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Short communication

A familiar face with a novel behavior raises challenges for conservation: American mink in arid Patagonia and a critically endangered bird

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ABSTRACT

Invasive American mink is a severe threat to endangered waterbird populations. In Europe and South America, control efforts have been increasing in the last decades. Mink has a proven acute impact on the Hooded Grebe, a critically endangered specialist of highland plateau lakes in Patagonia where a single mink attack can deplete up to 4% of the global population. We aimed to examine mink ecology in Austral Patagonia to inform ongoing control programs in the region and contribute to efforts elsewhere to counteract mink impact. We evaluated mink distribution at a regional scale and found that its distribution extends across the steppe-arid environment, often assumed to be an obstacle for mink colonization. Consequently, its current distribution fully overlaps with the Hooded Grebe breeding grounds. At a finer scale, we used 3 techniques to detect American mink at different times of the year and found a temporal sex-biased occupation-dispersion pattern: permanent presence of both sexes in areas around the plateaus used by grebes and upstream male biased dispersion in late summer (which leads young mink to the grebes' lakes). Therefore, plateau perimeters function as an invasion front that resets yearly. Lastly, from scat content analysis we detected a shift in mink diet from a generalist type in lowland rivers to a diet specialized on birds in highland lakes, where attacks are exclusively directed towards Hooded Grebes and where waterbird presence might be a determinant of mink presence (regardless of other prey). All of these findings have profound relevance for control schedules and priorities.

1. Introduction

It has been acknowledged that biological invasions are one of the most important problems for biodiversity conservation worldwide, but in most cases the consequences need to be addressed scientifically (Gurevitch and Padilla, 2004). Austral Patagonia is facing the invasion and expansion of a global invasive predator, the North American mink (*Neovison vison*) (Macdonald and Harrington, 2003; Roesler et al., 2012a; Fasola and Valenzuela, 2014). American mink are associated with conservation issues for native species in most of the areas where it has been introduced (Macdonald and Harrington, 2003; Bonesi and Palazon, 2007). The effects are directly related to prey availability (Macdonald and Harrington, 2003), to intrinsic characteristics of the prey species (Halliwell and Macdonald, 1996; Nentwig, 2007) and the vulnerability of individuals (Sargeant et al., 1973). For instance, solitary ground nesting species are particularly susceptible to predation (Schüttler et al., 2009) and individuals spatially confined or with a temporary reduction in flying capability show some disadvantage with respect to mink attacks (Sargeant et al., 1973).

American mink fur farms operated in Southern Argentina and Chile between 1940 and 1970, from which accidental and intended releases introduced wild mink populations (Jaksic et al., 2002). The American mink is a generalist predator that feeds on mammals, birds, fish and crustaceans depending on prey availability (Macdonald and Harrington, 2003). It has an estimated range of c. 450,000 km^2 in Argentina (Fasola and Valenzuela, 2014) that overlaps the reproductive area of two globally threatened species, the Critically Endangered Hooded Grebe (*Podiceps gallardoi*) (Roesler et al., 2012b) and the Vulnerable Austral Rail (Mazar Barnett et al., 2014; Roesler et al., 2014).

The Hooded Grebe is currently ranked 17th among the top 100

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priority bird species of the world, based on the EDGE criteria (Jetz et al., 2014; EDGE-ZSL, 2016). This grebe is an endemic breeder from Austral Patagonia (Santa Cruz Province, Argentina). Adults and juveniles overwinter on the Atlantic coast and migrate to the breeding fishless lakes on high plateaus in the pre-Andes Mountain range and remain there from October to April. Roesler et al. (2012b) have described several threats that risk Hooded Grebe persistence and the American mink was the last discovered (Roesler et al., 2012a). In 2011, a single mink individual was responsible for a surplus killing event on a Hooded Grebe colony with the devastating outcome that 4% of the global population was killed (Roesler et al., 2012a).

American mink was mentioned as one of the most important grebe predators (Fjeldså 2004). Some studies conducted on the mink's native area related the special breeding behavior of grebes to the presence of mink and other ground carnivores (Nuechterlein and Buitron, 2002), but, even when grebe species have evolved strategies to avoid mink depredation, there are reports of surplus killing events within the American mink native range (Breault and Cheng, 1988).

We started assessing the negative effects of the mink on the grebes after the surplus killing episode in 2011, and started studies on mink ecology in the reproductive area of the Hooded Grebe in order to design and set up a control program to stop mink impacting them (see Fasola and Roesler, 2016). In particular we addressed the following questions.

i) What is the mink distribution extent in relation to the Hooded Grebes' reproductive area?
ii) How do mink use the Hooded Grebes' reproductive grounds in Austral Patagonia?
iii) How do mink 'make their living' in this peculiar environment?
iv) Finally we discuss how understanding mink spatial and temporal behavior should help predator control planning for native prey conservation.

2. Material and methods

The study was conducted on the west portion of Santa Cruz Province, the southern part of continental Argentina. The area lies in the Patagonian steppe, which is temperate-cold and dry (annual precipitation: 500 mm to 250–100 mm) with strong winds from the west (Cabrera, 1971). Several basaltic plateaus (from 500 to 1500 m asl, Fig. 1) are immersed in the steppe matrix. The habitat on the plateaus is drier (High Andes District; Cabrera, 1971). Those plateaus are located east and along the Andes Mountain Range. Each plateau has a variable number of lakes (11 to over 1000; Roesler, 2016), mostly endorheic, naturally fishless basins that accumulate water from precipitation and melted snow accumulated over winter. Some of these lakes meet the environmental conditions that Hooded Grebe requires to breed, particularly those lakes covered by dense stands of the water macrophyte, milfoil *Myriophillum quitense* (Fjeldså, 1986).

American mink are semiaquatic mammals and concentrate their activities close to water (< 40 m; Harrington and Macdonald, 2008). They use steppe-rivers as corridors and eventually access the lakes where Hooded Grebe colonies are set. Several rivers cross the steppe and some of their headwaters are on the high plateaus (Fasola and Roesler, 2016).

We conducted a mink sign survey covering the Hooded Grebe reproductive grounds to update American mink distribution using a grid built of 50 × 50 km cells (limits: S46.60°, S50.41°, W70.23°, border with Chile). We selected at least two survey points per cell, separated by a minimum distance of 5 km and located at sites of feasible access to lakes or rivers. The 5 km distances between points were defined based on the reported average length for male mink territories (3.4 km, Harrington and Macdonald, 2008). We searched for signs (footprints and scats) along 600 m transects located on shores or riverbanks at 201 sites, from December 2012 to April 2013, April 2015 and March 2016. Mink presence/absence and habitat type was recorded (forest-steppe).

To assess mink use of the Hooded Grebes' reproductive grounds we concentrated survey efforts in the northern part of the study area (Fig. 1) at Buenos Aires Lake Plateau (BALP). We used three different standard detection methodologies: sign surveys, camera traps and trapping. Sampling sites were grouped into two categories: upper (> 900 m asl) and lower areas (< 900 m asl) with respect to the plateau. The 900 m asl was identified in relation to the lowermost grebe colony at BALP (see Roesler, 2016). In the upper area we sampled 11 lakes occupied by Hooded Grebe (most of those holding colonies). We also defined upper and lower sampling sites along rivers running down the plateau. Finally, we selected additional lower sampling sites in aquatic environments located on the surroundings of the BALP (at marshes, shallow lakes, streams and rivers). We conducted paired mink sign surveys in Spring-early Summer (November–December–early January) and late Summer-Autumn (late January–February–March–April) at 42 sites on 3 fieldwork seasons (2012–2013, 2013–2014, 2014–2015). Positive detections were considered only when fresh signs were found (i.e. extremely dry scats and unclear footprints were not considered).

We set camera traps at both groups of sites (upper and lower), on rivers and lakes. Seven cameras were left throughout the winter while others were set for shorter sessions of 2 to 4 weeks early and late in the season. We used Bushnell and Reconix surveillance cameras, set to trigger when the sensor detected motion. Whenever an American mink was unequivocally identified in at least one picture of the camera session, the session was recorded as positive.

The last source of information was lethal trapping. The trapping is part of an ongoing American mink control program started in 2013 in the BALP area (see Fasola and Roesler, 2016; Roesler et al., 2016). During two summer seasons (2013–2014 and 2014–2015) lethal traps were set on floating rafts from December to April along rivers (not lakes) at the upper (11 and 20) and lower plateau trapping sites (36 and 74 traps) and capture date was recorded. We only used information from the first two trapping seasons of the control program since we recorded a drop in mink occupancy in consecutive seasons (Fasola and Roesler, 2016) and therefore only the first two seasons reflected the initial conditions of mink population in Austral Patagonia.

We described the presence/use pattern of American mink of the upper and lower part based on positive detections recorded from these three methodologies at both early (November–December-mid January) and late (mid January–February–March–April) season.

We studied mink diet in the study area by scat analysis in order to generate a comparative analysis between lower and upper areas. We collected feces (old and fresh) during sign surveys along lakeshores and riverbanks at sites from both areas (upper and lower). Remains in scats were gently separated and sorted into prey categories: mammals, birds, fish, reptiles, crustaceans, insects and plant matter (see methods in Fasola et al., 2011). For each scat we recorded prey category presence and its percentage in the scat total volume. Given the unbalanced frequency among prey items, those less frequent were grouped into a single category. Therefore, the analysis considered only three prey categories: mammals, birds and 'others' (including fish, insects, amphibians, and crustaceans). We computed the RFO (relative frequency of occurrence) for each prey item and the DOM (dominance of each prey item) as the number of scats where the prey item volume percentage was ≥ 50% (Fasola et al., 2011). Then, we employed chi-squared tests to compare RFO and DOM between scats from the two groups (upper and lower).

We conducted fieldwork on lakes with known colonies of Hooded Grebe in the summer seasons from 2009–2010 to 2014–2015 to detect American mink prey selection. Lakes with colonies were monitored 1–5 times throughout the reproductive season until 2013 when a 'Colony Guardian Program' was set and grebes' colonies hosting > 10 nests were studied daily. Efforts to detect mink also became a daily activity for these trained conservation agents (see Roesler et al., 2016) from mid-December to late April. Every time mink were detected in a lake,

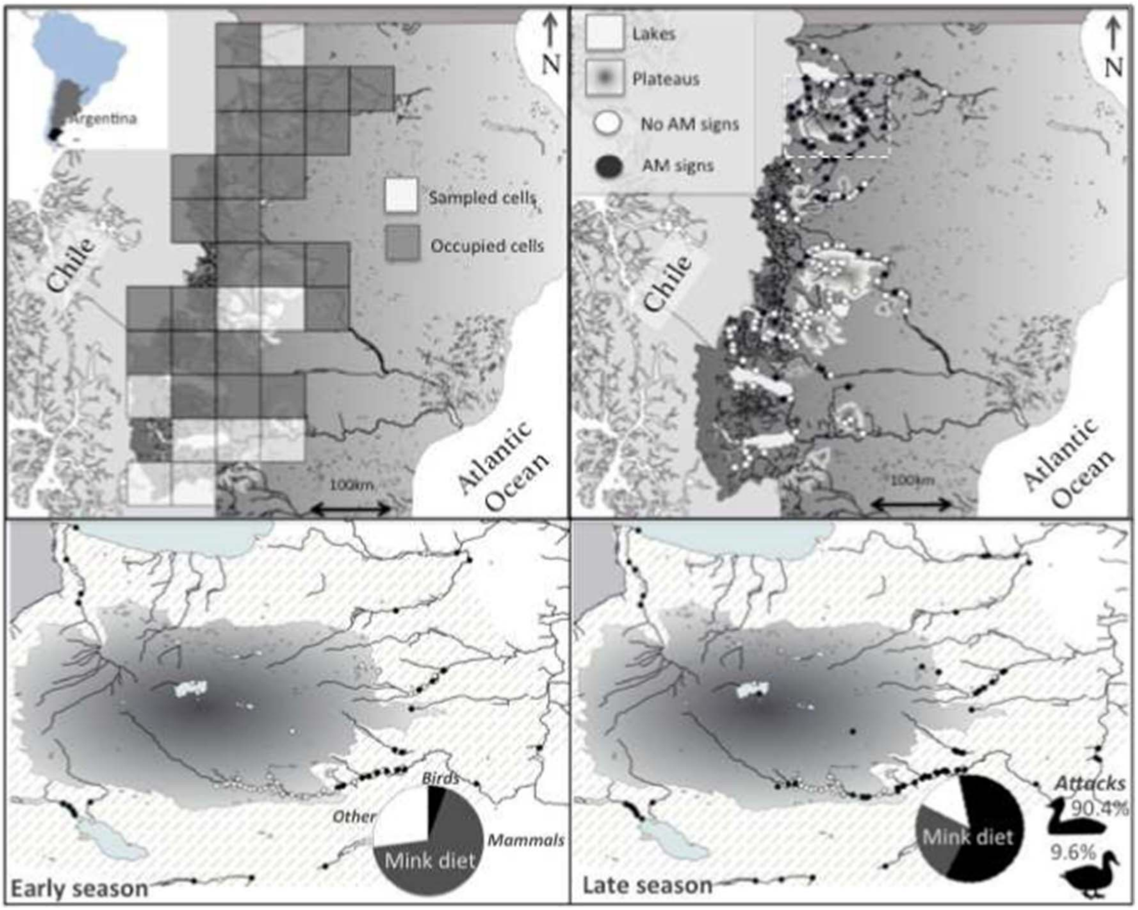

Fig. 1. Upper panels show the mink sign survey in the West of Santa Cruz Province, Argentina: occupied cells (left) and locations (right) (plateaus from North to South: Buenos Aires Lake -with a dotted lined rectangle-, Asador, Strobel, Siberia, Viedma Lake, Mata Amarilla and Vizcachas). Lower panels focus on the Buenos Aires Lake Plateau, where camera traps, sign surveys and trapping were used as detection methodologies to study mink dynamics at two periods: early and late grebes' reproductive season. Grey color indicates the elevated area (upper area) while lined area indicates the lower area where the source of American mink population is. White circles show the locations where camera traps, sign surveys or trapping was used to detect mink. Black circles indicate that mink was detected by at least one of the applied techniques. Pie charts show dominance of main prey items in mink diet in the lower area (left panel) and the upper area (right) when mink access the Hooded Grebe reproductive lakes. The average outcome of mink attacks (proportions) on grebes and other water birds during surplus killing events is also shown (right panel).

Table 1

Presence of the American mink in the upper and lower parts of the Plateaus expressed as detections over effort and percentages in brackets. Sign surveys: detections/total number of sampling sites. Camera traps: photos with mink over camera sessions. Lethal Trapping: trapped animals over the trap effort (number of operating traps ∗ days). ′11 and 18 upper zone traps for 2013–2014 and 2014–2015 seasons respectively; ″36 and 74 lower zone traps for 2013–2014 and 2014–2015 seasons respectively; trapping effort estimated as 30 days (average) for the early period and 107 (average) for the late period. Comparisons Early vs. Late for Sign surveys and Lethal trapping: [ab] $\chi^2 = 16.51$ $df = 1$ $p < 0.001$, [cc] $\chi^2 = 0.31$ $df = 1$ $p = 0.575$, [de] $\chi^2 = 5.95$ $df = 1$ $p = 0.015$, [ff] $\chi^2 = 3.10$ $df = 1$ $p = 0.078$.

	Sign survey		Camera traps		Lethal trapping	
Season	Upper	Lower	Upper	Lower	Upper′	Lower″
Early	2/20[a] (10.0)	17/22[c] (77.3)	0/14 (0.0)	2/50 (4.0)	0/1740[d] (0.0)	14/3300[f] (0.42)
Late	11/20[b] (55.0)	15/22[c] (68.2)	0/12 (0.0)	2/15 (13)	6/3103[e] (0.19)	51/11770[f] (0.43)

daily censuses of waterbird species were conducted. Lastly we searched for dead individuals using a spotting scope, a boat and walking along the lakeshore, and we identified any dead individuals to species level.

3. Results

From December 2012 to March 2016 we reached remote portions of Austral Patagonia in six different water basins. We surveyed 201 sampling points located at rivers (140) and lakes or marshes (61) at 35 of the 50 × 50 km-cells (Fig. 1). All cells where presence of Austral Rail or Hooded Grebe was confirmed were monitored, except on a few occasions where access was not possible due to geographical-distance impediments (Fig. 1). We found mink signs in 71% of the cells (25) at 42% of the sampled sites (84). Only 16% of the sites visited were in the forest while the rest were located in the Patagonian steppe. The occupied cells are all connected and represent an area of 85,000 km^2. This area includes the whole reproductive area of the global population of the Hooded Grebe and much of the locations where the Austral Rail is known to occur. We found signs of mink for the first time in Perito Moreno National Park and in Los Glaciares National Park we found evidence of a southward expansion of mink distribution (G. Aprile pers. comm.).

The three detection methodologies selected to evaluate the use of space by mink with respect to seasonality and altitude (low vs. upper areas) were consistent. Overall, mink detections (combining all techniques) at lower sites were more frequent (101 detections) than at higher locations (19) (Table 1). Also, while detection/effort at the lower sites was similar at different stages of the season, this measurement increased by the end of the season for the upper sites (Table 1).

We found the remains of birds, mammals, crustaceans, reptiles, amphibians and insects in the feces collected both in the upper and the lower areas (Fig. 2). Absolute frequencies of prey items from the upper

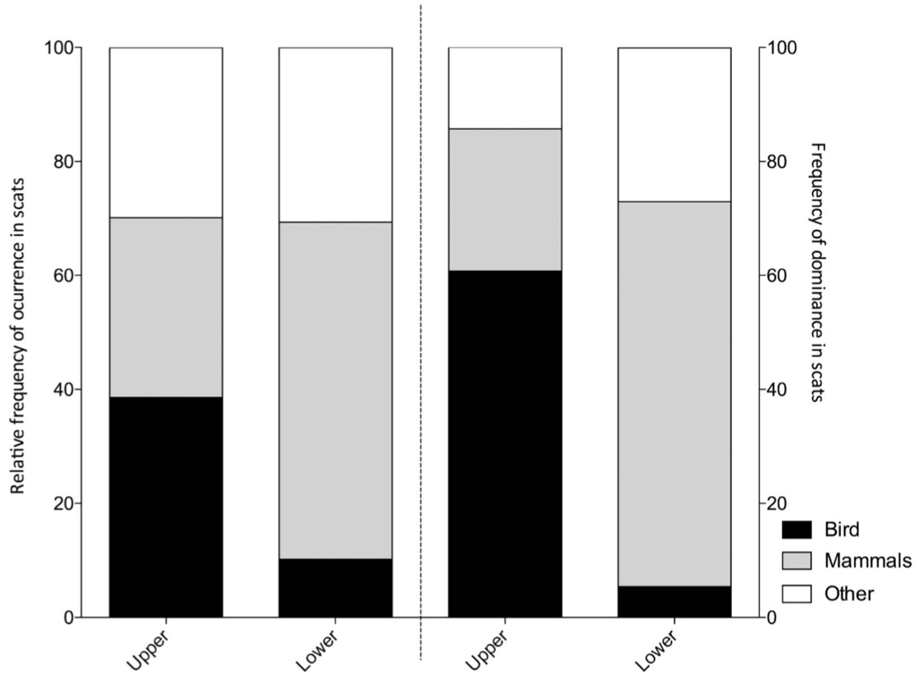

Fig. 2. Diet of American mink in the upper and lower areas of Buenos Aires lake plateau, Santa Cruz Province, Argentina, determined from faecal samples. A) Relative Frequency of occurrence of prey items: birds, mammals and others (fish, amphibians, reptiles, crustaceans and insects). B) Frequency of dominance of prey classes (for visual purpose proportions were relativized to the total number of dominant items as the FRO).

and lower parts were statistically different ($\chi^2 = 12.87$ $df = 2$ $p = 0.001$) as well as the dominance index (Exact Fisher Test $p < 0.001$ $df = 2$). The most remarkable difference in prey remains analyses was associated with birds' RFO. Bird items were the most frequent in samples collected in the upper sites (c. 40%) and the least frequent in samples from the lower sites (c. 10%). An increase in mammal RFO appears to compensate the decreases recorded in bird RFO. Also, bird remains dominated the feces content in the c. 51% of the samples of the upper part and only the c. 6% of the samples collected at the lower part (Fig. 2). Fish was only found in scats from the lower sampling sites since lakes and rivers in the upper part of the plateau are fishless.

We detected three surplus killing events by American mink between the summer seasons of 2010–2011 and 2012–2013. Two of those events occurred at El Cervecero Lake (BALP), and the third at C199 Lake (Siberia Plateau). American mink killed 62 Hooded Grebe adults and 13 juveniles. The relative predation of Hooded Grebe was greater than that of other waterbirds (Table 2). Only juveniles of Silvery Grebes *Podiceps occipitalis* and four individuals belonging to three species of ducks were depredated (Table 2). All three surplus killing events occurred over a span of 2–3 nights. In two out of the three occasions the mink were captured and removed from the lake. Both captured individuals were young males (first year males; identified by size and the teeth condition; see Fasola and Roesler, 2016).

Table 2
Number of birds present in the lakes at the time when predation events occurred - grouped as Hooded Grebe (adults and juveniles), Silvery grebe (SG) and other waterbirds - and number of predated individuals by American mink of each group. (*) only juveniles. T: total number of individuals. P: number of predated individuals.

		HG		Juvenile HG		SG		WTB	
Lake	Date	T	P	T	P	T	P	T	P
Cervecero	6/3/11	55	33	–	–	14	0	110	1
C199	24/3/13	228	12	63	10	94	4*	885	3
Cervecero	26/3/13	128	17	30	3	70	0	132	0
Total			62		13		4		4

4. Conclusions

The American mink continues its expansion in southern South America, particularly extending its range in Argentina. These results update American mink extent of occurrence in continental Austral Patagonia and confirm that steppe habitat (with low density of water bodies) does not present an obstacle for mink colonization. Areas with a low density of rivers and water bodies are usually not thought to be good habitat for mink (Ruiz-Olmo et al., 1997; Iordan et al., 2012). However, steppe areas in Argentina are energetically viable, perhaps better than forested areas based on a faster initial speed of dispersion (Pagnoni et al., 1986). Regarding the extent of occurrence of American mink, we found a complete overlap with Hooded Grebe reproductive area, with the exception on southernmost plateaus with grebes in the present (Mata Amarilla).

At a coarse scale our results show that geographic ranges of Hooded Grebe and American mink overlap almost completely. However, on analysis at finer scale we found heterogeneous occupation patterns in the spatial and temporal dimension. Mink have reached the top of half of the plateaus used by Hooded Grebe and this could be attributable to differences in mink density in the surroundings that depend on time since colonization and location from the closest invasion front. Furthermore, we found a peculiar pattern in the temporal dimension. In the low parts of Buenos Aires Lake Plateau, mink were equally present at any moment while in the upper part mink presence seemed to be impermanent. There, two out of three detection methodologies showed that mink presence was more frequent by the end of the summer season. Then, mink disappear at some point during winter, as only old scats are found in the upper part when fieldwork activities return to the area the following spring. No mink was ever recorded in cameras left overwinter. This means that when Hooded Grebes arrive at the lakes on the plateaus in spring, mink are not there. Colonies set and develop in the absence of the semiaquatic predator, but they still face threats from increased winds and nest predators (i.e. gulls). Even when these obstacles are overcome, mink might appear towards the end of the breeding season and reverse the results of months of investment by the grebes (nesting time, avoidance of nest and chicks predators, expensive parental care). A disturbance at this stage leaves no time to reset nesting (as usually happens when wind destroys nests earlier in the season). Mink individuals caught in the upper parts of rivers and lakes were exclusively young males from the current breeding season (see also Fasola and Roesler, 2016), suggesting a difference in dispersal capacity between males and females. This was also evidenced in the Cairngorms Water Vole Conservation Project in Scotland, were immigration following population control was strongly biased towards sub-adult males (Olivier et al., 2016). Areas where mink are effectively controlled in Scotland are equivalent to the upper areas that become unoccupied every winter in our case study. This means the upper areas can be considered constant sinks for animals coming from the lower parts of rivers and streams (source). These lower sources act as permanent invasion fronts that reset every year, with only young males going upward.

The American mink has a different diet in habitats of the upper area compared to those sampled at the lower area. Diet analysis revealed that when mink use the lake habitats on the plateaus, they mainly feed on birds, with increases in the relative frequency of birds in scats and the domination of bird remains in these scats compared to sampling sites at lower rivers and lakes. Mink appear to select Hooded Grebe over other species and this is probably due to a naïve behavior of Hooded Grebe towards an aquatic predator. Hooded Grebe's natural predators are raptors (Beltrán et al., 1992; Roesler, 2016) and therefore they are alert when a flying bird approaches them but they seem to be naive to aquatic predators. Another aspect of the predation events that were witnessed on the grebes' lakes is that they all showed surplus killing characteristics, with dozens of birds killed. Also these attacks revealed a positive selection towards Hooded Grebe among hundreds of other bird species, even when mink ability to prey on different waterfowl species and families has been reported several times. Events like the ones described here are expected during the first encounters of a skillful predator with locally abundant prey (with no antipredator defenses) during colonization (Short et al., 2002). Finally, we know from overwinter camera traps at lakes that waterfowl leave the lakes soon after these aquatic habitats freeze. These facts and the dominance of bird remains on mink scats strengthen the hypothesis that mink do not remain in the lakes area for long after the birds leave.

In Argentinean Austral Patagonia, the American mink showed a behavior different from what is known from observations elsewhere. First, there is an unexpected degree of colonization across the semiarid Patagonian steppe habitat. Second, there is a difference between sexes in dispersal capability enough to determine a spatial segregation between males and females (presence of males in areas females do not reach). Lastly, mink appear to respond to bird availability and naïve prey in plateau lakes as a specialist predator instead of a generalist and this dependence on birds as energetic source determines a spatio-temporal pattern of mink use of the plateau habitat (dominance of birds in diet indicates that mink leave the upper lakes after birds are gone, even when mammalian prey has a permanent presence in those habitats).

The behaviors we described here have profound consequences in conservation and management. First, endangered species thought protected by the imaginary barrier of the arid environment are not safe. Second, the timing and the preferences for Hooded Grebes shown by the American mink have a strong effect on the Hooded Grebe population as they can revert the outcome of a reproductive season (see Roesler et al., 2012a). Third, spatiotemporal patterns of mink use of water bodies in the upper part of the plateaus determine the schedule of conservation actions for Hooded Grebe protection as extra efforts that need to be applied on the upper part during the mink dispersal period to limit the chances of surplus killing events. Lastly, as only dispersing young males reach the upper areas, the control objective would be to push away reproductive females (source) beyond a certain distance to make sure that no male mink could get close to the Hooded Grebe populations, while simultaneously reducing mink abundance in the lower parts of the plateau (source) in order to prevent immigration to the upper parts (Fasola and Roesler, 2016). In other words, managing a buffer area around the conservation hot spot and reverting old sources of mink into new sinks as has proved successful elsewhere (Olivier et al., 2016), is a strategy that should be applied to plateaus where mink presence is confirmed only on the surroundings.

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