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RESPONSE

Eradication of invasive herbivores: usefulness and limits for biological conservation in a changing world

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Over the past 25 years, the international scientific community has recognized that biotic invasion is a major anthropogenic threat to ecosystems worldwide (Mack *et al*., 2000). More recently, it has been shown that in addition to major ecological impacts on many Earth biotas (Walther *et al*., 2002), climate change is expected to benefit invaders (Frenot *et al*., 2005; Walther *et al*., 2009). Facing such probable synergistic threats, we need a strong scientific background both to better understand these processes and to advise conservation managers and the public (Towns, 2011). The long-term monitoring of ecosystems undergoing restoration programmes, following eradication of one or several invasive species, is not only a major way to assess the impact of invaders but it can also reveal some of the unpredicted negative effects associated with management actions (Zavaleta, Hobbs & Mooney, 2001; Courchamp, Chapuis & Pascal, 2003; Bergstrom *et al*., 2009). When eradication projects take place in archipelagoes, the variety of islands often offer contrasting situations in terms of the presence/absence of introduced species, and monitoring provides invaluable information, including comparisons with control sites (Chapuis, Frenot & Lebouvier, 2002; Croll *et al*., 2005; Fukami *et al*., 2006; Towns *et al*., 2009). The Îles Kerguelen, where our study was carried out (Brodier *et al*., 2011), offered such a situation.

When restoration programmes were initiated on the Îles Kerguelen in 1991 (Chapuis *et al*., 1995), the expected trajectory of vegetation cover after the rabbit eradication was the recovery of native plant communities. Specifically, we predicted the re-establishment of the keystone native species, the Kerguelen cabbage, *Pringlea antiscorbutica*, extirpated by rabbits (Chapuis, Barnaud & Boussès, 1994). Then, following the re-colonization event, we predicted that the most favourable habitats would be rehabilitated with a subsequent improvement in both native vertebrate (burrowing seabirds) and macroinvertebrate communities.

Twenty years later, our initial predictions are neither fully supported nor rejected. The removal of rabbits from Île Verte was beneficial to blue petrels, *Halobaena caerulea*, as expected, and to its native predator, the brown skua, *Catharacta skua* (Brodier *et al*., 2011). However, converse to expectations, the increase in blue petrels did not result directly from the restoration of the plant cover but through an apparently more complex mechanism involving interspecific competition with rabbits. Suppressing rabbits' interference in burrow occupancy by breeding blue petrels highlighted an unreported competition process with a closely related sympatric petrel species, the Antarctic prion, *Pachyptila desolata* (Bonnaud & Courchamp, 2011). Therefore, the rabbit eradication restored competitive processes between native species, a result inaccessible without long-term monitoring of the ecosystem as a whole.

Concerning changes in the vegetation cover, our monitoring programme demonstrated that our initial assumption was partly wrong, mainly in relation to the unexpected consequences of climate change: after rabbit eradication on three islands (Chapuis *et al*., 2001), native communities did not restore. In fact, native monospecific *Acaena magellanica* communities started to regress, allowing an important increase of invasive plant species (Chapuis, Frenot & Lebouvier 2004). Invasion has been facilitated by the regression of *A. magellanica* due to the increased frequency of summer droughts, a trend observed over the last 15 years in Îles Kerguelen (Lebouvier *et al*., 2011). As a consequence, an increase in soil erosion has also been detected, particularly on the main island where rabbits affect plant cover (Robin, Chapuis & Lebouvier, 2011).

Unexpected cascade effects that could only be detected, thanks to the long-term monitoring in the context of climate change, raise new issues with regard to the biological conservation in the context of restoration. In our view, environmental managers are now facing three options on Kerguelen: (1) '*Laissez faire*', to investigate the consequences of climate change on the dynamics of communities (including biotic and abiotic interactions); (2) pursue the rabbit removal to improve plant cover in areas threatened by erosion processes, even if promoting the development of invasive plant species (at least in the medium term); and (3) limit the development of invasive plants while maintaining enough cover to fix soils and prevent erosion, using rabbit as an auxiliary species (see Walther *et al*., 2009). This latter option has gained some indirect support, as documented by one of us (JLC) in February 2011. On Île du Cimetière, rabbits have been maintained at low density over recent

years (through artificial control, see below), and invasive grasses have failed to invade until now. Furthermore, the grazing pressure of rabbits on dandelions (*Taraxacum* spp.) seem to favour the maintenance of *A. magellanica* after water stress by limiting competitive processes (J.-L. Chapuis, unpubl. data). One way to limit rabbit density would be to improve the circulation of the myxomatosis introduced on the Îles Kerguelen in the 1950s (Chapuis, Chantal & Bilenga, 1994). This could be accomplished by introducing the vector of the *Myxoma* virus, the oioxenous rabbit's flea, *Spilopsyllus cuniculi* (as it has been done on Macquarie Island: Skira, Brothers & Copson, 1983; Île du Cimetière: Chekchak *et al.*, 2000). Incidentally, such a regulation of rabbit populations will also have positive effects on seabirds by reducing the number of introduced domestic cats, *Felis silvestris*, which mainly prey upon rabbits (Pontier *et al.*, 2002), specifically in winter when most birds are at sea.

All three options presented here have costs and benefits. However, we believe that in subantarctic islands, climate change and soil erosion processes may be particularly pronounced and therefore must be taken into account in restoration programs, even those targeted toward threatened and flagship species. Interacting effects between biotic and abiotic factors, and ecosystem functioning as a whole, must be part of decision process in sound conservation management.

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