Eradication of beaver (*Castor canadensis*), an ecosystem engineer and threat to southern Patagonia

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ABSTRACT Beavers threaten ecosystems of global importance in southern Patagonia, causing significant impacts on biodiversity. Introduced in 1946, they have reached all the most important islands south of the Strait of Magellan and now are invading the Brünswick Peninsula, on the South American continent, occupying a total area of approximately 70,000 km^2. After years of trying to promote beaver control by stimulating their commercial exploitation, the governments of Argentina and Chile agreed to redirect management efforts and to attempt to eradicate the species throughout its entire range in South America. As a first bi-national activity, a feasibility study, conducted by international experts, was jointly initiated, to assess the technical, ecological, economic, social and cultural feasibility of eradicating beavers over their entire range. This study indicated that eradication was justified and feasible, although several issues must be resolved before an eradication operation is implemented. Beaver eradication in southern South America presents unique challenges, as well as unique opportunities, to develop a new cooperative model to handle complex and global environmental problems.

Keywords: American beaver, southern Patagonia ecosystems, new approach, bi-national agreement, Chile, Argentina

INTRODUCTION

Beavers (*Castor canadensis*) are ecosystem engineers that directly or indirectly control the availability of resources for other organisms by causing changes in the physical state of ecosystems (Jones *et al*. 1994). Exotic in South America, beavers are threatening biodiversity values of global significance in southern Patagonia, where temperate forest and peat bog ecosystems dominate the landscape in one of the world's largest and most pristine remaining wilderness areas. Together, these ecosystems play a key role in global circulation processes, since they constitute the most significant terrestrial carbon reservoirs and carbon sinks in these latitudes. However, Subantarctic ecosystems appear to be particularly vulnerable to invasion by introduced species (Mittermeier *et al*. 2001) such as beavers, which now impact the largest stands of Subantartic forests and Holocene peat bogs. This invasion is a good example of how the human footprint can dramatically reach the last of the wild areas of the world, and how global hazards, like biological invasions, can affect biodiversity and key ecological processes in very remote areas.

In order to establish a new fur industry, 25 breeding pairs of North American beaver were introduced in 1946 to Río Claro´s lower basin, south of Tierra del Fuego Main Island, the largest island of the Fuegian Archipelago (48,000 km^2) (Fig. 1). This archipelago, at the southernmost tip of South America, consists of hundreds of islands administered by Chile and Argentina. The area is surrounded by the Atlantic and Pacific Oceans and is influenced by an Antarctic climate, with extreme cold and wet conditions. In southern Patagonia, beavers have flourished with abundant food, water, and a virtual lack of predators and competitors. This has favoured their expansion, allowing them to colonise all existing habitats including deciduous and evergreen beech forests, peat bogs, Patagonian steppe, and Andean grasslands (Saavedra and Silva 2008). The beavers have since spread throughout the entire Fuegian archipelago and beyond.

The rate of beaver expansion has been estimated at 2-6 linear km/year (Lizarralde *et al*. 1996), and the total population is about 60,000 individuals (Skewes *et al*. 1999). In the first twenty years after their introduction, beavers occupied about 30% of the rivers of the Andean zone of the Main Island of Tierra del Fuego (Lizarralde 1993) and were recorded in Chilean territory in the 1960s, 16 years after their release in Argentina (Lizarralde 1993; Lizarralde and Escobar 2000; Lizarralde *et al*. 2004). Beavers subsequently crossed the Beagle Channel in 1962 and colonised the northern coast of Navarino Island. They are now found on almost all of the islands south of the Strait of Magellan, including the entire Isla Grande of Tierra del Fuego, Picton, Lenox, Nueva, Hoste, and Dawson (Fig. 1). In their invaded range, beavers have affected over 20,000 linear kilometres of streams, rivers and watersheds and their density is estimated in 0.7 colonies/km^2. In the 1990s, beavers crossed the Strait of Magellan and established on the Brunswick Peninsula, where they are starting to invade the southernmost part of the South American continent (Soto and Cabello 2007) (Fig. 1). The total area occupied is now estimated as 70,000 km^2.

Beavers in southern Patagonia have had significant impacts on native species, habitats, ecosystems and landscapes (Figs. 2A and B). *Nothofagus* forests have been particularly affected with understory diversity, structure and natural dynamics impacted in the cut and flooded zones and in abandoned ponds (Anderson *et al*. 2006). Beaver

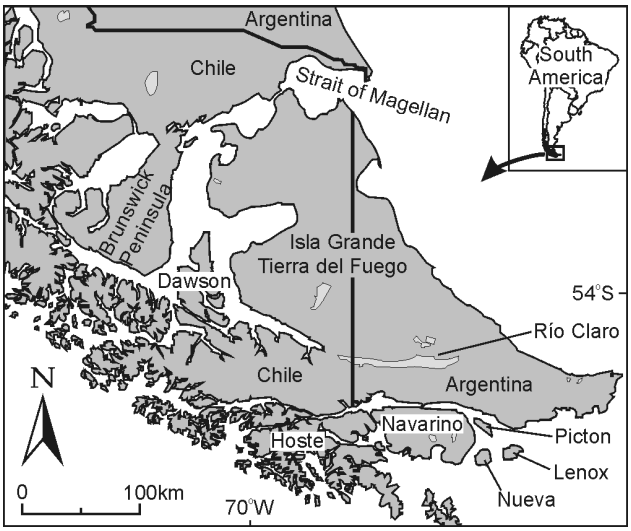

Fig. 1 Tierra del Fuego archipelago and Brunswick Peninsula in the South American continent where the introduced beaver population is spreading.

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dams, which directly change hydrological processes, have caused other serious impacts and sediment flows. Dams transform lotic environments into lentic ones. By creating flooded areas, beavers change drainage patterns and water table depth, cause the accumulation of sediments and organic matter, facilitate the alteration of nutrient cycles in *Nothofagus* forests (Lizarralde *et al*. 1996; Jaksic 1998; Lizarralde *et al*. 2004), accelerate the decomposition process, and alter water and soil chemistry (Lizarralde *et al*. 1996), with consequences to benthic and vertebrate communities (Anderson *et al*. 2009). Perhaps the most obvious impact of beaver invasion is the direct destruction of riparian southern beech forests preventing the natural recovery of forest ecosystems, which in the long term are transformed into grassland (Anderson *et al* 2006; Martinez Pastur *et al*. 2006).

Beavers also have economic impacts affecting aquaculture, agriculture and particularly forestry. These are important local industries and support a significant portion of the Chilean and Argentinean economies. Flooding as a result of beaver activity reduces the availability and quality of pastures for livestock, blocks culverts and destroys bridges and roads.

While they were confined to Tierra del Fuego, beavers were a remote problem. After crossing the Strait of Magellan and reaching the Brunswick Peninsula, beavers are now recognised as a serious threat to biodiversity and the economy of southern South America. The northward expansion of beavers, which is inevitable unless their expansion and establishment is stopped, will destroy further forests and lead to greater watershed contamination.

Fig. 2 Ecological impacts produced by exotic beavers in Tierra del Fuego ecosystems. A Vestiges of an original beach forest replaced by a "Beaver meadow" in and abandoned site. B Beaver lodge in a dammed and flooded riverine environment.

In this paper we describe a new bi-national approach that is being developed to manage beaver populations in Southern Patagonia. This approach will strategically test if the shift from localised control to eradication of all populations is achievable.

BEAVER CONTROL IN SOUTHERN PATAGONIA

In Argentina, control of beavers started in 1981 when the government authorised recreational hunting, followed by authorised commercial hunting in 1997 and the first management plan in 1999. At that time, the beaver populations was estimated at 30,000-50,000, increasing at 0.21- 0.23 and was close to maximum capacity (Lizarralde 1993). An elimination rate was set at 21-23% per year, with a required extraction of 7000-10,000 animals in the same period. Control was based on sustainable culling, implemented by local trappers, using Conibear 330 traps and assumed the creation and maintenance of a market for beaver products. Since 2001, a bounty was also paid for every tail delivered to local authorities. Together with the development of a fur market, the bounty was intended to provide an additional stimulus for beaver trapping. Furthermore, in order to stimulate beaver trapping, use of the meat was promoted. Despite these efforts, the necessary and planned extraction rate was not achieved. The Government also failed to maintain a monitoring system to guide or improve management decisions.

In Chile, the National Agriculture and Livestock Service officially recognised beavers as a harmful species in 1992. The first control programme was implemented in 1999, focused on the Isla Grande of Tierra del Fuego and Navarino Island. As in Argentina, the goal was to promote the economic benefits of the species and included a bounty system for private trappers who could profit from beaver pelts and meat. In 2004-2006, the Chilean government continued this programme, reinforcing the bounty system to promote beaver capture and the creation of a market for beaver products and sub-products. As a tool to mitigate beaver impacts, beaver hunting was concentrated in those areas closer to the mainland. As in Argentina, these plans failed to create a market, to promote beaver trapping, or to limit expansion of the beaver's range.

A KEY CHANGE OF VISION: BEAVER ERADICATION IN SOUTHERN PATAGONIA

Because efforts to control beavers were insufficient to reduce the beaver population or limit its expansion, beavers crossed the Strait of Magellan and established on the South American continent. In response, control programmes were critically reviewed and an historic first bi-national scientific and administrative agreement was reached in 2006 by the governments of Argentina and Chile. Both countries agreed to cooperatively work towards eradicating beavers throughout southern Patagonia. Key stakeholders from Chile and Argentina, along with international advisors, have since been working on ways to implement this new strategy. The goal is to restore natural southern Patagonian ecosystems through the eradication of beavers from their entire non-native range.

Key steps in this new approach include:

- A feasibility study conducted by a team of international experts and financed by the Governments of Chile and Argentina and the Wildlife Conservation Society.
- A bi-national agreement signed between Argentina and Chile (2008) under the bi-national Treaty on Environment (1992) and the specific shared Wildlife Protocol, to work towards beaver eradication as a necessary step to restore southern Patagonian ecosystems.
- The preparation of a Strategic Plan for the eradication of beavers from southern Patagonia, which will be adopted as a bi-national strategic reference document.

The feasibility study

This study assessed the technical, ecological, economic, social and cultural feasibility of beaver eradication over their entire range, whether beaver eradication was possible in a regional context, and if it is justified in terms of potential benefits relative to costs.

Different management options were: 1) removing beavers currently on the mainland of South America, with sustained control of source populations in buffer zones in the Fuegian Archipelago, along with surveillance and rapid response at mainland sites; 2) eradicating beavers from Tierra del Fuego and the South American continent; and 3) sustained control of beavers and other invasive species in high priority areas.

The eradication of beavers from southern Patagonia would avoid increasing damage on the continent and would remove impacts on biodiversity and economic values within the beavers' current range. Eradication would be a preliminary step to restoring southern ecosystems.

The control options would require the perpetual removal of beavers in specific areas in order to maintain impacts within acceptable levels. These options involve the sustained and regular input of resources that should be allocated to specific sites, which are selected and prioritised for their conservation values, or the need for protection from harm (Parkes *et al*. 2008).

Although eradication is ecologically, technically, and economically feasible, constraints include: 1) access to all types of land tenures (e.g., military lands, private lands) must be guaranteed; 2) organisational complexities involved with the bi-national character of the project must be resolved; 3) capacity to implement the project is currently absent from the region and must be developed; 4) technical and logistical complexity due to isolation and weather will need to be overcome; and 5) other minor constrains derived from the presence of native species that could incidentally become targets (e.g., native otter *Lontra provocax*). Such constraints present risks of failure that need to be tested, and management responses must be resolved before any eradication operation proceeds (Parkes *et al* 2008).

The feasibility study also identified risks and limitations and raised key questions that need to be answered before or during the implementation of each strategy, along with an indication of necessary resources and possible actions required (e.g., research, demonstration or pilot projects, monitoring). Also, it was clearly established that all technical, political, legal and operational tools must be available to guarantee complete beaver removal before any active eradication operation is started.

The removal of beavers from the continent was identified as of high priority and urgency. Its goal is to maintain areas at "zero density", which implies a permanent/sustained capture and monitoring regime to reduce immigration and reinvasion of beavers in the managed area. Beaver colonisation on the mainland seems to be slower compared to the island of Tierra del Fuego. Different invasion rates could be explained by reduced propagule pressure, or by the presence of predators such as pumas (*Felis concolor patagonica*) that are absent from islands (Wallen *et al*. 2007; Parkes *et al*. 2008). All these hypotheses remain to be tested.

All of the management options require assessment of the geographical range of beaver populations to ensure that all individuals in targeted populations are removed. Moreover, among other issues, the following additional information will be required for an effective management strategy: 1) mechanisms of beaver migration and establishment at continental sites; routes or pathways for access and movement on the continent; 3) frequency of immigration pulses; 4) sources of beaver populations: and 5) the relationship between dispersal and density of beavers.

Detection and surveillance methods that use probabilistic methods as a tool to provide transparent decision-making will be needed for areas to be declared beaver-free, and also to ensure the quick detection of any new arrivals.

The feasibility study recommended that pilot or demonstration projects should be used to resolve some of the above issues and to evaluate operational aspects of the eradication (Parkes *et al*. 2008). These projects should address key research, training and capacity-building objectives at different levels (e.g., public agencies, trappers, scientists). An adaptive process will also be required in order to learn and build capacity. The ultimate goal of this process will be to generate best practice and the highest operating standards to be applied in the effective planning, implementation and monitoring of a beaver eradication operation. Pilot or demonstration projects could also be used to present approaches and advances to key stakeholders such as politicians, financiers and other important actors needed to support and strengthen any eradication programme.

We suggest that the beaver eradication project should be organised in phases. Phase one should include establishment of the project and declarations of support from management agencies of both countries, as well as from other national and international stakeholders. It will also include the development of necessary capacities within management agencies to fulfil their roles and complete tasks to agreed standards. This will involve training in such varied fields as communications, population modelling and using radio transmitters. Project governance policies and procedures will need to be established. Baseline monitoring will need to be initiated and relevant management-driven research undertaken.

The eradication operation will involve beaver removal, beginning zone by zone, following a tactical, systematic, and adaptive approach.

The last phase of the project will involve monitoring and on-going surveillance.

Although no deliberate beaver eradication project has been undertaken previously -many populations of *Castor canadensis* were destroyed or heavily reduced by commercial fur trapping pressure in vast areas of their original range in North America (Baker and Hill 2003). Succession processes after pond abandonment and the effects that influence this process have been widely studied (Naiman *et al.* 1994, Collen and Gibson 2000, Wright *et al.* 2003, Anderson *et al* 2009, Burchsted *et al.* 2010, Hay 2010). However, it is unclear how this research will apply in South America. It thus remains unknown whether beaver removal, by itself, would be enough to promote the recovery of the ecosystems to a pre-beaver condition, at least in the short term. There is evidence (Martínez Pastur 2006) that *Nothofagus* forest restoration could need to be re-enforced by other practices such as long-term commitments to ecosystem management at the watershed level (Anderson *et al.* 2006)

Since beaver removal is aimed at the restoration of Patagonian ecosystems, specific information on restoration must be developed along with the eradication implementation, to assess the capacity and speed of recovery of ecosystems. Implementing appropriate measures to mitigate potential impacts of eradication activities should move the system into more acceptable trajectories (Parkes and Panetta 2009).

The cost of beaver eradication, which includes preparation, undertaking the operation and early stages of surveillance, but excluding on-going monitoring, is estimated at about US$ 35 million (Parkes *et al*. 2008). Although only indicative, the estimate includes the major cost components such as staff, equipment, and logistics.

Helicopters were viewed as an essential tool to implement the eradication, due to the large areas involved, their inaccessibility, the need to work in the shortest time possible to minimise risk of recolonisation, and to maintain commitment to the project at all levels (e.g., operational, governments, funding agencies). Helicopters are not widely used for conservation purposes in Argentina and Chile, although there is experience in their use for forest fire control activities and spraying crops.

Project governance will be challenging because it involves bi-national collaboration over administration, making decisions and evaluating progress. This project also has additional complexities including a large spatial scale, relatively long duration, logistical difficulties, and political, social and cultural challenges due to its bi-national nature, with the derived involvement of multiple jurisdictions, entities and organisations. These high levels of complexity will require the development and implementation of an appropriate governance structure and procedures to achieve project objectives (Parkes *et al*. 2008). Good governance also entails explicit processes for decision-making, and the establishments of transparent and efficient processes with clear lines of accountability. Moreover, appropriate and effective governance will be the key to retaining the political support required for the project to be implemented and for project goals to be achieved.

CONCLUSIONS AND NEXT STEPS

The processes so far completed have already provided useful lessons. First, beaver invasion in southern Patagonia is a global as well as a local problem. Addressing them in southern Patagonia will require international as well as local and national inputs. Second, the beaver problem must be completely understood by stakeholder communities, as well as by government authorities in Argentina and Chile (Soto *et al*. 2008). Third, beaver eradication in southern Patagonia appears feasible, but will be an enormous challenge. Finally, the environmental and economic benefits from beaver eradication will be extraordinary, and therefore, it is worth the effort to try to eradicate them.

Decision-making and the implementation of operational plans will now be guided by the strategic plan, which will provide an important basis for preparing funding proposals, and for potential funders and other agencies to evaluate the merits of the project based on anticipated outcomes and costs.

Planning should include a horizon of at least nine years, covering phases that include establishment, capacity building, implementation and biosecurity. Field activities should include the establishment of pilot or demonstration projects in which personnel can cooperate in research and trials, undertake training and refine management techniques and procedures.

The eradication phase should be organised in steps, clearing areas progressively zone by zone, and initiating active surveillance, to either confirm eradication or improve the process.

Eradicating invasive beavers from southern Patagonia presents special challenges associated, in particular, with the involvement of two countries, the presence of beavers in both continental and insular habitats, and the remoteness and size of the management area. Key issues associated with these challenges include the need to develop efficient and effective governance that reflects the necessary political support for making and implementing decisions and for securing and allocating funds. The development of an effective, goal-oriented management structure that can respond to logistic challenges imposed by these risks will be essential.

Beaver eradication in southern Patagonia is a novel and ambitious project. It will require the development and application of innovative tools and approaches. At the same time, it will allow Chile and Argentina, together with international players, to develop a new cooperative model to handle complex environmental problems. If effective in Southern Patagonia, similar collaborative models may help to improve the management of other global threats to biodiversity.

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