# Scale, connectivity, and incentives in the introduction and management of non-native species: the case of exotic salmonids of Patagonia

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## ABSTRACT

Several accidentally introduced species have taken over large areas of the world, producing millions of dollars in damages. The introduction of such pest species is universally condemned, while science and management efforts are geared towards eradication, containment, or prevention of future infestations. Meanwhile, another list of organisms is actively traded around the world, for food, fun, or aesthetic reasons, providing examples of the conflict between human development and conservation. When dealing with such species, are there ways to balance the competing goals of economic production and protection of nature? How can science help to identify suitable compromises? We attempt to answer these questions by analyzing three case studies dealing with exotic salmonids in Patagonia: trout aquaculture in shallow fishless lakes, trout recreational fisheries, and marine net pen salmon aquaculture. We propose that three interrelated properties of these case studies, scale, connectivity, and incentives for conservation, determine opportunities to reverse damaging situations and our ability to identify and promote situations that balance production and the integrity of nature.


## IN A NUTSHELL

- In the southern hemisphere, trout and salmon are economically valuable and wide ranging exotic species, with significant ecological effects.
- Three case studies of salmonids in Patagonia are used to show that as the scale of natural resource use increases, direct incentives for remedy diminish, and reversibility becomes less of an option.
- Regional governance and science need to be rethought and scaled up to meet the challenge of finding a balance between the use of natural resources and the integrity of nature.

## INTRODUCTION

The list of “most wanted” non-native species is dominated by accidentally introduced organisms that have already taken over large areas of the world, producing millions of dollars in damages. It is not difficult to raise public concern and spur government action when a new species poses direct threats to everyday life. Take as an example the Asian longhorn beetle (*Anoplophora glabripennis*), a tree-killer, which if left unchecked, could in a couple of decades destroy one-third of all urban shade trees in the US, with a replacement cost as high as $600 billion (Jenkins 2002). The introduction of such pest species is universally condemned, with science and management efforts geared towards eradication, containment, or prevention of future infestations (Myers et al. 2000).

Meanwhile, an alternative list of organisms is actively traded around the World, for food, fun, or aesthetic reasons. This list includes practically all domesticated plants and animals used as crops, livestock, garden plants, pets, and aquaculture species. While many of them can clearly be kept under control, many others escape from pots and pens, creating feral populations, often with large environmental costs. The introduction of species of commercial value exposes many of the intricacies involved in human development and environmental conservation.

Salmonids, which are non-native to the southern hemisphere, provide an interesting case study of this divide. They are highly valued species, used for both food and recreation. They can be found in receiving environments under a full range of confinement regimes, from strict captivity, to feral populations spreading over multiple river basins (Figure 1). Provided the right habitat, they are highly invasive, wide ranging, and dominant in recipient communities, with significant community-wide effects.

Questions arise: Can we balance demands for production with the integrity of nature? How can science and management help to achieve and promote such situations? In this review we attempt to provide some answers to those questions by analyzing three case studies dealing with exotic salmonids in Patagonia (Figure 2): trout aquaculture in shallow fishless lakes, trout recreational fisheries in lakes and rivers, and marine net pen salmon aquaculture. For each case study, we review our current state of knowledge and identify major uncertainties. We also analyze the positive and negative impacts brought about by exotic salmonids, discussing the prospects for finding suitable compromises. Finally, we propose that three interrelated properties of these case studies, scale, connectivity, and incentives for conservation, determine our ability to identify and promote such situations.

## THREE CASE STUDIES IN PATAGONIA

### Trout aquaculture in shallow meseta lakes

Only four large rivers flow east from the Andes to the Atlantic Ocean across the central steppe of continental Patagonia, an expanse of 14º of latitude. Some areas of this region, however, are spotted by natural depressions that collect water from snow and ice melt (Canevari et al. 1988). In the Santa Cruz Province alone, 10 different plateaus or "mesetas" hold a remarkable array of closed --or endorheic-- lakes, naturally devoid of fish (Figures 2 and 3). The strong wind characteristic of Patagonia forces the vertical mixing of the water, making these lakes very productive, often with a healthy cover of aquatic plants and a rich waterbird fauna.

We will focus our analysis on one of these plateaus, the Strobel Meseta (Figure 2, 48º30`S, 71º20´W, 900m a.s.l, 2500km$^2$), which holds over a thousand shallow lakes of various shapes and sizes (Figure 3). This meseta is a prime home for the hooded grebe, *Podiceps gallardoi*, a highly endemic, charismatic species (Figure 3) discovered in 1974 and listed as Near Threatened (BI 2004), and represents prime habitat for other 17 waterbird species, including threatened endemic species like the magellanic plover (*Pluvianellus socialis*) and the spectacled duck (*Anas specularis*).

Shallow-lake trout aquaculture in Santa Cruz started in the Strobel Meseta where today the activity is the most active in the region. In 1995, a landowner in search of alternatives to the more traditional sheep ranching stocked a few lakes with rainbow trout (*Oncorhynchus mykiss*), generating a growing aquaculture activity. Trout thrived on a natural diet of crustaceans, largely highly abundant amphipods. To date, 37 lakes have been planted (about 1400ha) with a potential annual production estimated at 55mt, an income of over US$120,000 and 25 direct jobs. Lakes under production represent about one half of the area suitable for trout aquaculture in the whole Strobel meseta and less than 15% of potentially available habitat in all Mesetas of the Santa Cruz province.

A bitter debate has been brewing between those promoting economic development through aquaculture and those concerned with the effects of trout on environmental integrity. Fishless lakes have in fact provided some of the best text book examples of community and ecosystem-wide effects of species introductions (Carpenter and Kitchell 1993, Scheffer 1998). Worse case scenarios include chronic depletions of the food of both trout and waterbirds, top down effects promoting phytoplankton blooms (so-called trophic cascades), and disruption of ecosystem structure and functioning through shading and the demise of macrophytes (so-called regime shifts).

While the debate is rooted in contrasting views about development and the environment, it is clearly fueled by the lack of locally relevant scientific information. Reissig et al. (2006) analyzed a collection of 18 steppe lakes spread throughout Patagonia, with and without introduced fish, and documented changes in plankton composition and body size in lakes with fish. This research considered a regional collection of diverse lakes, where different species of non-native fish were involved. Meanwhile, specific information is lacking on rainbow trout in mesetas lakes, a system that may not fit the archetypal case of Northern Hemisphere shallow lakes. For instance, there is a large uncertainty about the basic biology and trophic role of amphipods, the staple food of trout in these lakes. It is not clear whether the depletion of amphipods would project directly to zoo and phytoplankton, indirectly by way of trout diet shifts, or, alternatively, would be more strongly funneled to biofilms, benthos, or microbial components.

The particular setting of meseta lakes provides some opportunities for management to promote aquaculture practices compatible with ecosystem integrity. The discrete nature of these large collections of endorheic lakes allows for containment and rotation of aquaculture activities, as well as for the establishment of reserves. There is large variability in lake characteristics such as size, macrophyte cover, and turbidity, characteristics that correlate well with waterbird abundance and diversity (Julio Lancelotti, unpublished data). This situation creates opportunities for lake classification in terms of their importance for waterbirds and their quality for trout production, and for finding schemes to segregate production and critical waterbird habitat.

A characteristic of these lakes consequential for management is that fish are apparently not reproducing. In four years of work in the area we found no evidence of natural recruitment. Trout populations might then thin out and eventually disappear as plantings cease. Other important characteristics are that the system is relatively small --- 8 privately owned “estancias” span the whole meseta— and conservation incentives can be readily identified. For one, the high trout productivity is expected to depend to some degree on the health of the food base. Provided the right information, producers should be able to make the connection between aquaculture practices (loads, rotation, etc) and their benefits in terms of yields. A more direct incentive for conservation could be found in the potential effects of trout aquaculture on alternative economic activities clearly identified as potential sources of income by landowners, such as ecotourism and birdwatching, a growing industry in the region.

## Freshwater trout fisheries

In total, 15 fish species have been introduced into Patagonia, of which at least 11 have established self-sustaining populations (Pascual et al. 2007). Of those, salmonids are dominant, with three species widely distributed throughout the region: rainbow trout, brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*). There is no significant river basin in the region without some combination of these three species.

Trout recreational fisheries are quite important and growing in all districts of Patagonia (5 provinces of Argentina and the 3 regions of Chile, Figure 2). Fishing takes place in 35 major Pacific and Atlantic river basins. In 2005, over 70,000 fishing permits were sold in Patagonia, of which about 7% were bought by international fishers. An expansion of average expenditure by season by fisher (estimated in U$500 for domestic and U$2000 for international) provides annual economic revenues of over 42 million dollars. Figures on the number of jobs involved in the activity are not available, but conservative estimates based on the number of professional fishing guides registered and authorized by management agencies suggest that they may be at least a few thousand.

Issues about the use and conservation of river basins in Patagonia are strongly permeated by the conflict between the promotion of freshwater fisheries and aquaculture based on exotic salmonids and the conservation of native species (Pascual et al. 2007). There is practically no data on the composition and functioning of fish communities before the introduction of salmonids or throughout the century of salmonid establishment. Research about life history, community structure, distribution, and trophic relationships among species has started to emerge only in the last 15 years (reviewed by Pascual et al. 2007).

There is, however, some compelling evidence that the structure and function of freshwater communities have been significantly shaped by exotic fish species (reviewed by Pascual et al. 2002, 2007; Soto et al. 2006). Salmonids feed heavily on some native fishes, particularly on galaxiids and silversides. Patagonian silverside (*Odontesthes hatcheri*) was very abundant prior to salmonid introductions in places where today they are marginally abundant. While most native species show some degree of piscivory, trout are far more efficient predators of galaxiids than native predators (Macchi et al, 2007). Most studies found some degree of segregation between native and introduced species, either trophic, reproductive, geographic, or in habitat use. System level effects of salmonids in Patagonia are perhaps more conspicuously manifested through the quality of fisheries itself. Cases abound where bountiful fisheries of the past lost their quality, apparently due to top down effects of introducing top predators (Figure 4).

Major uncertainties about the ecological role and impacts on salmonids revolve around key processes in the functioning of Patagonian lake and river communities, a gigantic task when the geographic expanse and confounding processes ---stocking practices, habitat alterations, climate change and fishing pressure--- are considered (Pascual et al. 2007). In fact, basic inventory information is lacking for most river basins.

In general, containment or removal of established salmonid populations is simply not an option. Not only is impracticable from a logistic point of view, but it is unfeasible from a social perspective. Recreational, as well as economic opportunities of different sectors of the Patagonian society depend on the recreational use of salmonids. The only obvious management tools available are those related to fisheries management: supplementation and fishery regulations. Whether fisheries can be managed for the benefit of the system –species diversity, ecosystem services, fishing quality-- remains a matter of discussion (Pascual et al. 2002).

## Salmon net pen aquaculture in coastal waters

Beginning in the 1980s, the marine net-pen culture of salmon in Chile grew sharply, from a total of 53mt harvested in 1981 to well over 600,000mt today (Figure 5). The activity was initiated in Los Lagos region, but it is expanding south in search of new waters and settings. Production is dominated by Atlantic salmon (*Salmo salar*, over 60%), followed by rainbow trout (20%) and Coho salmon (*Oncorhynchus kisutch*, 17%), and a minor share by Chinook salmon (*O. tshawytscha*, less than 1%).

The growth of net pen aquaculture in Chile ---at present the leading salmon producer in the world--- is remarkable. A total of 10,000 ha are under production, with yearly incomes of over 1.7 billion dollars, and 38,000 direct and 15,000 indirect jobs provided by the activity. Salmon is today the second largest commodity exported by Chile after copper and projections made by the salmon industry contemplate a doubling in production volume by 2013 (http://www.salmonchile.cl).

In recent years, impacts attributed to salmon aquaculture have been the subject of scrutiny (Gajardo and Laikre 2003). Specific discussions on social impacts of salmon aquaculture can be found in Primavera 1997 and FAO 2006. Here we concentrate on ecological impacts, which occur at multiple scales, from local to global. At the local scale, the surroundings of net pens are impacted through the elimination of wastes (producing a kg of salmon produces 0.27-1.08kg of wastes), as well as antibiotics, vaccines, and other chemicals that salmon farmers employ, much of which can enter the water (Buschmann et al. 2006). Farms are also a source of diseases, which could be transmitted to wild fish. Wastes, chemicals, and diseases generated by salmon aquaculture are not restricted to marine waters, but also impact lakes, which are used as the primary location for net pen smolt production (León-Muñoz et al. 2007).

At the regional level, net pens have provided exotic salmon with a doorway into the wild (Castilla et al. 2005). As salmon production has increased, so have reports of fish escaping from net pens and straying into rivers in the Patagonia region of Chile and Argentina. Although these reports started as early as 1984, it was only recently that spawning and establishment of anadromous salmon populations have been confirmed in South American rivers. The most remarkable case is that of Chinook salmon, a species that despite its low share in salmon production, proved to be most successful at colonizing river basins in the region (Figure 6). Salmon add a whole new dimension to the potential environmental impacts by exotic fishes. They not only can have direct effects on freshwater communities as typical freshwater species, but they can affect marine communities as well (Pascual and Ciancio 2007). Moreover, salmon provide a novel link between rivers and oceans, importing marine-derived nutrients into fresh water. The fertilizing effects of carcasses of semelparous species (those that die in the rivers after spawning) are well demonstrated in North America (Levy 1997) and enrichment by marine nutrients is already being registered in some of the receiving rivers of Patagonia (Soto et al. 2007).

Aquaculture has developed into a highly globalized trade-dependent industry (Deutsch et al. 2007). Fishmeal and fish oil, produced in fisheries from all around the world, are key inputs to produce the feed for farmed species. Chile and Norway, the two largest salmon producers, went in recent years from being exporters of fishmeal to be active importers (Tacon et al. 2006). Aquaculture has often been heralded as an alternative to fisheries, which could help alleviate the pressure on over-exploited fisheries resources of the world (discussed in Naylor et al. 2000). The dependency on fishmeal has prompted several authors and environmental organizations to regard the aquaculture of carnivorous fish such as salmon not as much as an alternative, but as a promoter of fisheries (Pauly et al. 2002). Current Chilean salmon production consumes between 3 and 9 million mt of prey fish per year (depending on conversion rates used and the proportion fishmeal/fish oil in food). To understand the magnitude of these figures, consider annual average yields of Peruvian anchoveta (6.2 million mt) or Chilean Jack Mackerel (1,9 million mt), respectively the first and the fourth largest fishmeal fisheries in the world (Tacon et al. 2006). Oily fish typically used for fishmeal elaboration, such as anchovies, are at the base of marine food webs. The incipient development of such fisheries on the southern Atlantic Ocean has already raised concerns for their potential ecosystem effects (Skewgar et al. 2007).

Major uncertainties about salmon impacts are related to those processes and variables affecting the establishment of feral populations and their impacts once established. Research directed at identifying attributes of species and rivers that determine the probability of establishment is needed. The impacts of salmon, a largely uncharted issue, may not be insignificant (Pascual and Ciancio, 2007). Global effects are even more difficult to anticipate; they are linked to remote fishmeal fisheries and their ecosystem level effects.

High quality, disease-free waters are crucial to the quality of aquaculture products, so direct incentives exist for the salmon industry to preserve some of those attributes. Also, direct incentives may exist for the development and incorporation of technology to improve the uptake of feeds and to reduce the amount of medicines and chemicals used. Escapes can be reduced, but they are unlikely to be eliminated considering the open nature of net pen systems, the vagaries of weather and of human behavior, and the lack of direct incentives to prevent them to the point of elimination. Removal of established populations is hardly an option. The activity will depend on a sustained input of fishmeal, but the sustainable development of fishmeal fisheries will depend on governance and incentives at the local level of particular fisheries. Fisheries sustainability has become a matter of heated debate in recent years (Pauly et al. 2002, Hilborn et al. 2005), a discussion that often revolves around the sustainability of the crop itself, and seldom on effects on non-target species that do not feed back directly with the quality of harvest.

## SCALE, CONNECTIVITY, AND INCENTIVES

We presented three case studies involving extremely different geographic, economic and ecological scales (Table 1). From trout farming in small closed lakes, we moved to recreational fisheries that occur at the scale of whole river basins, and finally to ocean salmon aquaculture that extends across provincial borders and river-ocean boundaries, has financial roots of global magnitude, and ecological impacts unfolding well beyond national borders. The larger the scale of the system considered, the larger its connectivity and the degree to which impacts are exported outside of production grounds.  Salmon aquaculture, for instance, with its current geographic and economic extent, has created links and trade-offs between natural systems, users and interests across multiple scales.

Built-in incentives for environmentally sound practices will operate only if strong positive feedbacks with future revenues exist, and such incentives typically become fainter as scale and connectivity increase. For instance, keeping ecosystem integrity, profitable yields, and options for alternative activities should provide a direct incentive for landowners of Meseta ranches to favor sustainable aquaculture practices. Poor management will feed back directly with their future income and opportunities. On the other extreme, the higher-order ecosystem-level effects of salmon aquaculture through the expansion of fishmeal fisheries and the growth of escaping salmon will feedback so faintly with salmon production as to be completely irrelevant from a purely productive perspective. Incentives for counteraction are obviously more tenuous for remote impacts. Moreover, as new stakeholders arise conflicting interests multiply, sometimes in unsuspected ways. For instance, newly arrived salmon already created some recreational fisheries in Patagonia, but are generally unwelcome by those concerned with the preservation of native biota, as well as by many flyfishermen who fear they might have a negative impact on more traditional trout fisheries.

Reversibility is another important characteristic of natural systems under exploitation, because it determines the ability of the management system to respond to unexpected or unwanted outcomes. Scale, connectivity and incentives determine the practicality of reversing environmentally damaging situations. It must be understood that reversibility is not only a property of the ecological system, but has critical social and economic determinants as well. The readiness of society to revise its practices is clearly influenced by the associated costs in jobs and income. Removing trout from a fishless meseta lake is a feasible task, without apparent ramifications, but a whole-basin removal of a damaging exotic species, with recognized recreational value, is technologically daunting and socially unacceptable.

In summary, as the distribution and use of exotic species becomes broader, the scale and reach of their effects increase, stakeholders multiply, conflicting management goals emerge, direct incentives for remedy diminish, and reversibility becomes less of an option.

## PEOPLE, MANAGEMENT, AND SCIENCE

Public opinion about exotic species in Patagonia has been dominated by antagonistic views of the region´s future: either as one of the last pristine confines of the World or as a treasure island, offering great development opportunities based on its untapped resources. Governments have not been able to come up with more integral views. Opposing perspectives from different government offices or districts are not uncommon: provincial and regional governments directing nearly all efforts to promote sport fisheries and aquaculture of exotic species; national park services protecting native species from exotics in some of the same river basins. NGO´s advocacy fueled the polarization of the “development versus conservation debate”. Polarized views have, in turn, restricted the scope and integration of regional aquatic science. Fisheries biologists and aquaculturists in government and industry analyze yield from single crops, working in parallel with conservation oriented scientists in academia and NGO`s attempting to shield the environment from human activities. Different groups channel their ideas and advice through particular government offices, interest groups, or communication media.

Contrasting views need to be bridged by new perspectives that recognize that Patagonia is in reality a region under management, where sustainable development is unavoidably tied to the wise use of natural resources. When dealing with large and complex systems, it is extremely unlikely that partial views or reactive responses to specific issues could lead to sustainable use or ensure environmental integrity. We believe that only regional initiatives and programs, promoted by consortia of governments, NGO´s, private, and scientific sectors, could produce appropriate assessments of ecosystem changes, identify the drivers and the effects on ecosystem services, and design responsive plans.

It is not obvious, however, where such initiatives will emerge from. Pressured by social and economic demands, governmental agencies are largely dedicated to the promotion of new economic activities. NGO´s and private organizations can advance more integral perspectives, but their association to particular views or interest groups limits their ability to lead global initiatives. We propose that universities and associated research centers in the region, with their access to all sectors in government, private businesses, and NGO´s, have a pivotal role in leading such processes. While this may not be regarded as an essential function of academic institutions, no other organization appears to be able to generate integral perspectives on environmental matters.

Integral views will demand the support from scientific research that recognizes complex issues of large scale systems. As reflected by all three case studies, major uncertainties regarding trout and salmon in Patagonia have to do with community and ecosystem level impacts. Management requires an understanding of community and ecosystem level effects of salmonids and also how they feed back to affect fish and the quality of fishing. Meanwhile, most of the research done on aquatic systems of Patagonia is conducted at the population level, increasingly at the community level, and seldom at the ecosystem level. There is a need to promote novel research at higher ecological organization levels that could help synthesize, organize and design information taken at different scales. The new Center for the Study of Ecosystems of Patagonia (CIEP, Chile, www.ciep.cl) provides a good step in this direction. But research must go beyond the functioning of natural systems, integrating the activities of multiple users at different scales, and contemplating conflicting interests as they feed back into ecosystems functioning and services ---the benefits people receive from them (Daily et al. 1997).

Aquatic resources of Patagonia provide a typical case of resource management in an increasingly complex, globalized world, where sustainable use is an increasingly daunting challenge. Only integral, participatory management systems, supported by well-designed science have a chance to be up to the challenge.

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Table 1: Main attributes of the three case studies in this paper.

| | |
|---|---|
| *TROUT AQUACULTURE IN SHALLOW LAKES* | |
| Economic & social benefits | *Current (Strobel Meseta): annual economic revenue of US$120,000 and 25 direct jobs* |
| Ecological impacts | *Top down effects affecting supply of food for trout and waterbird. Worse case scenarios: phytoplankton blooms, disruption of ecosystem structure and functioning through shading and demise of aquatic plants* |
| Geographic scale of activity and impacts | *Current (Strobel Meseta): 37 lakes (1400 ha)*<br>*Potential (Strobel Meseta): 182 lakes (2872ha)*<br>*Basic production unit: single lake.*<br>*Economic unit: collection of lakes in an Estancia.*<br>*Impacts: restricted to single lakes for strict aquatic community, potentially larger for migrating waterbirds* |
| Management tools available | *Reserves. Stocking load, rotation, and harvest intensity* |
| Direct incentives for conservation | *Maintain community integrity and lake productivity due to impacts on:*<br>*Sustained trout production*<br>*Other activities such as ecotourism/birdwatching* |
| *FRESHWATER TROUT FISHERIES* | |
| Economic & social benefits | *Over 70,000 fishing permits sold in Argentina and Chile*<br>*Annual economic revenue of US$40-45 million. Direct jobs: at least a few thousand* |
| Ecological impacts | *Community level effects from heavy predation of salmonids on native fish and invertebrates*<br>*Declines in quality of sport fisheries by top down effects* |
| Geographic scale of activity and impacts | *35 major Pacific and Atlantic river basins, distributed throughout 5 provinces of Argentina and 3 regions of Chile* |
| Management tools available | *Supplementation; fisheries regulations: size and catch limits* |
| Direct incentives for conservation | *Maintain community integrity to sustain quality of sport fisheries* |
| *NET PEN SALMON AQUACULTURE* | |
| Economic & social benefits | *Annual production of over 600,000 mt*<br>*Income: US$ 1,7billion*<br>*Jobs: 38,000 direct; 15,000 indirect* |
| Ecological impacts | *Local: elimination of wastes, antibiotics, vaccines, etc.*<br>*Regional: escapes from net pens colonize river basins and establish populations. Impacts on marine resources.*<br>*Global: remote impacts on fisheries from around the world that produce fishmeal and oil for salmon feed* |
| Geographic scale of activity and impacts | *10,000ha under production, over three regions, 14$^o$lat.*<br>*Regional impacts expand east by way of escapes colonizing Atlantic river basins* |
| Management tools available | *Technological solutions to reduce local pollution by minimizing feed and chemicals used in farms*<br>*Minimizing escapes* |
| *Direct incentives for conservation* | *Keep clean, disease-free water on fish farm sites*<br>*Reduce economic losses by escapes*<br>*Search for dietary replacement with terrestrial plant proteins and oils* |

Figure 1: In support of the development of ranching of exotic salmon in Chile, Joyner et al. (1974) wrote "…. Is there any other way of tapping this vast Antarctic reservoir of protein? Since we cannot yet harvest krill economically by ourselves, ought we not to try to get help from some other creature better equipped by nature to do it?...". Today, introduced salmon are colonizing river basins throughout the region. In the image, Julián Gallardo, a student at the Universidad Austral de Chile, with a chinook salmon, Picacho River, Aysén, Chile.

Figure 2: Patagonia, the southern tip of South America, shared by Chile and Argentina. Text corresponds to regions cited throughout the document. Black circle: the Strobel Meseta described in the first case study.

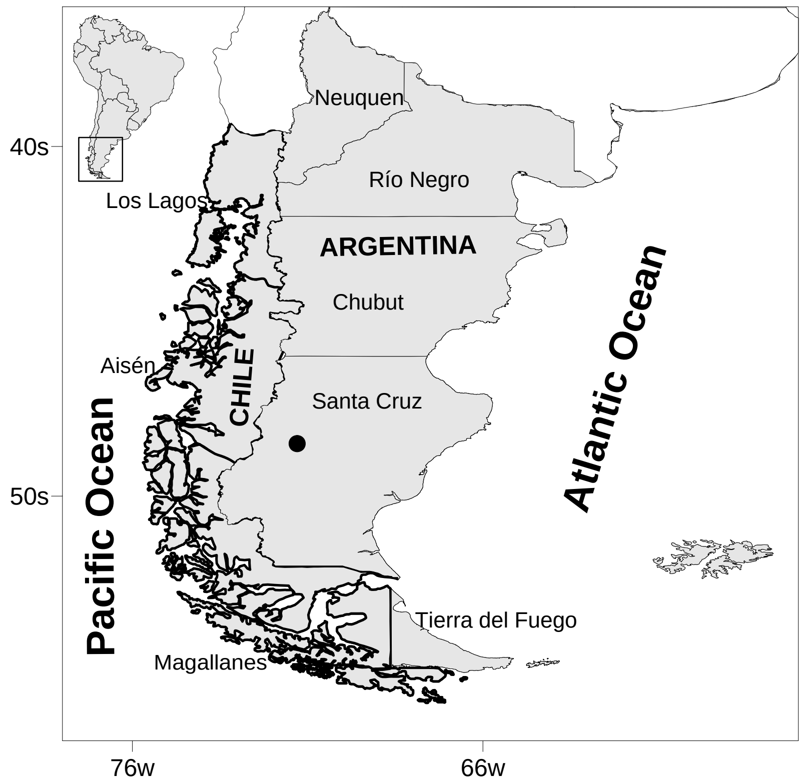

Figure 3: The Strobel Meseta lake system (a; location in Figure 2), a typical lake where rainbow trout have been introduced (b), and the hooded grebe (*Podiceps gallardoi*), an endemic species potentially affected by introduced fish (c).

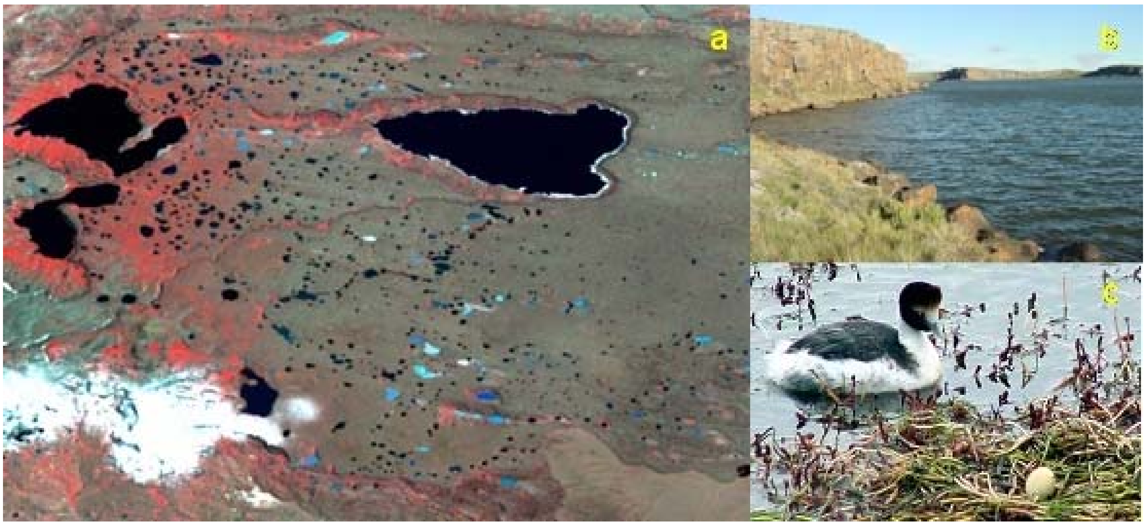

Figure 4: Picture taken in the 1940´s of Harold Hardy, a British fisherman, and his catch of brook trout (*Salvelinus fontinalis*) in the Nahuel Huapi National Park, Argentina. At the time Hardy said that for the first time in his life “he was tired of fishing” (Photo and quote extracted from a 1949 booklet on fishing in Nahuel Huapi, printed by the Argentinean National Park Service). Nowadays, it would be exceptional to catch brook trout of this size in the same sites visited by Hardy.

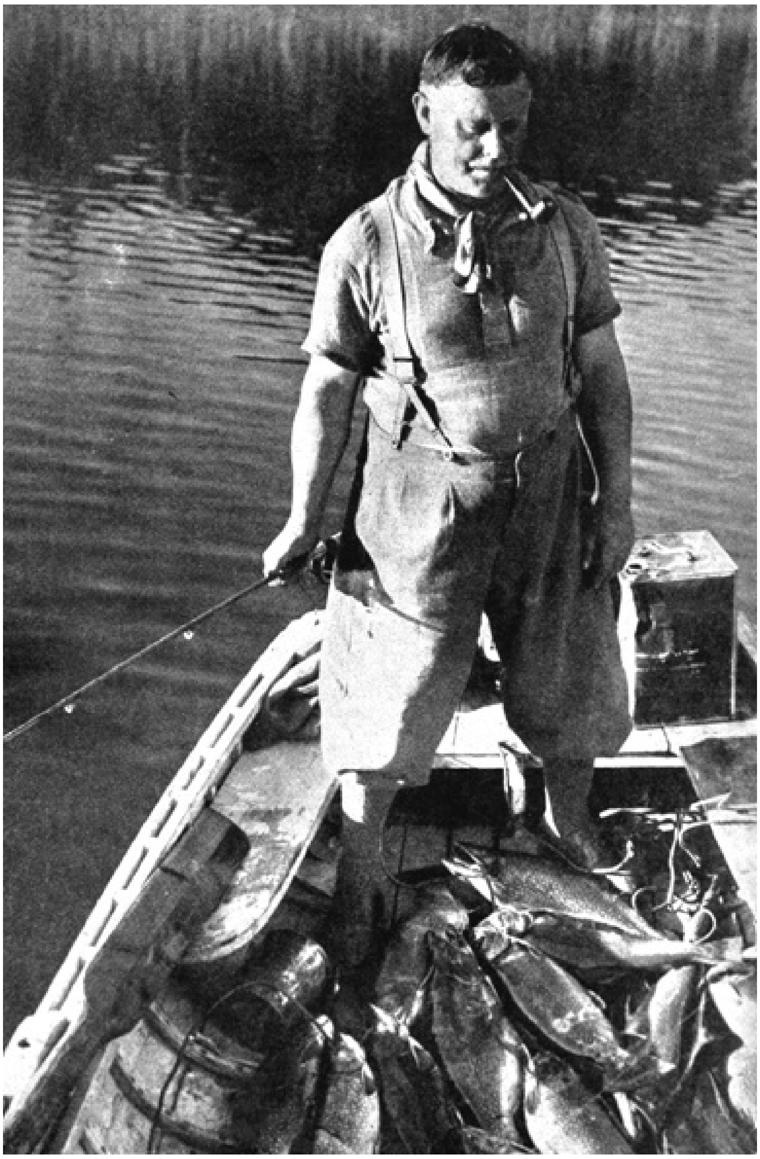

Figure 5: The growth of salmon production in Chile by species. Source: Servicio Nacional de Pesca de Chile (www.sernapesca.cl)

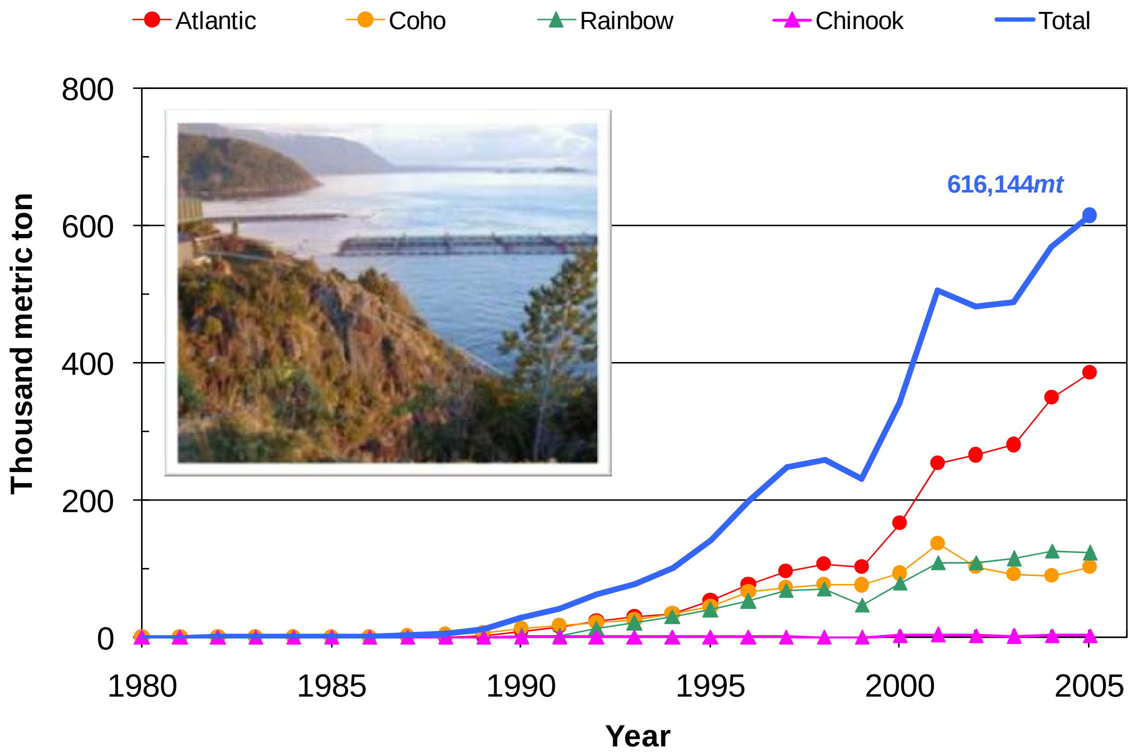

Figure 6: Total net pen salmon production in Chile by regions. Chinook salmon have colonized several river basins in the region (yellow circles), including the Santa Cruz River, an Atlantic River basin (Ciancio et al. 2005, Soto et al 2007). Main ocean currents favor the transport of salmon south and west into the Atlantic, on the Patagonian shelf (Becker et al. 2007).