fishes possessing male-hetero sex chromosomes. Although administration of sex steroids has proven effective in producing sex-reversed male (Yamazaki, 1983), treatments other than steroids are preferred as sex-manipulation techniques, considering the safety of both environment and fish.

Temperature treatment for sockeye salmon

When the incubation temperature is not manipulated results in sockeye salmons in normal (1:1) sex ratios (Craig, 1996). However, the *hime* salmon, which is a land-locked typed of sockeye salmon in Japan, showed distorted sex ratios when the incubation temperature was manipulated (Azuma et al., 2004). Four temperature-treatments were carried out at different stages of development (Figure 5.). It was concluded that exposing sockeye salmons to higher temperatures during embryonic development distorted the sex ratio towards males. The portions of the sex-reversed fish decreased as the temperature treatment started later. It was also proposed that the direction of sex reversal depends not on a pivotal temperature, but on the magnitude of the shift from the basal temperature. Although this research needs further studies, it opens a new technical method to produce all-male populations by exposing to higher temperatures later in the developmental stage.

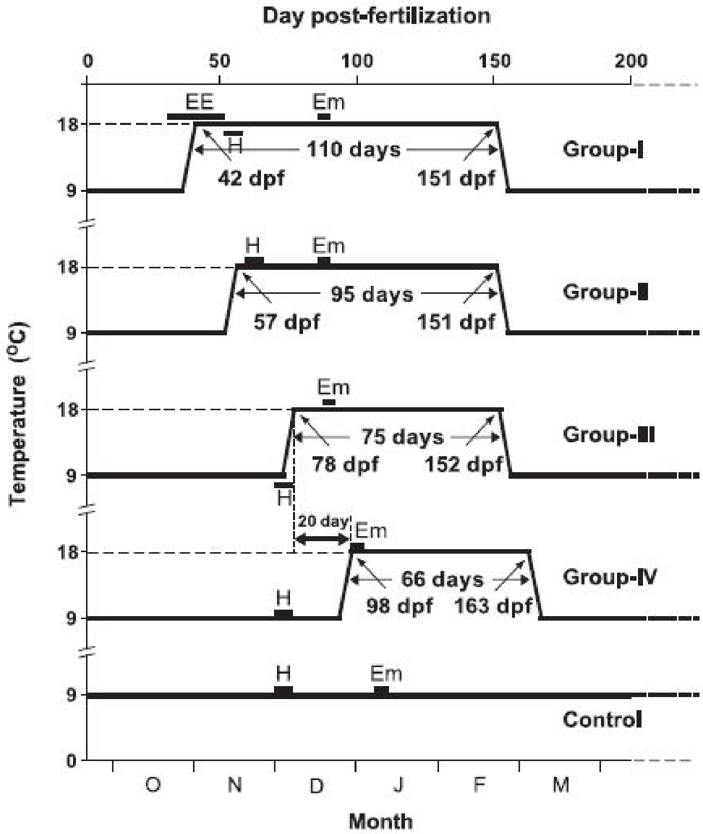

Figure 5. Different thermal treatment groups at different developmental stages: (1) in the middle of the eyed stage; (2) just before starting of hatching; (3) just after the completion of hatching; (4) 20 days thereafter. Therefore, the absolute durations of exposure to high temperature differed among treatments (Azuma et al., 2004).

Sex reversal in wild population

It is important to consider how thermal tress effects wild populations also. The earlier mentioned experiment with the closely related sockeye salmon (Craig, 1996) shows that an experimental temperature shift during embryo incubation can cause a significant increase in the number of males within the population. The wild male and female chinook salmon (*O. tshawytscha*) spawning in Columbia River in British Columbia, were the subjects for another study to examine whether they were correctly expressing their genetic sex (Nagler, 2002). Pacific salmon have a genotypic sex-determining system with male heterogamety; therefore the male is XY and the female is XX (Hunter, 1983). A DNA marker specifically for the Y chromosome can only be found in genetically male chinook salmon (i.e., Y chromosome specific) and it is not present in genetic females (i.e., XX genotype) (Devlin, 1991).

It was tested whether wild chinook salmon with a male phenotype possessed this marker and conversely whether phenotypic females did not. The results of this study show that a high proportion (84%) of phenotypic female chinook salmon tested positive for the male-specific DNA marker. It was indicated that these female chinook salmon carry a male-specific DNA, Y chromosome within their genome.

The most likely possibility is that these fish are genetically male (i.e., XY) and have been sex reversed. This characteristic appears to be widespread in fish that develop in the wild, but not found in closely related fish that were raised under hatchery conditions. The results of this study could be evidence that genetic males have been sex reversed and have the appearance of phenotypic females. In this case, it is possible that fluctuations in water temperature during a period of early embryonic development, affected sex determination in a proportion of wild male chinook salmon.

The connection between climate change and thermal impairment of fertility in Atlantic salmon

Climate, defined as the meteorological conditions, including temperature, precipitation, solar radiation and wind that prevail in a particular region (Harrod, 2009), determines water temperature and flow of watercourses. Therefore, it is a reasonable expectation that salmonids are particularly susceptible to climate change due to their distributional preferences for cooler water (Pankhurst, 2011). Atlantic salmon, *Salmo salar* has an approximate upper limit of thermal tolerance of 22–24°C (Barton, 1996), but their distribution in the North Atlantic Ocean shows that fish typically stay between the 4 and 10°C isotherms (Reddin et al., 2000). Similar data have been reported for sockeye salmon *Oncorhynchus nerka* with both species showing preference for quite narrow temperature ranges (Welch, 1998). Their low tolerance to high water temperatures is due to the low solubility of oxygen in warm water and their metabolic energy costs increase with water temperature.

Sockeye salmon die after spawning while Atlantic salmon do not and this knowledge opens an opportunity to use repeat salmons (Pankhurst et al., 2011). When repeat and maiden Atlantic salmons were treated with synthetic analogues of gonadotropin releasing hormone (GnRHa) (Pankhurst et al., 2011), fertility was only restored when applied in combination with a graded reduction in temperature (Fig. 8). However, the use of repeat spawning stock may partially offset the effects of exposure to elevated temperature and this may offer a management alternative. The implication is that hormone therapy is only likely to be partially effective at offsetting the damaging effects of exposure to high temperature, although the more direct effects of gonadotropin or steroid therapy remain to be investigated (Pankhurst and King, 2010)

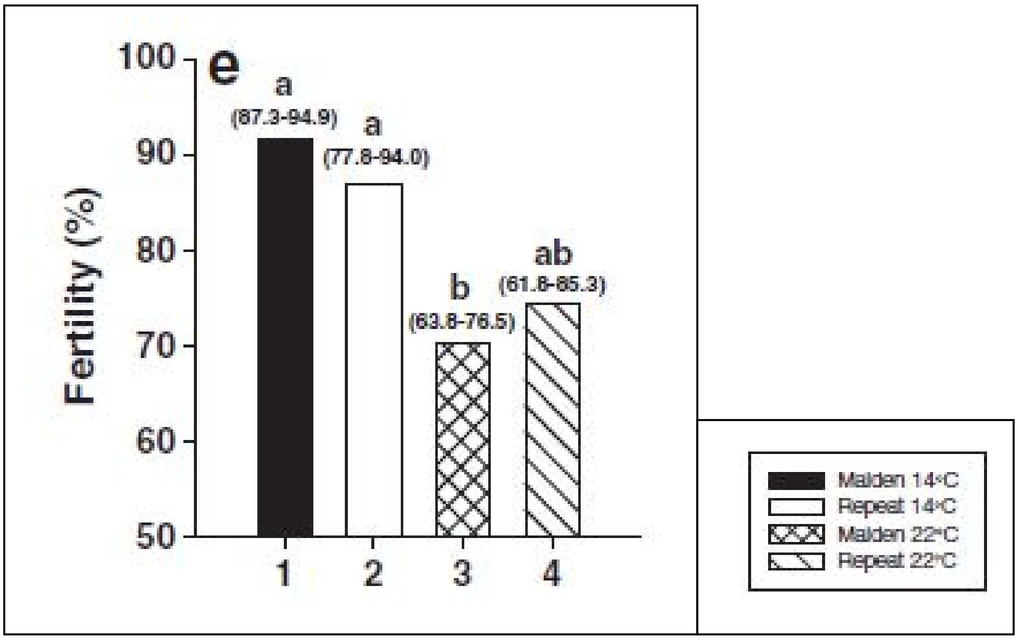

Figure 8. All maidens (first spawning, 2+ year old fish) and repeats (second time spawning, 3+ year old fish) were maintained at the nominated temperature (14 or 22 °C) until early April when all fish were exposed to a temperature ramp down over 11 days to 8 °C to induce final oocyte maturation and ovulation. The outcome was definite that highest value of fertility (~90%) was at 14°C, yet the repeat group at 22°C showed a higher fertility value than the maiden group (Pankhurst et al., 2011).

Comparing thermal treatments with hormone treatments and genetic alteration

Thermal treatments offer a more consumer and environmental friendly approach than hormone usage which has various issues realted to it, i.e. possible effects of treatments residues on water quality and biodiversity,growing concerns for food security, finding a sex control alternative based on non-hazardous treatments and an overall need to a high level of control over the procedures. Although, most of the studies showing sensitivity to temperature are hindered because the sex determination mechanisms of most these species have not been able to be well characterized yet (Baroiller et al., 2008). On the other hand, biotechnological approaches lead to the creation of the freeze resistance in transgenic salmon, the AquAdvantage Salmon®, by using an antifreeze protein gene (Muir, 2011). In spite of the several fold growth performances in these fish, there is a real concern that if transgenic fishes were to escape into the ocean they would become an invasive species that might out-compete wild populations for food. Also, it is a constant debate whether the public would find these organisms healthy for human consumption. Therefore, the author of this paper emphasizes with need to conduct extensive studies about thermal sensitive species in order to evaluate the productivity of thermal treatments and invent a cost-effective facility to farm them in an environmentally friendly manner.

(*AquaBounty Technologies, 2015*)

Figure 9. The difference between two 18 months old Atlantic salmons. In the front is the standard salmon behind it the AquAdvantage®Salmon.

Proposed solution

The author of this paper emphasizes with the great need for implementing new methods to farm salmonids to balance the ecological impact of the fish farms with the economic considerations. Furthermore, marine salmonid cultivation can also introduce significant quantities of nutrient wastes from uneaten feed, faeces and excretory products into the local environment (Cheshuk, 2003). The most visible effects of fish cage aquaculture are; (i) output of particulate organic waste that will increase biochemical oxygen demand, (ii) release of dissolved phosphorus and (iii) dissolved nitrogen.

There has been an increased interest in combined aquaculture systems, described as integrated multi-trophic aquaculture (IMTA). By integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed and shellfish), the wastes of one resource user become a resource (fertilizer or food) for the others. By adapting integrated polytrophic practices, the aquaculture industry should find increasing environmental, economic and social acceptability and become a full and sustainable partner within the development of integrated management frameworks (Chopin, 2001).

For example, to exploit these nutrients as a resource input, and at the same time reduce the risk for the eutrophication of the environment, *Grucilaria chilensis*, when cultivated at 10m distance from the cages had up to 40% higher growth rate, compared to growth at 150 m and 1 km distance (Troell, 1997).

Therefore, it would be highly productive if an IMTA system could be also integrated with thermal treatments (Pankhurst & King, 2010) and smolt pheromone application (Nordeng, 1977; Yambe, 2006; Solomon, 1973) to increase effectiveness and quality of salmonid farming (Figure 9.). However, this structure of salmon farming needs an extensive further research.

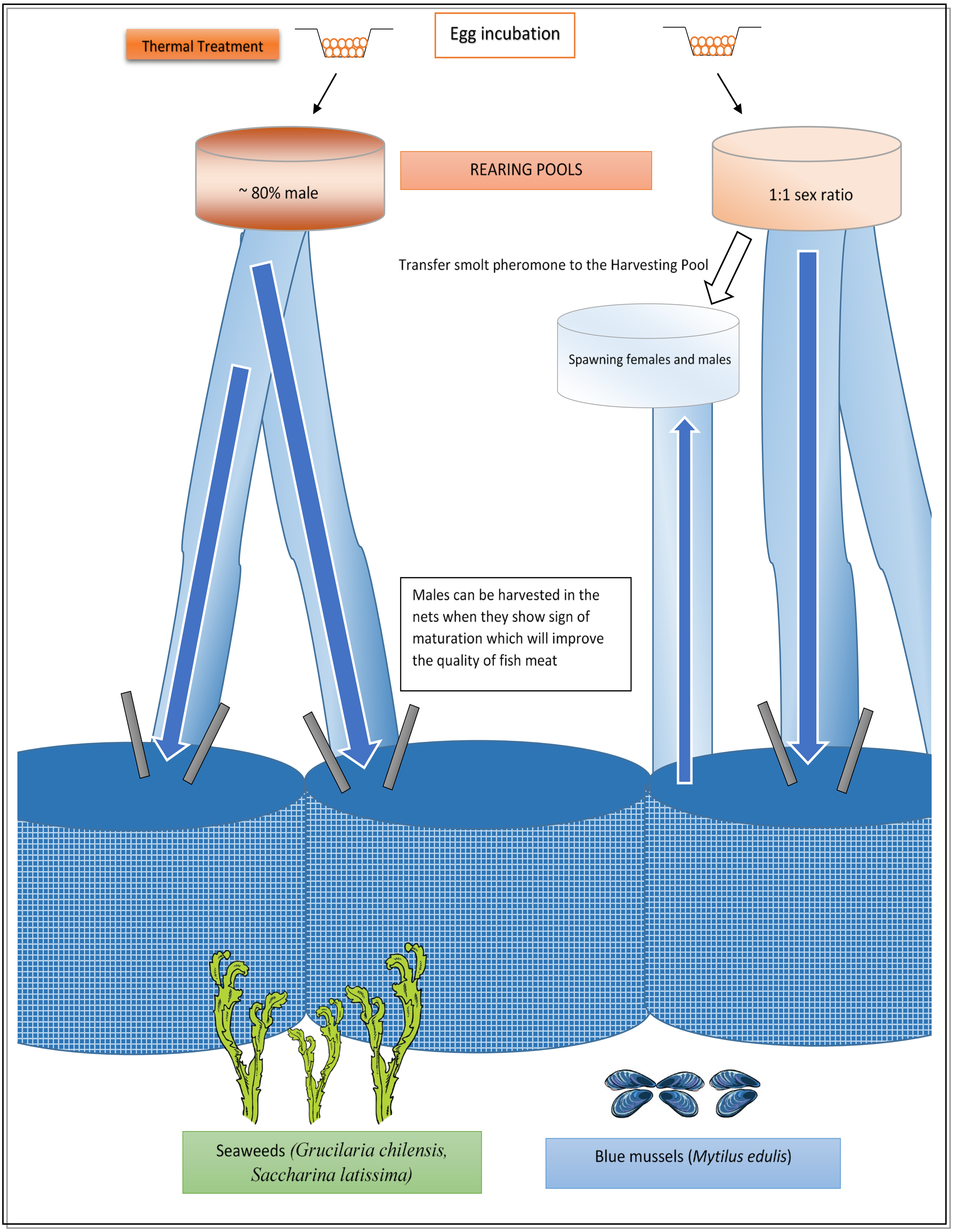

Figure 9. Salmon farming structure hypothesized by the author of this paper. The system consists of incubation and rearing facilities, artificial rivers which join the ocean via a dam which can be sealed off. The net cages are located in a bay which does not coincides other salmon's migratory routes. Due to the transfer of the smolts urine in the water, it will initiate the spawning of mature fish (Nordeng, 1977), which will partially separate females and males due to the time difference of maturation.

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