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Native-predator–invasive-prey trophic interactions in Tierra del Fuego: the beginning of biological resistance?

The Magellanic sub-Antarctic ecoregion in southwestern South America is a remote area identified as one of the 24 wilderness regions remaining in the planet (Mittermeier et al. 2003). However, it has recently been invaded by several exotic mammal species, coming mainly from the northern hemisphere. One of the most conspicuous and studied invasive species in the region is the American beaver (*Castor canadensis*). By building dams and cutting trees, beavers have modified large areas of forest into meadows, thereby greatly transforming the landscape (Henn et al. 2016). By creating ponds, beavers facilitate the establishment of other invaders, such as the muskrat (*Ondatra zibethicus*), which in turn, facilitates the rapid spread of another invasive mammal: the American mink (*Neovison vison*; Crego et al. 2016). The impacts of these invasive species in Tierra del Fuego require further investigation so that we can better understand the implications for the evolution of the native communities in this remote and still unspoiled region of our planet. We examine the trophic relationship between the endemic Culpeo fox (*Pseudalopex culpaeus*) and the invasive muskrat on Tierra del Fuego, to compare with the nearby fox-free Navarino Island where the three invasive mammals have been previously described (Crego et al. 2016). Between December 2014 and February 2015, we conducted two expeditions along the Beagle Channel, on the southern edge of the large Island of Tierra del Fuego (Tierra del Fuego). One was to Caleta Ferrari in Yendegaia National Park (54°50′ S, 68°49′ W) and the other to Alberto de Agostini National Park, specifically in the areas of Pia, Alemania, and Holanda glaciers (see Crego et al. 2015). We monitored terrestrial mammals using camera-traps baited with canned fish, and indirect evidence such as scats, tracks, or the presence of burrows. We also recorded the presence of the native Culpeo fox and collected its scats to study its diet (Fig. 1). Additionally, we searched for evidence of other mammals' activity, particularly of the American mink, the American beaver, and the muskrat.

The most prevalent prey item in the Culpeo's diet appears to be the invasive muskrat (Fig. 2). The muskrat, introduced to Tierra del Fuego in 1948, shared a similar motivation for the introduction of the mink and beavers, the fur industry (Jaksic et al. 2002). Nonetheless, to the best of our knowledge, the presence of muskrat in the diet of the native fox has not been previously reported, as was also the case of the abundant beaver (Wallem et al. 2007). The Culpeo is the apex predator in Tierra del Fuego. Reports of its diet consisted mainly of small native rodents and the medium-sized introduced lagomorphs (*Oryctolagus cuniculus* and *Lepus europaeus*), with occasional occurrence of birds and young guanacos (*Lama guanicoe*; Novaro et al. 2000). Despite similar to us, Novaro et al. (2000) reported a high percentage in occurrence (51%) and dry mass (83.5%) of introduced mammals in Culpeo's diet, they did not find muskrat being consumed by native foxes between 1989 and 1994 (data collection time interval). Our findings show that the muskrat has become an important prey of the sampled foxes, being the second most frequent item and representing the highest percentage of dry mass in the scats (around 90% when it is present; Fig. 2C). This suggests that Culpeos are intensively preying on these invasive rodents and changing the proportion of previously prey in their diets. However, further investigation is needed to understand the strength and scale of this predator–prey interaction and the negative effects on the muskrat population. To accomplish this, it will be necessary to measure the rates of muskrat consumption by Culpeos in Tierra del Fuego and the resulting impacts on foxes and muskrat's per capita growth rate. Tierra del Fuego could be a case of native resistance to invasion because of consumption of an invasive species by a native predator. However, other important community-level consequences are expected from this new predator–prey interaction. Our predictions are that the mink would be affected by the Culpeo, as a competitor for the muskrat as prey, and/or as a potential prey, prediction than need to be tested with empirical data, currently unavailable. Notwithstanding, the nearby Navarino Island, offers a suitable point of comparison with Tierra del Fuego, where mink, beavers, and muskrats interact in the absence of foxes. In this system, Crego et al. (2016) suggested two positive feedbacks among these invaders. By transforming the fast water rivers into meadow ponds, beavers create suitable habitat for muskrats. In turn, muskrats have become the main prey item for mink living in inland habitats, away from the seacoast. On Navarino Island, the mink is the only new top terrestrial predator; however, in Tierra del Fuego, the predator community includes two foxes and a native otter (Valenzuela et al. 2014). Culpeo fox are likely competing with mink consuming muskrat. What could be the impacts on fox population and the other fox preys, under a complete or significant removal of the

Fig. 1. Culpeo fox photographed using a camera trap in Caleta Ferrari, Yendegaia National Park, Tierra del Fuego, Chile.

muskrat? Also interesting is the ecological role played by Culpeo foxes in Tierra del Fuego, potentially impacting muskrat populations would also impact on mink population through competitive mechanisms. An interesting aspect in this trophic network is that muskrat may increase apparent competition with native Culpeo's prey, by subsidizing fox populations.

Evolution, ecology and management converge when biological invasions are studied (Allendorf and Lundquist 2003). Predator interactions in Tierra del Fuego are complex and multiple, and the muskrat may disrupt the natural predator–prey dynamics. On one hand, we must understand the natural history of the invaders as well as their potential native predators to prevent undesired

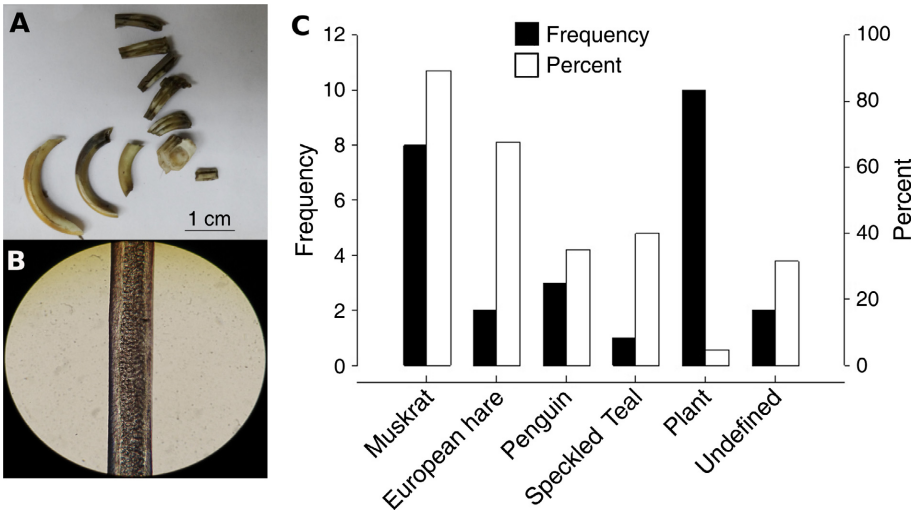

Fig. 2. Culpeo fox diet in Tierra del Fuego, southern Patagonia. Panel A shows muskrat teeth found in one scat and panel B muskrat hair medullar pattern. In panel C the fox diet composition is shown as the frequency of each item (i.e., the number of scats in which each food item was identified out of 11 samples) and the percent as the estimation of the dry mass of each item. For example, muskrat is present in 8 out of 11 samples, and it represents ~65% of the dry mass of the scats where it is present. [Color figure can be viewed at wileyonlinelibrary.com]

management effects, such as the remotion of invasive preys might cause invasive predators to consume more native prey (Glen et al. 2013). On the other hand, a comparison of Tierra del Fuego with Navarino Island opens the opportunity to evaluate hypotheses in the field of community ecology (Shea and Chesson 2002) and ecosystem level effects, such as cascade effects of native ecosystem response to invasive species (Strayer 2012). Carlsson et al. (2009) and Mooney and Cleland (2001) pointed out the need to identify mechanisms that explain how native predators respond to introduced prey and other predators in an evolutionary context. In a broader scope, we open the discussion on how the new communities formed will shape the course of evolution into the future. If we want to conserve pristine areas, like the sub-Antarctic Magellanic ecoregion, the question that arises is: would it be the same in the future if we do not take into account the disruptions of evolutionary lines into new communities and species interactions? We believe that some insights can emerge from the study of the evolutionary trajectory of ecological networks and invasive species such as the example examined here.

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