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Introduction to the 8th International Workshop on Smoltification and a synthesis of major findings

1. Introduction

The early life history of anadromous salmonid fishes, be they Atlantic (*Salmo salar*) or Pacific salmon (*Oncorhynchus* spp.), trout of those genera, or charrs (*Salvelinus* spp.), appears much more complex than previously thought. The seaward movement or migration is extremely polymorphic among and within species. To help provide understanding of the processes involved, and implications for conservation, management and husbandry, the 8th International Workshop on Smoltification was held on September 20–24, 2009, with participants (Fig. 1) from 9 different countries. Because the native distribution of these fishes is in northern latitudes, more or less circumglobally, similar workshops have been held roughly every four years in various countries, starting in LaJolla, California; and subsequently in Stirling, Scotland; Trondheim, Norway; St. Andrews, Canada; Muonio, Finland; Westport, Ireland; and Tono, Japan. Papers emanating from these previous workshops can be found in earlier Special Issues of *Aquaculture* while those from the 2009 workshop are presented here.

Juvenile anadromous salmonids occupy freshwater habitats that appear at first blush as being rather similar across the species. However, habitat use by juvenile salmon is quite variable within and across the species. Similarly, aquaculture practices for these species appear rather similar on the surface, when in reality there can be considerable differences even between relatively geographically close culture stations. The fact remains that the nature of the freshwater habitat of anadromous salmonids can be profoundly different among populations of the same species. Hence, one of the agendas of these international workshops has been aimed at understanding the variation associated with the smoltification process. Such variation may concern Zeitgebers, others the hydrograph, and yet others the fish themselves. For instance, the extreme light conditions that fish can experience were evident to the smoltification workshop participants in Trondheim, just below the Arctic Circle around summer solstice with only 3 h of dusk, and in Muonio, above the Arctic Circle at winter solstice with only the tiniest glimmer of light during midday. The workshop at Tono was at the very southern edge of the salmon distribution in Japan.

The 8th International Workshop on Salmonid Smoltification was held in various locations in Oregon, U.S.A., to expose participants to extremes in environmental gradients to which anadromous Pacific salmonids could be exposed, even within the same watershed. These locations reflect the wide range in habitat types that can all be considered "good" freshwater habitat for several species of Pacific salmon such as Chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon and steelhead (*O. mykiss*) for both rearing and parr–smolt transformation. The technical sessions of the workshop commenced at the Hatfield Marine Science Center, Newport, Oregon; watersheds in this area receive an average of 173 cm of rainfall that occurs primarily in the fall, winter and spring. This location also represents estuarine habitats that can be used for rearing juvenile salmon during the movement of these fishes into marine waters and as part of the smoltification process of some populations. The workshop then "migrated" to the Oregon Hatchery Research Center in the Coast Range Mountains where streams in this location are short and flow directly into the Pacific Ocean, necessitating a smolt journey of 10's of km and certainly less than 100 km. The landscape of the above two habitats can be considered rainforest. This was followed by the workshop moving to Oregon State University, Corvallis, which is located in the highly agricultural Willamette Valley. Here, the hydrograph is driven by 102 cm of precipitation that is a mix of rain and snow that occurs primarily in the winter and spring and migratory distances may be 500 km. Participants were also able to visit the Fish Performance and Genetic Laboratory and the Salmon Disease Laboratory of Oregon State University. The workshop then moved to the arid, high-desert and high elevation landscape at Sunriver at the eastern base of the Cascade Mountains. Rivers here are part of the Columbia River drainage where migratory distances can range up to 1000's km. This habitat is characterized by a hydrograph that is naturally driven by spring mountain snowmelt, with much of the landscape through which the fish must migrate receiving sometimes less than 20 cm of moisture throughout the year. En route, participants had the opportunity to visit Willamette and Bonneville hatcheries and observe rearing tactics as well as demonstrations of various forms of telemetry.

2. Synthesis

Contributions to each of the successive workshops have built one upon the other. Emergent topics at the 8th workshop from a physiological perspective included the osmoregulatory role of aquaporin; and the claudins and myostatin were discussed. The importance of the pyloric caeca, accounting for 85% of the surface area of the gut, was brought up as an area of study deserving much more careful attention. Additionally, the significant change in shape of fish following seawater entry was considered. However, while considerable research still targets understanding of physiological processes fish undergo as they smolt, the 8th workshop suggested that there is an increased emphasis on the understanding of the natural history of the fish as well as the importance of the environment.

There appear to be many tactics that anadromous salmonids can employ as they implement the strategy of smoltification. Developmental trajectories can vary greatly within some species, leading to smoltification of individuals at numerous ages and developmental rates within and between populations. The question of smolting being a default tactic (i.e., the natural process that happens in the absence of some directing or controlling factor

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Fig. 1. Participants at the 8th International Workshop on Smoltification taken at the Oregon Hatchery Research Center. Picture taken by Joseph O'Neil.

such as accelerated growth that can lead to precocious male maturation) was raised. How puberty and the tactic of becoming a "mini-jack", a juvenile-sized adult male, relate to smolting was discussed. Participants suggested that comparing salmonids with other species that experience major life history transitions, such as metamorphosis in flatfishes or "smolting" in anadromous shad and lamprey, could be quite informative.

There was considerable discussion at the workshop on temperature and the potential importance of climate change. Temperature has a major role in directing physiological processes and the nature of juvenile migration. Temperature can operate at various biological levels of organization, affecting initiation, duration, and termination of migration. Even extremely small changes in temperature could affect fish movement. It can also have important consequences by affecting both proliferative and non-proliferative pathogens and the infectivity and resistance of hosts. The negative relationship between parasites and smoltification was documented, and new insights into the role of temperature as a controlling factor for disease were brought up. Climate change and events such as near-shore oceanic hypoxic areas could affect early ocean entrants.

The workshop led to the conclusion that landscape-level processes appear important for smoltification. Discussions along these lines included the interesting suggestion that terrestrial subsidies such as leaf litter in the fall could drive the trophic web, influencing smolting and seaward movement in the subsequent spring. Understanding estuaries and the biology of fish as they transition to full strength sea water could be important. Some out-migrant forms may need estuaries for foraging and growth, but very significant mortality may occur in certain estuarine locations as fish move seaward. The connectivity of freshwater, estuaries and oceans by smolt migration is further emphasized by findings that exposure to contaminants in freshwater can affect marine survival. While the role of pesticides in smolting had been considered previously, the role of pH and aluminum in estuaries emerged as a topic at this workshop. The energetic costs associated with osmoregulation during tidal fluxes could affect the smolting process. The nature of smolting by fish in bar-bound streams (those where a sandbar prevents smolt exit into the ocean until a storm breaks down the bar) is also interesting and further emphasizes the importance of habitat connectivity.

In general, our sense is that there is still disagreement about the definition of the word "smolt" and hence "smoltification". Study of this process is exceptionally complex because we do not have beginning or endpoints that clearly indicate when the process starts or is completed. That said, it is amazing how far the field of "smolt biology" has come since the first workshop. The unknowns that were highlighted at this last workshop provide the challenges and joy that we take with us into the science of the future.

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