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Native Fish Society

The Effect of Hatchery Breeding on Inbreeding and Survival of Wild Populations of Fish

Waples, Robin S., Kjetil Hindar, Sten Karlsson, and Jeffrey Hard. 2016. Evaluating the Ryman-Laikre effect for marine stock enhancement and aquaculture. Oxford University Press

Each year, staggering numbers of captively-reared individuals are intentionally released into the wild, where they can interact with (and potentially interbreed with) wild populations. These programs, which have varying goals but typically seek to enhance harvest opportunities, cover a wide range of taxa and are particularly widespread in the fields of fisheries, forestry, and wildlife management (Laikre et al. 2010). Unintentional escape into the wild of individuals or gametes from aquaculture and agriculture creates additional opportunities for genetic exchange between captive and wild populations.

Genetic and ecological risks that captive individuals pose for natural populations have been well described theoretically and well documented empirically. Genetic risks are of three general types: 1) loss of diversity within populations; 2) loss of diversity among populations; and 3) loss of fitness.

In a classic paper, Ryman and Laikre (1991) were the first to explain how selective enhancement of a portion of a wild gene pool can reduce effective population size (N_e), leading to increased rates of genetic drift and more rapid loss of genetic diversity, thereby limiting evolutionary potential. In general, the purpose of captive breeding is to bypass high mortality that typically occurs in early life stages in the wild. The common scenario that motivated Ryman and Laikre's study can be summarized as follows:

- A small number of individuals are removed from the wild population to use for captive breeding;
- The captive breeders produce more offspring per parent than do individuals reproducing in wild;
- If the program is successful, offspring of the relatively few captive parents can make up a substantial fraction of the next generation;
- These offspring of captive parents will all be closely related, and when they interbreed the next generation their offspring will be inbred. This increased level of inbreeding will reduce overall N_e (effective population that leads to inbreeding effects on the population) and can lead directly to reduced fitness of inbred offspring.

The Ryman-Laikre (R-L) effect is an increase in inbreeding and a reduction in total effective population size in a combined captive-wild system, which arises when a few captive parents produce large numbers of offspring.

The reduction in overall N_e in the captive-wild system due to selective enhancement of part of the gene pool has been termed the Ryman-Laikre (R-L) effect. It can be thought of as a kind of artificial bottleneck, because a large fraction of all the genes that pass from one generation to the next must be funneled through the few captive breeders.

We show how the modified equations can be used to obtain answers to questions that are commonly of management/conservation interest, including:

- What scenarios will ensure that overall N_e is not reduced by the R-L effect?
- What scenarios will ensure that the ratio of treatment to control N_e is no smaller than a specified value?

- What scenarios will ensure that, even if overall N_e is reduced by the R-L effect, it remains above some target level?
- Under what scenarios can captive rearing actually increase overall N_e , and if so what is the maximum increase that can be achieved?

We have the following recommendations for scientists, managers and conservation practitioners. First, it is important that the potential for a Ryman-Laikre effect be taken into consideration in any program for marine stock enhancement and aquaculture. The data necessary to evaluate the effect can be estimated in any captive-wild system by combining methods for estimating census and effective population size with methods for identifying captive offspring in the wild.

Our second recommendation is to establish a consistent, rigorous monitoring program that follows the captive and wild populations over time. Important metrics to monitor include the magnitude and frequency of escapes from closed aquaculture, the frequency of reproductive encounters between captive and wild individuals, the occurrence of F1 hybrid offspring and backcross descendants in the wild (indicative of genetic introgression), phenotypic variation in key life history traits (e.g., size, age, growth) for both groups, and estimates of within-population genetic diversity as well as wild fitness and productivity (Kapusinski et al. 2007; Senanan et al. 2007). Ideally, the monitoring programs would be designed so that it can track genetic introgression into wild populations (Karlsson et al. 2014) and ecological/life-history changes in the wild population following introgression (Ford 2002; Reed et al. 2015).

To minimize inbreeding problems in captivity, captive breeding should strive to maximize diversity among breeders and minimize the variance in adult family size by—to the extent feasible—equalizing breeder sex ratios and employing factorial mating schemes that maximize representation of all potential breeders. Such practices have been widely recommended in the fish culture literature.

<http://cz.oxfordjournals.org/content/czoolo/early/2016/05/10/cz.zow060.full.pdf>

While this paper correctly points to the problems created by fish culture in an open system where cultured and wild salmonids breed with each other, it assumes that an expensive and competent scientific process will be implemented to control the detrimental impacts of hatchery fish on wild populations. We know that fish management agencies are strapped for funding so even if they were interested in managing hatchery fish to reduce the impact on wild salmonids it is unlikely to be included in the management program. The funding required for protecting wild populations from hatchery fish does not produce more fish for harvest. It is wasted and increases the cost to provide hatchery fish that are harvested which already can be many thousands of dollars. But setting all this aside, this paper also assumes that the protection of wild salmonids is a purpose of the management agencies when it is an expensive institutional drag on production of a product for the market economy. The gap between scientific application of science and management is a dominate issue, for the fishery agencies treat it as an elective not a requirement. Therefore compliance with science and existing laws and rules to protect wild salmonids is the burden of the public, requiring legal action. The courts defer to the expertise of the fishery agencies to do a better job protecting wild salmonids, a task that they resist. For example the federal court has rejected the Columbia River agency plans for ESA protected wild salmon many times and the National Marine Fisheries Service remains unresponsive. Therefore the public is not only paying for management that is sacrificing wild salmon, it pays for legal actions to hold the agencies accountable.

BMB



Lower Snake River is a New Home for Siberian Prawn

Erhardt, John M. , , Kenneth F. Tiffan . 2016. Ecology of nonnative Siberian prawn (*Palaemon modestus*) in the lower Snake River, Washington, USA. Springer International Publishing.

We assessed the abundance, distribution, and ecology of the nonnative Siberian prawn *Palaemon modestus* in the lower Snake River, Washington, USA. Analysis of prawn passage abundance at three Snake River dams showed that populations are growing at exponential rates, especially at Little Goose Dam where over 464,000 prawns were collected in 2015. Monthly beam trawling during 2011–2013 provided information on prawn abundance and distribution in Lower Granite and Little Goose Reservoirs.

Seasonal length frequencies showed that distinct juvenile and adult size classes exist throughout the year, suggesting prawns live from 1 to 2 years and may be able to reproduce multiple times during their life. Most juvenile prawns become reproductive adults in 1 year, and peak reproduction occurs from late July through October. Mean fecundity (189 eggs) and reproductive output (11.9 %) are similar to that in their native range. The current use of deep habitats by prawns likely makes them unavailable to most predators in the reservoirs. The distribution and role of Siberian prawns in the lower Snake River food web will probably continue to change as the population grows and warrants continued monitoring and investigation.



Domestic Salmon have reduced overall athletic robustness compared to wild Salmon

Zhang, Yangfan, Gerrit Timmerhaus, Katja Anttila, Florian Mauduit, Sven Martin Jørgensen, Torstein Kristensen, Guy Claireaux, Harald Takle, Anthony P. Farrell. 2016. Domestication compromises athleticism and respiratory plasticity in response to aerobic exercise training in Atlantic salmon (*Salmo salar*). *Aquaculture*. Elsevier.

<http://www.sciencedirect.com/science/article/pii/S0044848616302514>

(This study compares domesticated Atlantic salmon to wild salmon, concluding that commercially selective breeding of Atlantic salmon primarily for rapid growth can compromise cardiorespiratory robustness and its related phenotypes. Could this be a factor in the poor performance of hatchery produced Pacific salmon following release into nature compared to wild salmon? Maybe this should be tested by the Oregon Hatchery Research Center as they try to cultivate a hatchery salmon that is equal to wild salmon. BMB)

“Commercially selective breeding of Atlantic salmon (*Salmo salar*) primarily for rapid growth may compromise cardiorespiratory robustness and its related phenotypes. Therefore, a suite of respiratory indices was used to evaluate aerobic capacity and hypoxia tolerance to test the hypothesis that exercise training can improve the athletic robustness in both domesticated and wild strains of Atlantic salmon, but with the domesticated strain having a less cardiorespiratory plasticity and a lower athletic robustness than the wild strain. We also tested a second hypothesis that a constant acceleration screening protocol should segregate fish according to athletic robustness based on their swimming ability. These hypotheses were tested with parr from domesticated and wild strains of Atlantic salmon that were reared under identical hatchery conditions.

“While exercise training produced several tangible benefits for the wild fish, it produced very few for the domesticated fish.

“Thus, the domesticated strain appeared to be athletically less robust than the wild strain. These results imply that approximately ten generations of selective breeding for rapid growth in commercial aquaculture have reduced the overall athletic robustness of domesticated salmon as compared to their wild conspecifics, and given the success in improving athletic robustness of the wild strain, it still remains to be seen whether an exercise training protocol can be developed that will provide benefits to the salmon aquaculture industry.

“We used a suite of respiratory indices to evaluate athletic robustness and hypoxia performance in individual fish. We discovered that a domesticated strain of Atlantic salmon demonstrated a reduced athleticism and less plasticity in response to a short exercise-training regime compared with a wild strain of Atlantic salmon.



Phenotypic traits can often change dramatically in a few generations

Philipp W. Messer¹, Stephen P. Ellner, Nelson G. Hairston Jr. 2016. Can Population Genetics Adapt to Rapid Evolution? *Trends in Genetics*.

<http://www.sciencedirect.com/science/article/pii/S0168952516300191>

Population genetics largely rests on a ‘standard model’ in which random genetic drift is the dominant force, selective sweeps occur infrequently, and deleterious mutations are purged from the population by purifying selection. Studies of phenotypic evolution in nature reveal a very different picture, with strong selection and rapid heritable trait changes being common. The time-rate scaling of phenotypic evolution suggests that selection on phenotypes is often fluctuating in direction, allowing phenotypes to respond rapidly to environmental fluctuations while remaining within relatively constant bounds over longer periods.

Trends

Studies of evolution in action show that phenotypic traits can often change dramatically over the course of just a few generations.

This differs markedly from the paradigm of slow molecular evolution commonly adopted in our population genetic models.

To assess whether our models are still appropriate, we need to better understand how rapid phenotypic evolution impacts the trajectories of genetic variation in a population.

New population genomic datasets will make it possible to directly observe how polymorphism frequencies change in a population over time, allowing us to test and refine our population genetic models.

Why is this important? Salmon are locally adapting to fluctuating environments and their ability to successfully cope means they develop traits that allow them to be as flexible as their environmental changes require. Their environment is constantly selecting for survival and successful breeding. Management practices that select against traits important for survival such as harvest and hatchery production can impose changes. Some scientists are concerned that production goals of management are stripping fish of traits important to survival. The reduced fitness in hatchery fish compared to wild fish in the natural environment points this out. While maintaining genetic diversity is important for the long term survival of salmonids it is also important to maintain the associated traits that promote short-term response to changes in their environment. For example, it was recently found that 30 % of adult coho returns were from juveniles that used alternative rearing in the lower river including estuary influenced areas. It was previously thought that these “nomadic” coho did not survive.



Beaver Restoration and Livestock Grazing

Brian A. Small, Jennifer K. Frey and Charlotte C. Gard. 2016. Livestock grazing limits beaver restoration in northern New Mexico. *Restoration Ecology*.

<http://onlinelibrary.wiley.com/doi/10.1111/rec.12364/abstract;jsessionid=D5909A79D12AA3498A5EFC76F12825BA.f04t04?userIsAuthenticated=false&deniedAccessCustomisedMessage=>

Abstract

The North American beaver (*Castor canadensis*) builds dams that pond water on streams, which provide crucial ecological services to aquatic and riparian ecosystems and enhance biodiversity. Consequently, there is increasing interest in restoring beavers to locations where they historically occurred, particularly in the arid western United States. However, despite often intensive efforts to reintroduce beavers into areas where they were severely reduced in numbers or eliminated due to overharvesting in the eighteenth and nineteenth centuries, beavers remain sparse or missing from many stream reaches. Reasons for this failure have not been well studied. Our goal was to evaluate certain biotic factors that may limit the occurrence of dam-building beavers in northern New Mexico, including competitors and availability of summer and winter forage. We compared these factors at primary active dams and at

control sites located in stream reaches that were physically suitable for dam-building beavers but where none occurred. Beaver dams mostly occurred at sites that were not grazed or where there was some alternative grazing management, but were mostly absent at sites within Forest Service cattle allotments. Results indicated that cattle grazing influenced the relation between vegetation variables and beaver presence. The availability of willows (*Salix* spp.) was the most important plant variable for the presence of beaver dams. We conclude that grazing by cattle as currently practiced on Forest Service allotments disrupts the beaver-willow mutualism, rendering stream reaches unsuitable for dam-building beavers. We recommend that beaver restoration will require changes to current livestock management practices.

(I spent some good days with Wayne Elmore, BLM, Prineville, on Bear Creek and his work to restore that small arid land stream. He told me that one project involved relocating beaver to a stream that needed the restoration that beaver could supply, but their food was limiting. To help the beaver out, he and others with the BLM cut willows from a stream, piled them in a pickup and drove the food to the beaver. This lasted for some time until the willows they planted took and began to grow a source of food. Changes in livestock use were required to provide a suitable habitat for beaver. Helping beavers to colonize eastern Oregon streams is good for streams, wildlife and trout. BMB)



Adaptive Management and Wild Salmon Recovery

Gunderson, Lance H., Barbara Cosens, Ahjond S. Garmestani Adaptive governance of riverine and wetland ecosystem goods and services. 2016. Journal of Environmental Management.

<http://dx.doi.org/10.1016/j.jenvman.2016.05.024>

“As our capacity to manipulate the environment has increased, we have also sharpened the focus of how we manipulate the environment to secure ecosystem goods and services.

“We seek to control ecosystems by decreasing the natural or inherent variation in ecosystems in order to procure a specified set of ecosystem goods and services. We build dams in river ecosystems in order to control flooding during wet periods and to store water for dry periods.

“Dams dampen the fluctuations in river flows, by controlling the amount of water released downstream, but also facilitate diversion of water for other types of ecosystem services.

“In these and many other cases, we stabilize ecological processes in order to achieve economic and social outcomes. In doing so, we optimize for specific goods and services by enhancing efficient production, use and allocation of some at the expense of others. These three objectives; control, stability and efficiency have been achieved in many ecosystems, but not without a cost.

“There is a growing body of evidence to indicate that ecosystem management that removes inherent variation, homogenizes spatial patterns and optimizes extraction of a few ecosystem goods increases the vulnerability of these systems to dramatic and unwanted changes.

“For example, development of dams to provide hydropower, irrigation and flood control in the Columbia River basin has evened out flow reducing spring flood and increasing late summer and fall flow.

“Such compartmentalization to control water movement in the mighty rivers of the western U.S. has decreased the variation in flow volumes, slowed the movement of sediments, created new ecosystems, and led to endangerment and extirpation of populations of Pacific salmon as well as nonanadromous species.

“Similar approaches in fisheries or wildlife management also attempt to limit or constrain variability in order to sustain efficient outputs. However, this pattern of ecosystem modification generates an unintended consequence of increased vulnerability (Carpenter et al., 2015), described as *the pathology of resource management* (Holling and Meffe, 1996). This pathology results from the unexpected response of complex systems to simple management approaches.

While attempts at increasing control over nature have been successful in achieving social and economic objectives, they often have come at the cost of ecological and environmental components. Most regional scale water systems in the U.S. are critical habitat for multiple taxa listed as endangered or threatened. For example, in the Columbia River basin, 8 salmon, 4 steelhead, and 2 resident fish species are listed under the ESA.

“Other common resource issues that map into ecosystem services include losses in ecosystem functions due to invasive species and water quality degradation. In many cases, the changes resulting from intensive management have resulted in new or novel ecosystem configurations (Holling and Meffe, 1996).

“The degradation of ecosystem services, such as...declines in biodiversity can indicate a loss of ecosystem resilience and resulting shift in ecosystem regimes. An ecological regime is characterized by a set of structural and functional features.

“Regime shifts occur when the dominant structural features of an ecosystem are replaced by alternative ones. Such regime shifts can be viewed as ecological crises signaling a shift in individual or bundled ecosystem goods and services.

Ecological crisis may result in unintended and unexpected consequences that substantially alter and reduce services that society has come to rely on. Such crises can reveal failures in policy and management approaches (Gunderson et al., 1995).

“By the end of the 20th century in the US, scholars and practitioners were recognizing this loss of resilience and noticing that failures in the top-down governmental approach were leading to new attempts at governance.

“The NRC (2004) acknowledged the tendency of legislatures to set resource use policy via legislation, and in doing so, decoupled management decisions from local ecosystem dynamics. Such policies led to undesirable outcomes for the ecosystem (collapse of fisheries, crises in forest management) and frustration by stakeholders who depend upon various ecosystem goods and services.

“As a result of these crises and failures, new forms of governance emerged; one of which has been described as adaptive governance. Adaptive governance provides space to bring together formal institutions with informal ones to understand, manage and solve complex environmental issues.

“Many formal resource management institutions are geographically defined entities. In addition, many agencies have strictly defined limits on the subject matter they may address.

“While this fragmentation in authority and focus may be viewed as inefficient, combined with the capacity to cooperate across boundaries, it sets the stage for polycentricity.

“Polycentricity implies that smaller, more local units of governance exist within large, more general ones, and provides institutional diversity and redundancy (Chaffin et al., 2014b). Finally, the third characteristic of adaptive governance is the production and dissemination of new social and ecological knowledge, thus reconnecting management decisions to ecosystem dynamics. Adaptive governance can provide the coproduction and dissemination of knowledge among communities of science, management and resource users. Such governance engages a broad set of stakeholders and the public.

“Gunderson and Light (2006) defined adaptive governance as the set of institutions and framework that facilitates and fosters adaptive management. Adaptive management and adaptive governance have been attempted in many large resource systems, such as the Everglades (Gunderson and Light, 2006; LoSchiavo et al., 2013), and Columbia River system (Lee, 1993; Cosens and Williams, 2012). In both of these systems, adaptive management was applied so that managers could address and resolve inherent uncertainty associated with meeting social objectives.

“Kai Lee (1993) in writing about experiences with adaptive management in the Columbia River system, was among the first to point out that in such complex systems, managers must confront two different forms of uncertainty. One form of uncertainty involves technical and scientific questions associated with how to resolve resource issues, such as how manipulation of flow regimes influence the recovery of endangered species in the Columbia.

“The second type of uncertainty that Lee identified lies in the articulation and prioritization of social objectives and goals, an uncertainty he thought was addressed through a deliberative, democratic process. How these different forms of

uncertainty are addressed have been critical components to describe the utility and efficacy of adaptive approaches (Gunderson and Light, 2006; Garmestani and Benson, 2013).

“The remainder of this article explores linkages among adaptive management, adaptive governance and ecosystem services. We do so by positing that 1) adaptive management can help highlight trade-offs among ecosystem goods and services and 2) adaptive governance seems to emerge during times of great uncertainty (such as environmental crises) during which decisions about trade-offs among ecosystem services are evaluated and discussed. We begin with a review of ecosystem goods and services in two complex ecosystems that have histories of adaptive management and adaptive governance; the Columbia River Ecosystem and the Everglades.

“Adaptive governance and adaptive management are learning based approaches that can help to systematically resolve key uncertainties of these complex systems. Yet global issues of climate change and economic development that decreases ecosystem services and goods pose great uncertainties for managers. Adaptive approaches may help us learn how to deal with the complexities of trade-offs and uncertainties in evaluating how to provide and sustain multiple ecosystem services.”

While interesting and necessary, applying adaptive management within government agencies depends upon their interest in doing so. In my experience that interest waxes and wanes depending upon leadership. The agency management framework and associated rewards to employees creates its own momentum and shapes the outcome of policy decisions. Government management for Pacific salmonids since the 1860s has been primarily for commercial interests with a subset of concern for overdoing it and losing the salmon runs. Agency budgets are approved by legislators who understand the social demands but seldom understand science. That creates a lopsided policy table. Natural resource agencies are organized to serve the economic interests of their constituent user groups and commitments are made that are not easily revised when scientific evaluation elevates concerns regarding the decline of salmonids. Obviously, Pacific salmonids are 1 -3 percent of historic abundance, many populations have gone extinct and most are now ESA protected species, so there is a legitimate concern that the focus on social and political concerns has done its damage. The management framework for salmonids is based on mitigation for wild salmon losses. Artificial propagation is the primary mitigation response because it is a better fit with established salmon management policy. Without any proof the fishery agencies claim that hatcheries can be used to rebuild and recover wild salmon. The adaptive management I am familiar with is securing public funds from the federal government to continue the same commodity production framework. Over \$15 billion has been spent on salmon recovery in the Columbia River yet the wild populations continue to decline and some have gone extinct. The state fishery agencies have increased their funding but wild salmon recovery remains an unrequited promise.

BMB



Homing and straying in Anadromous Fish

Kefer, Matthew L., Christopher C. Caudill. 2013. Homing and straying by anadromous salmonids: a review of mechanisms and rates. Reviews in Fish Biology and Fisheries March 2014, Volume 24, Issue 1, pp 333-368

Abstract

There is a long research history addressing olfactory imprinting, natal homing, and non-natal straying by anadromous salmon and trout (Salmonidae). In undisturbed populations, adult straying is a fundamental component of metapopulation biology, facilitating genetic resilience, demographic stability, recolonization, and range expansion into unexploited habitats. Unfortunately, salmonid hatcheries and other human actions worldwide have affected straying in ways that can negatively affect wild populations through competitive interactions, reduced productivity and resiliency, hybridization and domestication effects, and outbreeding depression. Reduced adult straying is therefore an objective for many managed populations. Currently, there is considerable uncertainty about the range of ‘natural’ stray rates and about which mechanisms precipitate straying in either wild or human-influenced fish. Research in several disciplines indicates that adult straying is affected by endocrine physiology and neurological processes in juveniles, incomplete or interrupted imprinting during rearing and emigration, and by complex interactions among adult maturation processes, reproductive behaviors, olfactory memory, environmental conditions during migration, and senescence physiology. Reported salmonid stray rates indicate that the behavior varies among species, among life-history types, and among populations within species. Most strays enter sites near natal areas, but long-distance straying also occurs, especially in hatchery populations

that were outplanted or transported as juveniles. A majority of past studies has estimated straying as demographic losses *from* donor populations, but some have estimated straying *into* recipient populations. Most recipient-based estimates have substantiated concerns that wild populations are vulnerable to swamping by abundant hatchery and farm-raised strays.

With some searching around one can find estimates of natural stray rates for wild salmonids. Natural stray rates for wild salmonids should be used to determine the level of strays from artificially produced fish that could be the least risk to the native, wild population. "Homing to the natal site is the characteristic behavior in all salmonids; about 95-99% of the fish that survive to adulthood do so." (Quinn 2005) National Research Council (Upstream 1996) "Therefore, the estimated rate of straying among these local breeding populations (Klamath River chinook) is about one stray per year within each reproductive population. (page 150) Christie et al. 2011 Studies have found that the rate of straying for wild steelhead is typically between 1% and 3% (Shapovalov & Taft 1954; Quinn 2005; Keefer et al. 2008).

A stray rate of 10% has been adopted by the fishery management agencies based on recommendations by the HSRG. It is likely that this "official" stray rate is based on making room for hatchery operations in the salmonid ecosystem. Since there is no effective way to preclude hatchery strays from spawning and interacting with wild salmonids ecologically, the stray rate criteria are meaningless. It is also unusual for such criteria to be an active agent of control for hatchery origin fish and is unlikely to be effectively implemented. BMB



Coho salmon shifts in the spatial arrangement of habitat conditions through time

Jeffrey R. Baldock, Jonathan B. Armstrong, Daniel E. Schindler, Jackie L. Carter. 2016. Juvenile coho salmon track a seasonally shifting thermal mosaic across a river floodplain. *Freshwater Biology*. DOI: 10.1111/fwb.12784

(This study builds on the accumulating information regarding the meaning of locally adapting populations of salmonids by showing fine scale use of fluctuating habitats for rearing and growth. As the authors conclude: "In river ecosystems, allowing the processes of erosion, deposition and succession to play out across floodplains is likely critical for producing and maintaining the shifting habitat mosaic and the growth opportunities they provide for fishes and other mobile taxa.")BMB

Summary:

1. Seasonal variation in river water levels creates a shifting mosaic of habitat conditions associated with variables such as water temperature, chemistry and prey availability to consumers. Previous work has shown that fishes can exploit spatial variation in water temperature, but less is known about how they respond to shifts in the spatial arrangement of habitat conditions through time.
2. Juvenile coho salmon (*Oncorhynchus kisutch*) are the numerically dominant fish species in many southwest Alaskan streams, which exhibit seasonal variation in water level and temperature due to changes in precipitation and snowmelt. We assessed the degree to which juvenile coho salmon exploit the associated shifting mosaic of water temperature by monitoring the spatial distribution of water temperatures and juvenile coho salmon in the lake-influenced reaches of a southwest Alaskan stream. We also monitored the diets of juvenile coho salmon relative to the spatial distribution of prey taxa.
3. Juvenile coho salmon exhibited two scales of movement to track spatiotemporal variation in habitat conditions. First, over the course of 6 weeks, individuals moved among off-channel units, tracking shifts in the location of warm water habitat caused by receding water level. Second, individuals moved at diel time scales, foraging on benthic macroinvertebrates in the cold thalweg of the stream at night and then digesting prey in warmer off-channel habitats during the day.
4. Seasonally asynchronous variation in water temperature among off-channel habitat units produced portfolio effects in habitat conditions, such that coho salmon had continual access to warm habitat for digestion despite its ephemeral availability at discrete locations.

5. Our study demonstrates that behavioural thermoregulation by juvenile fishes can be important throughout the growing season and is not restricted to ephemeral events such as resource pulses or heat stress. Our results have implications for the conservation of highly connected, heterogeneous landscapes, and their ability to support economically and ecologically important species such as coho salmon.

“How organisms exploit shifting habitat mosaics – especially on fine spatial and temporal scales – remain poorly understood and represents a key knowledge gap in developing habitat conservation strategies and habitat restoration goals for floodplain rivers.

“...inundated floodplains serve as important spawning and nursery habitats for fish that spend most of their lives in the main stem of large rivers...our understanding of how interhabitat fish movements track changes in habitat conditions is limited.

“On finer time scales, mobile organisms exploit spatial contrasts in environmental conditions through cyclic habitat use, such as diel horizontal migration (DHM). For example, sub-adult bull trout (*Salvelinus confluentus*) moved between deep pools and channel margins in response to changes in light intensity, presumably for feeding purposes.

“Armstrong et al. (2013) showed that juvenile coho salmon (*Oncorhynchus kisutch*) exhibit DHM behaviour to exploit spatial heterogeneity in water temperature and trophic resource subsidies – gorging on eggs in cold water where sockeye salmon (*O. nerka*) spawn and then moving upstream to warmer areas to digest their unusually large meals. However, over a 5-year period during which mean stream flows varied more than 5-fold, the spatial patterning of water temperature shifted. Under low-flow conditions, juvenile coho salmon performed DHM along the longitudinal axis of streams by feeding on high-quality salmon eggs in cold water and then migrating upstream to digest in warm headwater reaches.

“Under high-flow conditions when longitudinal variation in temperature was eliminated, coho salmon moved into off-channel habitats to access warm digestive habitat that was not available during low-water conditions. Thus, juvenile coho salmon adjusted their DHM behaviour to continually access warm patches of habitat in the face of interannual variation in the spatial patterning of water temperature (Armstrong & Schindler, 2013).

“One question that remains is whether fish can track mosaics of temperature that shift at finer time scales, such as within a single season. Stream water levels exhibit large fluctuations during the early portion of the growing season in Alaska, yet little is known about how fish track thermal heterogeneity across river floodplains during this energetically critical period.

“The high-quality resource pulse provided by spawning sockeye salmon in streams is highly ephemeral compared to the length of the growing season for juvenile coho salmon. In the Wood River system of southwest Alaska, the period over which trophic subsidies are available to consumers may be less than 3 weeks within a single stream (Schindler et al., 2010), <1/4 of the growing season (June–Sept.). The ability of juvenile coho salmon to exploit the short, high-latitude growing season is likely critical as juvenile body size is generally positively correlated with smolt-to-adult survival in coho (Holtby, Andersen & Kadowski, 1990) and other Pacific salmon species (e.g. Henderson & Cass, 1991; Koenings, Geiger & Hasbrouck, 1993). Feeding on stream invertebrates in the early summer before the arrival of marine-derived subsidies from spawning salmon likely provides the resources coho salmon the need to rebuild depleted energy stores and grow large enough to exceed the size threshold for consuming salmon eggs (~70 mm fork length; Armstrong et al., 2010).

“During the early growing season, stream water temperatures may be quite cold, as stream thermal regimes are dominated by snowmelt and backwash from downstream lakes. Whether juvenile coho salmon exploit spatiotemporal variation in water temperature and in situ trophic resources is not understood.

“We quantified how juvenile coho salmon interact with spatial and temporal heterogeneity in water temperature and in situ prey resources during the early portion of the high-latitude growing season of a small floodplain river. We (i) mapped the shifting mosaic of water temperatures available to juvenile coho salmon during June and July, (ii) characterised the benthic invertebrate prey community available across this mosaic, and (iii) monitored the spatial distribution and foraging behaviour of coho salmon in response to seasonal shifts in the patterning of thermal and trophic resources across the flood plain as water levels changed.

“The spatial patterning of water temperature across the stream–floodplain complex of lower Bear Creek shifted over the early summer feeding period as water levels receded. The observed patterns were consistent across multiple years; however, the exact date at which certain shifts occurred differed due to substantial interannual variation in lake level dynamics. Typically, lake level peaked in early June and then declined throughout the summer (Fig. 2). In some years, major precipitation events resulted in a rise in lake level during this overall period of decline, but never during the early portion of the growing season prior to the arrival of spawning sockeye salmon.

“High lake levels inundated the floodplain in the downstream portion of Bear Creek (up to 300 m upstream of mouth). While lake inundation greatly increased the area of off-channel habitat, the effect on water temperature was spatially variable (Fig. 3). The thalweg and lake were cold during the period of peak lake levels (24-h mean = 5–8 °C). Portions of the floodplain influenced by stream flow or wave action remained cold, whereas areas with stagnant water warmed substantially (mean of point measurements = 12.5 °C). The off-channel unit at the edge of lake inundation was warmest; as lake level receded, the location of warm, stagnant bodies of water shifted as units either became dominated by upwelling groundwater (~3 °C, unit A: ~107 cm) or dewatered.

“This progression of off-channel units sequentially characterised by relatively warm water conditions was consistent across 6 years of variable lake dynamics.

“Over the course of the early summer, the spatial distribution of juvenile coho salmon shifted among off-channel habitats as lake level receded (Fig. 4), and was coordinated with shifts in the thermal landscape.

“As water level receded, the distribution of juvenile coho salmon shifted to track the spatial patterning of warm water in the floodplain (i.e. from unit A to B, and B to C as each unit warmed and subsequently cooled or dewatered) although the exact lake level at which shifts occurred differed slightly among years due to interannual variability...

“Juvenile coho salmon exhibited a strong affinity for warm water and were never observed in off-channel units with temperatures that were equivalent or colder than the thalweg. On average, off-channel habitat units occupied by juvenile coho salmon were 4.1 °C warmer than adjacent thalweg habitat.

“A comparison of the benthic macroinvertebrate community between off-channel and thalweg habitats, and fish diet contents demonstrated that juvenile coho salmon made high-frequency cyclic movements between these habitats, coupling areas of high digestive capacity (warm-off channel) with areas of high foraging potential (cold thalweg). Analysis of the benthic macroinvertebrate community revealed distinct differences in the taxa associated with thalweg and off-channel habitat types. There was a significant difference in the invertebrate communities representative of off-channel versus thalweg habitats. Diptera were common in off-channel habitats and Plecoptera larvae were common in the thalweg. A significant, 62-fold difference in the relative abundance of Diptera versus Plecoptera larvae was found in off-channel habitats. Despite differences in the invertebrate prey communities, the diets of fish caught in either habitat type were remarkably similar. There was a statistically significant difference in the diets of fish caught in alternate habitats.

“Our results support previous work describing how scales of movement are driven by scales of change in resource availability (van Moorter et al., 2013). The behaviour we document here complements earlier observations in this system where juvenile coho salmon were shown to track interannual variation in the spatial patterning of water temperature that arises due to variation in summer precipitation (Armstrong & Schindler, 2013).

“The striking shifts in the abundance of coho salmon among the three units provide strong evidence that fish were indeed tracking the shifting mosaic of water temperature. These results build on prior work illustrating how intact, heterogeneous landscapes produce portfolio effects in habitat quality that buffer mobile organisms from variation in environmental conditions. (Kindvall, 1996; Oliver et al., 2010; Schindler, Armstrong & Reed, 2015)

“In high-latitude freshwater systems, it is well known that fish lose energy overwinter due to resource scarcity and reduced physiological performance and that positive energy balance may be restricted to as few as 1–4 months of the year (Conover, 1992; Biro et al., 2004). During this brief growing season, juvenile fish must not only grow towards adult size but also recover from overwinter nutritional stress and acquire energy stores for the following winter.

“Our study showed that behavioural thermoregulation can be an important tactic for coho salmon not only during the high-magnitude pulsed subsidies of marine-derived resources during late summer and fall [sockeye salmon spawning] but also while fish are targeting invertebrates and in situ trophic pathways earlier in the growing season.

“Our analysis suggests that juvenile coho salmon reside in warm off-channel habitat during the day to accelerate assimilation (i.e. the process that spans digestion and absorption) and perhaps to opportunistically feed, although any contribution to total dietary needs appears slight. At night, many of these individuals leave off-channel habitats, making feeding forays into the cold thalweg.


“We argue that coho salmon residing in warm-off channel habitats experience increased growth rates by relieving thermal constraints on assimilation (as well as other physiological processes). We have shown experimentally that our study fish require multiple days to assimilate large meals and that the cold temperatures in the thalweg severely constrain assimilation.

“Ecological simplification (e.g. reduced niche diversity) due to loss of landscape complexity and ecological integrity is diagnostic of human-dominated landscapes worldwide and shoreline armoring directly suppress the mechanisms that generate and maintain active floodplains that provide growth opportunities to mobile organisms.

“Most habitat restoration efforts focus on engineering ‘desirable’ habitat features (Roni, Hanson & Beechie, 2008) due to strict and narrowly defined aspects of river systems put forth by environmental legislation (e.g. US Clean Water Act, US Endangered Species Act). Restoration efforts may have improved success if they instead address key landscape dynamics that are often overlooked, but ultimately responsible for nested biotic responses.

“Restoring landscape complexity (including the processes responsible for spatially and temporally variable temperature regimes) would allow for the natural formation of habitats that are flexible to environmental variability and would foster the resilience and stability of animal populations that inhabit them.

“This study highlights the biological importance of microhabitat features generated and maintained by multiple interacting landscape processes. We showed that juvenile coho salmon employ multiple scales of movement to exploit asynchrony in resources (temperature and food) within the context of the shifting habitat mosaic of a stream delta ecotone; this strategy should allow fish to increase energy acquisition during a critical life stage.

Further, we demonstrate how intact floodplains generate portfolio effects in habitat conditions, in which asynchronous variation among habitats reduces the probability that conditions will become unsuitable across the aggregate of habitats available to mobile organisms. In river ecosystems, allowing the processes of erosion, deposition and succession to play out across floodplains is likely critical for producing and maintaining the shifting habitat mosaic and the growth opportunities they provide for fishes and other mobile taxa. 

FISH AND WARM WATER DON'T MIX

Planning for the heat could help avoid a repeat of the disaster of 2015.

JUNE 20, 2016

JOHN HARRISON

<http://www.nwcouncil.org/news/blog/sockeye-warm-water-update-june-2016/>



Heat-stressed sockeye in the Little White Salmon River, a Columbia tributary, 2015. Seattle Times photo.

Federal and state fisheries managers are watching the weather carefully, and a bit nervously, this year, hoping the summer of 2016 won't be a repeat of the disastrous summer of 2015 when hot weather led to extreme water temperatures in the Columbia River and its tributaries and the deaths of more than a quarter million fish, most of them summer-migrating sockeye salmon. Agency representatives discussed their emergency preparations with the Council at a meeting last week.

About a half million sockeye returned from the ocean last June and July, but more than half died as they migrated in the spa-like river, particularly in the 146 miles between Bonneville and McNary dams on the Columbia. The forecast sockeye return this year is much smaller – 101,000 fish -- but it could be higher. The run so far is above the number counted this time last year, and river water so far has been cool – below 68 degrees.

Water warmer than 68 degrees not only stresses fish metabolism but also increases the growth of pathogens that lead to fish diseases; many of the fish that died in the extreme heat last year had evidence of fungus and disease. In places, Columbia River water was in the 70s and the Okanagon River, a major sockeye tributary, was close to 80 degrees. Only about 10 percent of the returning Snake River sockeye, an endangered species, lived to spawn, and some of those were trucked from Lower Granite Dam to a hatchery.

If temperatures rise again this summer, more fish will likely die, but fish and dam managers are ready to respond quickly and have a rapid-response plan to coordinate actions. Options include releasing cold water from upriver storage reservoirs like Grand Coulee and Dwoshak dams, temporary suspensions of fishing seasons, and piping cold water from deep below the surface into adult fish ladders to attract fish and help them pass the big dams.

See more information from the Columbia Basin Report: <http://www.cbulletin.com/436997.aspx>



Warm temperatures mean decline in Pacific salmon

By Marc Montgomery
Tuesday 21 June, 2016

Record warm temperatures have been recorded along the Pacific coast of North America this past week.

Last year also saw record heat in and around the Pacific.

The federal agency known as Fisheries and Oceans Canada (DFO) has just released a report saying the high temperatures will result in declines in Pacific salmon for at least the next three years.

“We’ve seen the warmest winter temperatures [and] water temperatures ever observed in the northeast Pacific in 2014 and 2015,” said Dr. Ian Perry, a research scientist with the DFO. Reports indicate that ocean temperature in 2016 are the highest recorded.

The report said five species of salmon in British Columbia will be negatively affected: sockeye, pink, chinook, coho, and chum.

Warm temperatures bring predators, pathogens, poor food supply

The DFO panel said at a Monday press conference that the warmer ocean currents have disrupted the regular food supply by bringing smaller and less nutritious food supply to the Pacific salmon. At the same time the warmer water is attracting predators like shark and mackerel that feed on young and old salmon.

Warmer temperatures and less precipitation have also had a negative effect upon the salmon through lower river levels and higher water temperatures which reduces migration ability along with survival, and spawning.

Temperature anomalies are expected to continue, they said, bringing along with them salmon-attacking pathogens that thrive in warmer water.

Many British Columbia salmon fishing areas will be closed to commercial operations and in rare cases only local aboriginal fishing will be allowed.

Chief Bob Chamberlin of the Union of BC Indian Chiefs (UBCIC), who observed the press conference on Monday morning, was quoted in the National Observer saying the “principles” of the Cohen report are what’s going to save B.C. salmon, but first, DFO needs to talk about climate change. The Cohen report — and in particular the 2005 Wild Salmon Policy — must now be examined through the lens of global warming, he explained, and expanded upon in collaboration with First Nations.

Cohen Commission: <http://cohencommission.ca/about/>

DFO- wild salmon policy:

<http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especies/salmon-saumon/wsp-pss/index-eng.html>

