

Anadromous salmonids on the patagonian Shelf: riders of the cold estuarine southern zone?

Miguel Pascual, Javier Ciancio & Carla Riva Rossi¹

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¹ Centro Nacional Patagónico, CONICET, Puerto Madryn, Chubut. E-mail: pascual@cenpat.edu.ar

Introduction

Pacific salmon are important components of river ecosystems throughout their native range. By way of their amphidromous life cycle, salmon provide a link between marine and freshwater ecosystems, importing nutrients from the oceans, where they attain most of their growth, to the rivers, where they spawn and, in the case of most species, die (Ben-David et al., 1998). The ensuing fertilization effect improves rearing conditions for juvenile salmonids (Bilby et al., 1996), a positive feedback that we will hereafter call *the anadromous salmon feedback loop* (ASFL). Nutrients imported by salmon from the oceans permeate riverine food webs, with far reaching effects on freshwater ecosystems of the Pacific Rim (Willson and Halupka, 1995; Naiman et al., 2002).

While Pacific salmon have helped define the quality of life in the North Pacific of North America for centuries and are important to the region for historical, cultural, economic and ecological reasons, the productive capacity of streams and rivers of the region is declining. Streams are producing fewer and fewer fish as a result of human induced changes, including urban and industrial development, roads and highways, agriculture, fisheries, forestry, and hydropower development (www.nwr.noaa.gov). The results are dramatic: salmon have disappeared from over 40% of their historical breeding ranges in Washington, Oregon, Idaho, and California and many remaining populations are severely reduced (NRC, 1996).

Meanwhile, salmonids have been among the most successfully introduced species around the world (Lever, 1996). But while river-resident species and varieties have colonized freshwater ecosystems in all continents (MacCrimmon, 1971), the establishment of anadromous populations has been more uncommon (Pascual and Ciancio, in press). Yet, a budding collection of cases is starting to show that anadromous salmonids have been rather successful at colonizing rivers of Patagonia, the southernmost region of Chile and Argentina (Figure 1, Table 1). Exotic anadromous salmonids are being heralded both as exceptional natural resources that help promote a fast emerging eco-tourism industry (thousands of web pages on flyfishing in Patagonia), and as a threat to a poorly known native freshwater biodiversity (Pascual et al., 2002). Anadromous salmonids can also affect marine

communities (Pascual and Ciancio, in press). While there has been a tendency to neglect the potential effects of introduced salmon on apparently boundless marine resources, some preliminary results indicate that food consumption by medium size salmon populations can be significant (Pascual, 1997; Pascual and Ciancio, in press).

Table 1: Anadromous salmonids in Argentinean Patagonia. (?) indicates tentative data

Species	Location	Origin	Year	References
Chinook salmon <i>Oncorhynchus tshawtscha</i>	Chubut Province: -Futaleufú, Corcovado and Pico R.	Chile's net pen aquaculture or ranching experiments	1980+	Di Prinzio (2001)
	Santa Cruz Province: -Santa Cruz R.	Ranching experiments in southern Chile, originally from U. of Washington hatchery	1983+	Ciancio et al. (unpublished info) Becker, 2004
Steelhead rainbow trout <i>Oncorhynchus mykiss</i>	Santa Cruz Province: -Santa Cruz R.	McCloud River	Early 1900's	Pascual et al. (2001) Riva Rossi et al. (2004)
Sea-run brown trout <i>Salmo trutta</i>	Santa Cruz Province: -Gallegos R.	?	1930's(?)	---
	Tierra del Fuego Province: -Grande and Ewan R.	?	1940's(?)	---
	Malvinas/Falkland: - San Carlos, Malo, and Murrel R. (E. Island) - Warrah and Chartres R. (W.Island)	Chile, US, England, Scotland	1940's	McDowall et al. (2001) Stewart (1980)

Anadromous salmonids in Patagonian rivers provide a contrasting view with that of declining populations in North America. In fact, two of the most threatened species in the north ---chinook and steelhead rainbow trout--- are among the thriving invaders in the south. Anadromous salmonids in the Northern and Southern Hemispheres can therefore be regarded as two sides of the same coin. The success in the South hints at the existence of particular habitat characteristics or dynamic processes, both in-river and in the ocean, that facilitate the occurrence of anadromous species and life history types. From the perspective of salmon conservation in North America, unraveling what those processes and characteristics are can point to crucial determinants of the health of salmon habitat and populations in their native range. From the perspective of freshwater conservation in South America, the same kind of information can help understand what determines the

invasiveness of particular anadromous species and the invasibility of river ecosystems. It can also help understand what their impacts on receiving ecosystems might be.

Within this general view, and in the framework of the Antorchas project, we are investigating:

- a. The trophic role and potential effects of exotic anadromous salmonids in receiving marine communities.
- b. How oceanographic processes, both physical and biological, affect and modulate distribution, population size, productivity and life history in exotic anadromous salmonids.

Ecology of anadromous salmonids

The basic life cycle of anadromous salmonids encompass a freshwater rearing period (few months to 3 years depending on species and stocks), an estuarine/open ocean life period (one to seven years depending on species and stocks) until maturation, and a homeward migration to freshwater where they spawn and, in the case of several species, die.

The marine stages of the life cycle are characterized by extensive migrations. In fact, salmonids provide some of the most dramatic cases of long-range migration in the animal kingdom. For example, sockeye salmon (*Oncorhynchus nerka*) from the Pacific Coast of North America can migrate as far as 6000km from their native rivers (Burgner, 1991). But the marine distribution of salmonids is extremely variable; for example, introduced salmonids are known to have developed less extensive distributions than those of their parental stocks, as is the case of chinook salmon introduced in New Zealand (Unwin and James, 1998). As they grow in the ocean, salmon occupy different trophic roles, from forage fish as juveniles to top predators as maturing fish.

Juvenile salmon are known to utilize river plumes and frontal regions as transitional nursery habitats and to capitalize on their relatively high prey densities (St. John et al. 1992). The initial weeks-to-months of ocean life are critical for determining recruitment success in salmonids, and it has been shown that salmon with the highest growth rates are the most

likely to survive (Pearcy, 1992). It therefore appears likely that juvenile salmon gain a critical advantage in survival if they arrive in a coastal area rich with fronts. In fact, the value of fronts to salmon is emerging as a focal point in the ocean ecology of salmonids, provided that the distribution of fish is clearly associated with characteristics of frontal areas (Brodeur et al., 2000).

Anadromous salmonids in Argentinean Patagonia

At the turn of the century, when Patagonia was still a remote and unpopulated wilderness, the federal Argentinean government was already considering the introduction of fish species for sport and commercial uses. Between 1904 and 1910 eight major shipments of salmonid eggs were sent to Patagonia from the U.S (Pascual et al., 2002). In the next 20 years, local hatcheries, complemented by private efforts from European settlers, continued to raise and plant salmonids throughout the region. As a result, landlocked salmon, rainbow, brown, and brook trout inhabit today nearly every lake and stream in Patagonia (Pascual et al., 2002), and sustain some of the most attractive trout fisheries in the world.

In recent years, fishermen, administrators, and scientists became aware of the presence of different populations of anadromous salmonids in river basins throughout the region (Table 1). A number of research projects have been started to study some of these populations from three viewpoints: their adaptation to the new environments (Di Prinzio, 2001; Becker, 2004; Riva Rossi, 2004; Riva Rossi et al., 2003; Riva Rossi et al., 2004), their management as sport fish (Arguimbau, 1999); and their impact on the receiving communities (Javier Ciancio, PhD thesis underway).

The various anadromous species and populations found in river basins of Patagonia have different origin and acclimatization history (Table 1). Anadromous rainbow trout in the Santa Cruz River originated from eggs brought from the Sacramento River in California in the early 20th century to establish wild populations (Riva Rossi et al., 2004). Anadromous brown trout in Santa Cruz and Tierra del Fuego Provinces and in Malvinas Islands were introduced later, but with the same goal. Meanwhile, chinook salmon has colonized both Atlantic and Pacific basins of Patagonia from aquaculture initiatives in Chile. In the case of Pacific basins of the Chubut Province, the most likely source is net-pen aquaculture in

Chile's X Region. Chinook salmon in the Santa Cruz River, on the other hand, originated from a ranching experiments in Chile's XII Region, near Punta Arenas and Puerto Natales, invading Atlantic basins of Argentina through the Strait of Magellan or the Beagle Channel (Becker, 2004).

What is currently known about the distribution and trophic position of different species in the ocean is part of a finished PhD thesis (Riva Rossi, 2004) and a PhD thesis underway (Javier Ciancio, U.Nac.Comahue). In general, salmonids appear to be more abundant in ocean waters of southern Patagonia (south of San Jorge Gulf). Sea surface temperatures at these latitudes correspond to those preferred by salmonids in the north Pacific ocean. Meanwhile, the water of northern locations appears to be too warm for the development of salmon populations. Correspondingly, anadromous salmonids are found in rivers south of 50° S.

Chinook salmon catches in the ocean, as reported by commercial bottom trawlers, come from a relatively small area, between lats 49 and 50°S, and at depths of 80-100m. Stable isotope analysis indicates that chinook salmon might have a diet similar to that of magellanic penguins in colonies of Southern Santa Cruz province, most likely based on patagonian sprat (*Sprattus fueguensis*). Rainbow trout catches, on the other hand, occur over a much wider latitudinal range along the coast and have been mostly reported by coastal sport fishermen. However, carbon isotope signals indicate a stronger association of this species to oceanic waters than chinook salmon. Nitrogen signatures indicate that rainbow trout are feeding on lower levels in the food web than chinook salmon. The overall picture of catches and isotope analysis indicate that rainbow trout may have a wider and shallower distribution than chinook salmon, feeding most likely on marine invertebrates.

Major research themes associated to the Antorchas project

Links between anadromous salmonids and ocean fronts of southern Patagonia

The current picture we possess of salmon distribution is at a coarse grain. Interactions and effects of salmon, as well as conditions that affect their life cycle, will occur at a much smaller scale. But unlike large fishery resources where distribution and abundance can be

studied through surveys and observer programs, salmon occurrences in the ocean as recorded by our current methods are rare events. Distribution and abundance have then to be reconstructed from bits and pieces of information coming from indirect techniques, such as satellite imagery, isotope analysis and indirectly from the distribution of preys.

In correspondance to the main hypothesis of the Antorchas project, by which major ecological processes and biodiversity are expected to be associated to boundary systems, we hypothesize that salmon also has to be associated to such areas. Therefore, the study of the genesis and characteristics of patagonian shelf fronts can help us construct and refine distributional hypothesis for salmon during their ocean life, further defining interacting species.

Links between the Pacific and the Atlantic Oceans through the anadromous salmon life cycle

Basic salmon biology, together with the overall oceanographic characteristics of the continental shelf, and our data on salmon occurrences in Patagonian waters indicate that over the continental shelf salmonids are most likely to be associated to the cold estuarine zone generated by the patagonian current in southern Patagonia (Acha et al., 2004; Sabatini et al., 2004). The oceanographic dynamics of this region are strongly modulated by the water exchange between the Pacific and the Atlantic oceans, through the Drake Passage, the Beagle Channel, and the Strait of Magellan. The colonization of the Santa Cruz River by chinook salmon originating in ranching experiments of southern Chile hints at a strong association between salmon and such trans-oceanic oceanographic processes. This is particularly important from an applied point of view, because as net pen aquaculture in the X Region of Chile reaches carrying capacity, the salmon aquaculture frontier is moving south to the XI and XII regions. The chinook salmon experience may repeat in the future as salmon aquaculture intensifies. Even without actually colonizing Atlantic basins, salmon populations breeding in Pacific basins could conceivably use the argentinean continental shelf as foraging grounds. In fact such a behavior was anticipated in the early 1980's by Tim Joyner, who supervised ranching experiments in Chile. He proposed that salmon ranching in Chile should be conducted in southern waters where fish, favored by oceanographic currents, had ready access to rich Atlantic waters (cited by Basulto, 2003). Understanding the

oceanographic dynamics at the tip of South America may then prove critical for anticipating trans-oceanic invasion events of salmonids, as well as of other marine species with free-ranging dispersal stages.

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