Predatory impacts and variables determining the spatiotemporal occupancy of the invasive American mink (*Neovison vison*) on a pristine island in Southern Chile

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INTRODUCTION

The Cape Horn Biosphere Reserve (CHBR), located at the southern extreme of South America, encompasses a large archipelago covered by sub-Antarctic forests (Rozzi et al. 2006). It is recognized as one of the most pristine regions of the world given the high cover of native forests and low human population density (Mittermeier et al. 2003). However, invasive species threaten local biodiversity (Anderson et al. 2006). The American mink is a mid-sized, semi-aquatic mustelid native to North America (Lariviere 1999) that was first introduced to Patagonia in the 1930s (Jaksic et al. 2002; Fasola et al. 2011), and arrived to the CHBR in the late 1990s (Rozzi and Sherriffs 2003).

Negative effects caused by American mink invasions on the native fauna are well known in Europe (Bonesi and Palazon 2007). In Patagonia, several studies have addressed American mink effects on native species, mink's diet and dispersal abilities (Previtali et al. 1998; Fasola et al. 2010; Medina-Vogel et al. 2013). Particularly on Navarino Island, several studies have documented the American mink diet (Schüttler et al. 2008; Ibarra et al. 2009), habitat preference and abundance (Schüttler et al. 2010), and predatory negative impacts on flightless steamer ducks (*Tachyeres pteneres*) and upland geese (*Chloephaga picta*) (Schüttler et al. 2009).

However, all these studies focused on freshwater systems or along the coast line of Navarino and little is known about mink ecology and predatory effects on forest habitats away from water sources. Given mink's ecological plasticity and the low abundance of freshwater prey on Navarino Island (the natural source of food for mink), they will likely expand their niche into the forest to prey on native populations of forest bird and small rodent species, away from the rivers and coastlines (Crego et al. 2014). Moreover, no research has been conducted to assess if native prey that had *not* been exposed to terrestrial carnivores are developing antipredatory behaviours in response to the mink.

American mink have no competitors or natural enemies on Navarino Island, establishing them as a new top predator in this fragile ecosystem, where most prey species are likely naive to predation (Rozzi and Jiménez 2014). More research is crucial to better understand how American mink adapt their needs in this new environment and how prey adapts to the new predator. This essential information is crucial to develop management strategies to control or even eradicate this invasive species on Navarino Island and eventually from the CHBR, ensuring protection of local biodiversity.

In this project, I aimed to determine how the invasive American mink adapts to a pristine- island ecosystem and to assess how mink impact native biodiversity. During 2014 and summer 2015, I used camera traps and occupancy models to investigate mink occupancy and habitat selection. Also, I studied mink's diet, estimated rodents and bird abundances, and investigated the predatory-risk perception of a native rodent species to the novel predator. Finally, I proposed new management strategies to be implemented by the Chilean Agriculture and Livestock Bureau (SAG) to control the mink population on the island during 2015. Four students, Matias Barcelo, Nicolas Carro, Simon Castillo, and Gabriel Gomez participated as technicians.

OBJECTIVES

In this project I specifically aimed to (A) estimate occupancy and detection probabilities of the invasive American mink in Navarino Island, Chile, during three different seasons, including winter, spring, and summer; (B) model associations of habitat factors and prey abundances with American mink occupancy and detection probabilities across the year; (C) study spatial and temporal relationships between American-mink diet and prey abundance; (D) investigate rodent prey naivety to American mink predation; and (D) propose a management plan to control or eradicate American mink from Navarino Island.

Mink occupancy and detection probability

The ability of a species to become invasive relies on how they respond spatially and temporally to three factors in the new environment: the amount of resources (Petren and Case 1996; Pintor and Sih 2010), the presence of natural enemies (Settle and Wilson 1990), and the physical environment (Moyle and Light 1996). New "niche opportunities" are critical in determining the success of an invasion and the impact the invasive species will have on the new community of which they become part (Shea and Chesson 2002). Moreover, habitat selection is influenced by intra- and interspecific competition and predation, and it is also a density-dependent process (Rosenzweig 1981). Initially, species tend to occupy optimal habitats to increase fitness, but as the population grows and intraspecific competition increases, species expand the habitat to later occupy also suboptimal areas (Rosenzweig 1991). The American mink have several new niche opportunities on Navarino Island, as mink lack natural enemies and even competition with other mammalian carnivores. In addition, on Navarino, American mink lack the natural food source found in its native range, freshwater fish and crayfish (Lariviere 1999); therefore, mainland birds and rodents have become the main component of their diet (Schüttler et al. 2008; Ibarra et al. 2009).

I hypothesize that American mink on Navarino Island will expand from semi-aquatic habitats, what is considered their natural niche, to inland forests, beyond rivers and coastlines; and second, throughout the year, occupancy will be mainly affected by the complexity of understory vegetation where mink will have more hunting opportunities.

To address the following two objectives, I set 98 camera stations following the north border of Navarino Island, in four accessible areas (Fig. 1). During summer 2014, spring 2014 and summer 2015, I set cameras in the 98 stations. During winter 2014, however, given extreme weather conditions and access limitations to the most remote places, I set cameras in 49 stations (Omora and Caleta Eugenia). Cameras were fish-baited, operated 24 h/day for 20 days and spaced at least 750m apart. For the analysis, I used the following variables: i) main habitat type (mature forest, secondary forest, meadow, and coastal shrubs), ii) altitude, iii) shortest distance to coast, iv) shortest distance to fresh water (river or pond), and v) understory vegetation height and density using the Robel Pole technique (Robel et al. 1970).

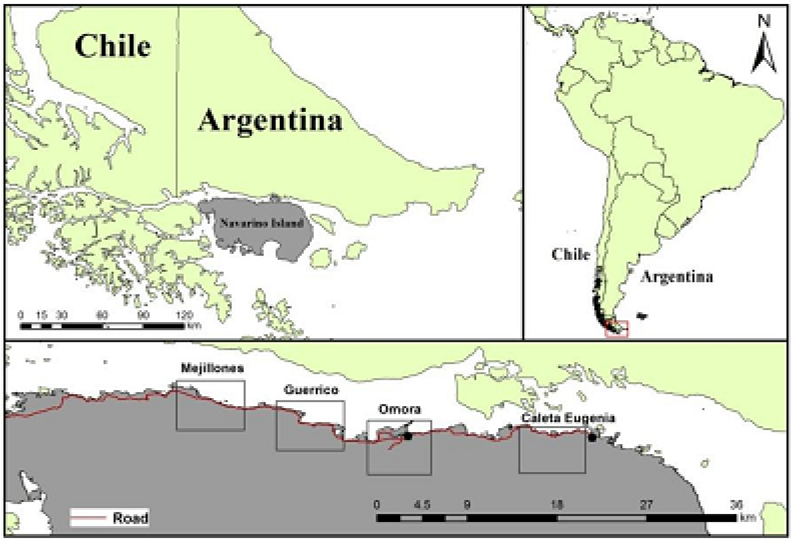

Fig. 1. Map of the southern tip of South America, with the study area, Navarino Island. The four sampling regions are shown in the bottom panel.

A- To estimate occupancy and detection probabilities of the invasive American mink on Navarino Island, Chile, during three seasons: summer, winter, and spring.

Assuming >60 min between two detections for independence, during February and March 2014 (summer) I detected a total of 239 mink visits to trap cameras; during June and July 2014 (winter), 49 mink visits; during October and November 2014 (spring), 27 mink visits; and finally, during February and March 2015 (summer) 165 mink visits. Capture rate was 12.19 detections/100 trap nights for summer. It dropped to 5 detections/100 trap nights during winter, and dropped even further during spring to 1.4 detections/100 trap nights. However, capture rate increased again to 8.58 detections/100 trap nights for summer 2015. Mink capture rate dropped 89% from summer to spring of 2014, but increased again the following summer 2015 (Fig. 2).

I fit single-season occupancy models to estimate occupancy (ψ) and detection probability (*p*), using a logit function (MacKenzie et al. 2006). I defined 4 surveys of 5 days each. I performed statistical analysis using unmark package in R programming software (R Development Core Team 2014). Mink were detected at 48 of 98 stations (naïve occupancy 49%) during the summer 2014. However, the adjusted occupancy for observed detection probabilities was 65%. During winter 2014, mink were detected at 14 of 49 stations (naïve occupancy 29%). However, the adjusted occupancy for observed detection probabilities was 36%. During spring 2014, mink were detected at 15 of 98 stations (naïve occupancy 15%). The adjusted occupancy for observed detection probabilities was 49%. Overall, adjusted occupancy dropped 24% from summer to spring of 2014. However, during summer 2015, mink were detected at 45 of 98 stations (naïve occupancy 46%). The adjusted occupancy for observed detection probabilities was 62%, similar to the 65% estimated for summer 2014.

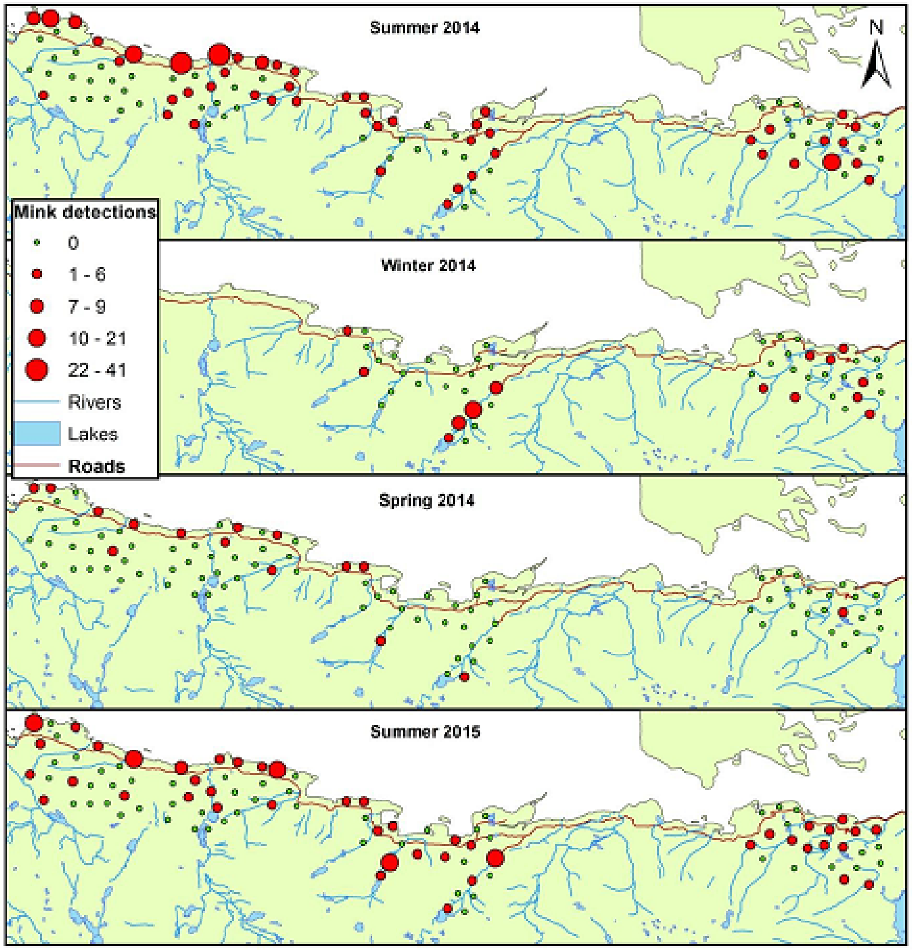

Fig. 2. Map showing American mink detections during summer, winter, and spring 2014, on the Northern coast of Navarino Island, Chile.

B- To model associations of habitat factors and prey abundances with American mink occupancy and detection probabilities during the three seasons.

To address this objective for the summer and winter seasons, I used the information on American mink detection and habitat covariates to build probabilistic models of occupancy estimating ψ and *p*, once again using a logit function (MacKenzie et al. 2006) and defining 4 surveys of 5 days each. I first built models holding ψ constant, but allowing *p* to be a function of covariates, to determine the effect of habitat variables on *p*. I selected the most parsimonious model according to Akaike's information criterion corrected for small sample size (AICc) (Burnham and Anderson 2002). I used the most parsimonious model to later model ψ.

For summer season 2014, in the most competitive model, detection was affected by altitude (Table 1). Detection probability was higher at lower altitudes and lower at higher altitudes (Fig. 3). Over the set of occupancy models, occupancy was affected by the understory vegetation (Table 2). Occupancy increased with higher understory vegetation height and density (Fig. 4).

Table 1. Model selection results of models for detection probability (*p*) with associated occupancy (ψ) and standard error (SE) for American mink on Navarino Island during February and March 2014.

Model	AICc	ΔAICc	AIC w_i	no.Par.	Ψ	SE
ψ (.),p(Alt)	376.66	0.00	0.64	3	0.65	0.08
ψ (.),p(H)	377.89	1.23	0.34	5	0.63	0.08
ψ (.),p(RP)	384.80	8.14	0.01	3	0.60	0.08
ψ (.),p(DC)	386.02	9.36	0.01	3	0.59	0.07
ψ (.),p(.)	390.80	14.14	0.00	2	0.54	0.06
ψ (.),p(DFW)	392.36	15.70	0.00	3	0.54	0.06

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

Table 2. Model selection results of models for occupancy (ψ) while maintaining the most parsimonious detection model (Alt) for American mink on Navarino Island during February and March 2014.

Model	AICc	ΔAICc	AIC wi	no.Par.
ψ (RP),p(Alt)	372.42	0.00	0.57	4
ψ (RP + Alt),p(Alt)	374.40	1.98	0.21	5
ψ (.),p(Alt)	376.66	4.24	0.07	3
ψ (Alt),p(Alt)	376.91	4.49	0.06	4
ψ (DFW),p(Alt)	378.13	5.71	0.03	4
ψ (RP + H),p(Alt)	379.20	6.79	0.02	7
ψ (H),p(Alt)	379.66	7.24	0.01	6
ψ (DC),p(Alt)	380.94	8.52	0.01	4
ψ (RP + Alt + H),p(Alt)	381.24	8.83	0.01	8

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

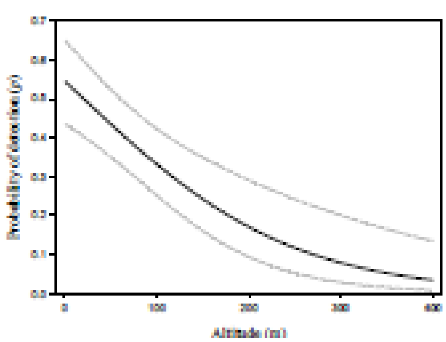

Fig. 3. Probability of detection (95% confidence intervals) as a function of altitude for American mink on Navarino Island during February and March 2014.

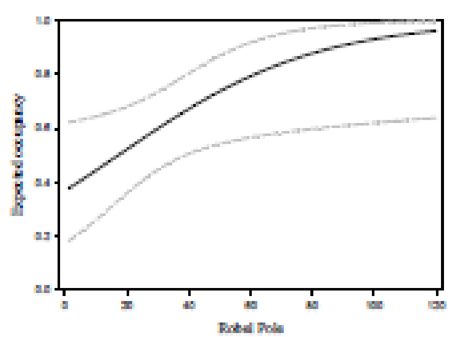

Fig. 4. Expected occupancy (95% confidence intervals) as a function of Robel Pole for American mink on Navarino Island during February and March 2014.

For winter season, in the most competitive model, detection was affected by distance to fresh water (Table 3). Detection probability was higher near to fresh water systems and lower at higher distances from water (Fig. 5). Over the set of occupancy models, two models were almost equally competitive, one including distance to coast and the other setting occupancy constant (Table 4). Occupancy increased with higher distances to the coast (Fig. 6).

Table 3. Model selection results of models for detection probability (*p*) with associated occupancy (ψ) and standard error (SE) for American mink on Navarino Island during June and July 2014.

Model	AICc	ΔAICc	AIC w_i	no.Par.	Ψ	SE
ψ (.),p(DFW)	124.10	0.00	0.77	3	0.36	0.09
ψ (.),p(Alt)	128.77	4.67	0.07	3	0.35	0.09
ψ (.),p(Habitat)	129.68	5.58	0.05	5	0.39	0.11
ψ (.),p(.)	129.94	5.83	0.04	2	0.30	0.08
ψ (.),p(DC)	129.98	5.87	0.04	3	0.36	0.11
ψ (.),p(RP)	130.99	6.89	0.02	3	0.30	0.07

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

Table 4. Model selection results of models for occupancy (ψ) while maintaining the most parsimonious detection model (distance to coast) for American mink on Navarino Island during June and July 2014.

Model	AICc	ΔAICc	AIC w_i	no.Par.
ψ (DC),p(DFW)	123.82	0.00	0.32	4
ψ (.),p(DFW)	124.10	0.29	0.28	3
ψ (DFW),p(DFW)	125.99	2.18	0.11	4
ψ (Alt),p(DFW)	126.03	2.21	0.11	4
ψ (RP),p(DFW)	126.07	2.26	0.10	4
ψ (RP + Alt),p(DFW)	127.84	4.03	0.04	5
ψ (H),p(DFW)	128.88	5.07	0.03	6
ψ (Full model),p(DFW)	130.62	6.80	0.01	10
ψ (RP + H),p(Alt)	131.14	7.32	0.01	7
ψ (RP + Alt + H),p(Alt)	134.00	10.18	0.00	8

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

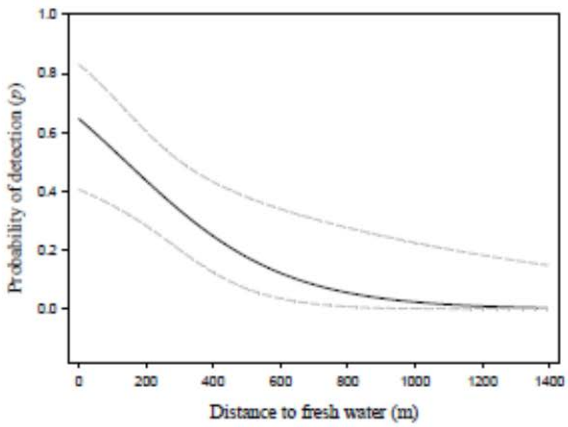

Fig. 5. Probability of detection (95% confidence intervals) as a function of distance to fresh water for American mink on Navarino Island during June and July 2014.

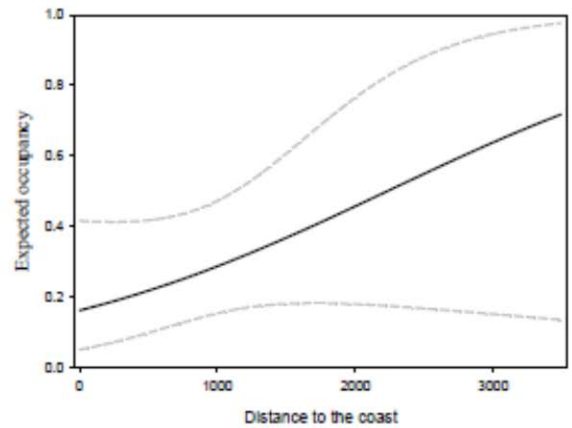

Fig. 6. Expected occupancy (95% confidence intervals) as a function of distance to the coast for American mink on Navarino Island during June and July 2014.

For spring season, in the most competitive model, detection was affected by understory vegetation structure, measured with the Robel Pole technique (Table 5). Detection probability increased with vegetation height and density (Fig. 7). Over the set of occupancy models, three models were the most competitive, one including Robel Pole measure, one including habitat, and the last one included both variables (Table 6). Similar to summer season, occupancy increased with vegetation height and density (Fig. 8A) and was higher for coastal bush habitat, where vegetation is more complex, and lower for the other three habitat types, primary forests, secondary forests, and meadows (Fig. 8B).

Table 5. Model selection results of models for detection probability (*p*) with associated occupancy (ψ) and standard error (SE) for American mink on Navarino Island during October and November 2014.

Model	AICc	ΔAICc	AIC w_i	no.Par.	Ψ	SE
ψ (.),p(RP)	151.83	0.00	0.41	3	0.49	0.18
ψ (.),p(H)	152.04	0.21	0.37	5	0.51	0.18
ψ (.),p(Alt)	154.49	2.65	0.11	2	0.33	0.12
ψ (.),p(DC)	155.63	3.79	0.06	3	0.35	0.20
ψ (.),p(.)	157.12	5.28	0.03	2	0.24	0.08
ψ (.),p(DFW)	159.00	7.17	0.01	3	0.23	0.07

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

Table 6. Model selection results of models for occupancy (ψ) while maintaining the most parsimonious detection model (Robel Pole) for American mink on Navarino Island during October and November 2014.

Model	AICc	ΔAICc	AIC w_i	no.Par.
ψ (RP),p(RP)	149.58	0.00	0.23	7
ψ (RP + H),p(RP)	149.58	0.00	0.23	4
ψ (H),p(RP)	150.22	0.64	0.17	6
ψ (DC),p(RP)	151.72	2.14	0.08	4
ψ (RP + Alt),p(RP)	151.80	2.22	0.08	5
ψ (.),p(RP)	151.83	2.26	0.08	3
ψ (DFW),p(RP)	152.12	2.54	0.07	4
ψ (Alt),p(RP)	152.69	3.11	0.05	4
ψ (RP + Alt + H),p(RP)	154.47	4.90	0.02	8
ψ (Full Model),p(RP)	160.98	11.40	0.00	10

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robert Pole; (.) indicates that the parameter was constant.

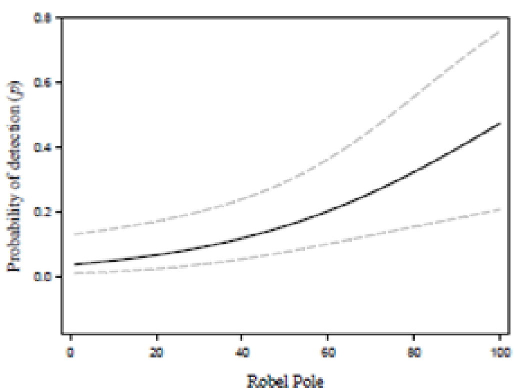

Fig. 7. Probability of detection (95% confidence intervals) as a function of Robel Pole for American mink on Navarino Island during October and November 2014.

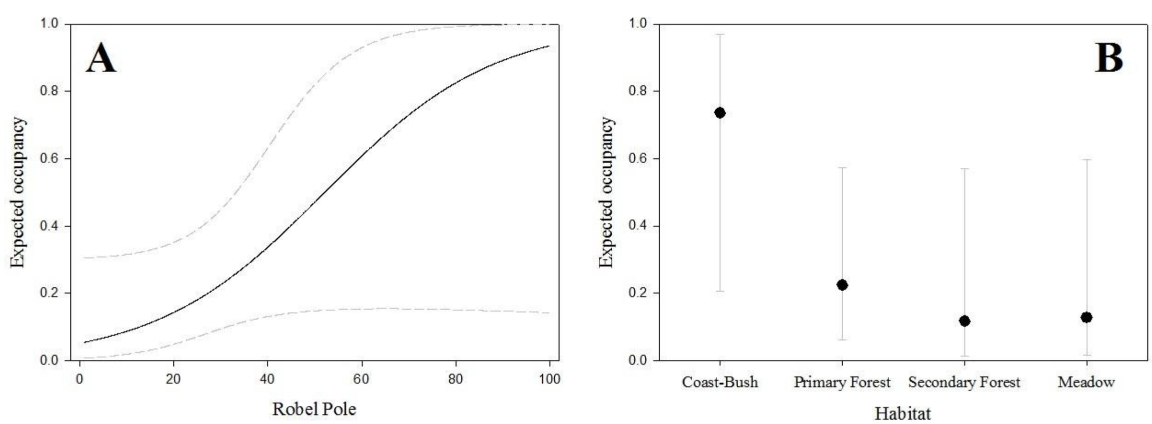

Fig. 8. Expected occupancy (95% confidence intervals) as a function of Robel Pole (A) and Habitat (B) for American mink on Navarino Island during October and November 2014.

For summer season 2015, in the most competitive model, detection was affected by habitat type (Table 7). Detection probability was higher at the coastal bushes, compared to forests and meadows (Fig. 9). Over the set of occupancy models, occupancy was affected by the understory vegetation (Table 8). Occupancy increased with higher understory vegetation height and density (Fig. 10).

Table 7. Model selection results of models for detection probability (*p*) with associated occupancy (ψ) and standard error (SE) for American mink on Navarino Island during February and March 2015.

Model	AICc	ΔAICc	AIC w_i	no.Par.	Ψ	SE
ψ (.),p(H)	329.61	0.00	0.90	5	0.62	0.09
ψ (.),p(DC)	334.76	5.14	0.07	3	0.57	0.08
ψ (.),p(RP)	337.28	7.67	0.02	3	0.56	0.09
ψ (.),p(Alt)	338.60	8.99	0.01	3	0.55	0.08
ψ (.),p(.)	345.30	15.69	0.00	2	0.49	0.07
ψ (.),p(DFW)	346.28	16.67	0.00	3	0.49	0.07

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole; (.) indicates that the parameter was constant.

Table 8. Model selection results of models for occupancy (ψ) while maintaining the most parsimonious detection model (Alt) for American mink on Navarino Island during February and March 2015.

Model	AICc	ΔAICc	AIC w_i	no.Par.
ψ (RP),p(H)	329.09	0.00	0.30	6
ψ (.),p(H)	329.61	0.52	0.23	5
ψ (Alt),p(H)	330.80	1.71	0.13	6
ψ (DC),p(H)	331.36	2.27	0.10	6
ψ (RP + Alt),p(H)	331.36	2.27	0.09	7
ψ (DFW),p(H)	331.89	2.80	0.07	6
ψ (H),p(H)	333.32	4.23	0.04	8
ψ (RP + H),p(H)	333.38	4.29	0.03	9
ψ (RP + Alt + H),p(H)	334.77	5.68	0.02	10
ψ (Full model),p(H)	340.77	11.68	0.00	12

H: habitat; DC; distance to coast; DFW; distance to fresh water; Alt: altitude; RP: Robel Pole ;(.) Indicates that the parameter was constant.

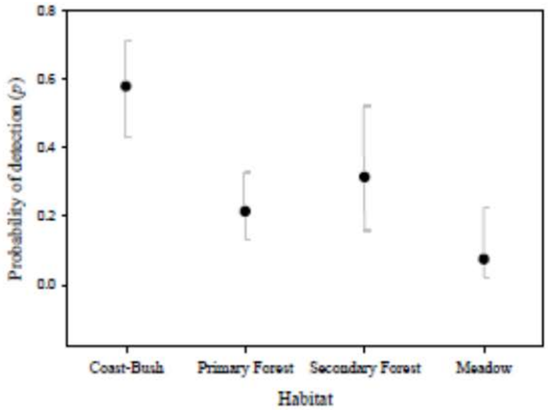

Fig. 9. Probability of detection (95% confidence intervals) as a function of type of habitat for American mink on Navarino Island during February and March 2015.

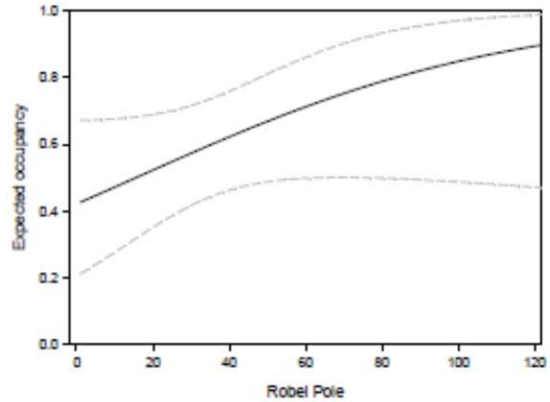

Fig. 10. Expected occupancy (95% confidence intervals) as a function of Robel Pole for American mink on Navarino Island during February and March 2015.

Discussion

Results from this study showed that the American mink presented a high occupancy, over 60%, on Navarino Island during summer seasons; however, such occupancy was significantly lower in winter and spring. In accordance with my hypothesis, during the summer season's American mink on Navarino Island were not associated with fresh water systems as this variable did not seem to affect probability of mink detection or occupancy. Distances to coast or habitat type did not affect mink occupancy either. Mink were almost completely occupying the coastal areas at low altitudes (Fig. 2), where resources are more abundant, but as these territories become occupied, other members of the population may be moving inland, so mink also occupied the interior where forests and wetlands dominate. Therefore, during summers the understory vegetation height and density explained occupancy, likely because it is in dense vegetation where mink have better hunting opportunities given more abundance of prey. However, such occupancy dropped significantly during the winter. Also, unlike my hypothesis, during the winter mink were more associated with fresh water systems. Approximately 35% of avian species on Navarino Island are migrants, staying in the island during the breeding season in the spring-summer (Ippi et al. 2009); therefore, rodents, both native and small, and exotic muskrats (*Odontra zibethicus*), become more common prey during the winter when avian abundances decrease (*Schüttler* et al. 2008). Therefore, during winter and spring, mink occupied habitat close to freshwater and the coast, respectively. The drop in occupancy may be explained by a high mortality rate, as other studies show that mink are not well adapted to wintering fasting (Mustonen et al. 2005b; Mustonen et al. 2005a). It is likely that part of the population occupying lower-quality habitat, perhaps dispersing juveniles, died during the winter.

It is important to highlight that the analyses performed for this report are preliminary.

Much work is needed on the analysis and preparation of predictor variables to run the occupancy models. For instance, the geographic information data I have now present some spatial error that needs to be corrected. This will occur when I return to the University of North Texas, Denton, TX, USA to write my doctoral dissertation. Also, I am planning to fully investigate vegetation data collected during sampling to include as covariates in the models, distinguishing analyses at micro-habitat level, from macro-habitat level. Finally, it is also likely that beaver (*Castor canadensis*) dams play an important role in explaining mink population dynamics, as I have observed that muskrats are highly associated with these modified habitats. Unfortunately, I do not have good geographic information to include this variable in the models. However, it is my goal to map beaver dams and include this variable in the analysis.

Several studies focusing on the American mink population on Navarino Island documented diet, abundance, and predatory effects on birds (Schüttler et al. 2008; Ibarra et al. 2009; Schüttler et al. 2009; Schüttler et al. 2010; Maley et al. 2011). However, these studies have focused solely on aquatic or semi-aquatic habitats. Little was known about mink ecology, movement dynamics, and predatory effects on forest habitats away from water sources.

Additionally, the mink population dynamic may have important implication for management. Currently, SAG conservation agents are trapping mink intensively during the summer, and primarily trapping sub-adults. However, if mortality of mink is high during winter, it would be more efficient to intensify trapping at the end of the winter, to increase trapping of reproductive females. Consequently, SAG will have a better impact controlling the mink population, and avoid spending resources in trapping animals that likely will not survive the winter.

C- Diet and prey abundance

** To study spatial and temporal (seasonal) relationships between American mink diet and prey abundance**

Small rodents

I estimated abundance of small rodents using 16 grids of Sherman traps (5 x 5; 10 m spacing) during summer 2014 and 2015 spring 2014, and 8 grids during winter 2014. Traps were active during 5 nights. During summer 2014, I live-captured 20 individuals of *Abrothrix xanthorhinus*, 1 of *Oligoryzomys longicaudatus* and 4 of *Mus musculus*; winter 2014, 7 individuals of *Abrothrix xanthorhinus*, and 4 of *Mus musculus*; spring 2014, 4 individuals of *Abrothrix xanthorhinus*, 1 individual of *Oligoryzomys longicaudatus,* and 1 of *Mus musculus*; and summer 2015, I live-captured 6 individuals of *Abrothrix xanthorhinus*, 4 of *Oligoryzomys longicaudatus* and 7 of *Mus musculus* (Table 9).

Table 9. Relative abundance (RA = [number of captures/ (number of traps * number of nights)*100]) of three rodent species during summer 2014, winter 2014, spring 2014, and summer 2015 on Navarino Island, Chile.

Grid	Site	Habitat	Summer 14			Winter 14		Spring 14			Summer 15		
			RA of *A.x.*	RA of *O.l.*	RA of *M.m.*	RA of *A.x.*	RA of *M.m.*	RA of *A.x*	RA of *O.l*	RA of *M.m.*	RA of *A.x.*	RA of *O.l.*	RA of *M.m.*
1	Mejillones	Primary Forest	0	0	0	-	-	0	0.8	0	0	0	0
2		Secondary Forest	0	0	0	-	-	0	0	0	0.8	0	0
3		Coast – Shrubs	0.32	0.8	0	-	-	0	0	0	2.4	0.8	0
4		Meadow	0	0	0	-	-	0	0	0	0	0	0
5	Guerrico	Primary Forest	0	0	0	-	-	0	0	0	0	0	0
6		Secondary Forest	0.8	0	0	-	-	0	0	0	0	0	0
7		Coast – Shrubs	0	0	0	-	-	0	0	0	0	0	0
8		Meadow	0	0	0	-	-	0	0	0	0	0	0
9	Eugenia	Primary Forest	0.8	0	0	0	0	0	0	0	0	0	0
10		Secondary Forest	0	0	0	0	0	0	0	0	0	0	0
11		Coast – Shrubs	17.6	0	0	5.6	0	8	0	0	6.4	0	0
12		Meadow	0.8	0	0	2.4	0	0	0	0	0	0.8	0
13	Omora	Primary Forest	0.8	0	0	0	0	0	0	0	0	0	0
14		Secondary Forest	0	0	0	0	0	0	0	0	0	0.8	0
15		Coast – Shrubs	0	0	5.6	1.6	2.4	0	0	0.8	0	0	4.8
16		Meadow	0	0	0	0	0.8	0	0	0	0	0	1.6

A.x. = Abrothrix xanthorhinus; O.l.= Oligoryzomys longicaudatus; M.m= Mus musculus;

In all seasons, a higher relative abundance of small rodents was found in the coastal shrubs, with a lower abundance in other habitat types (Table 8). Abundance was higher during summer compared to winter and spring, with the lowest abundance in spring. There was a constant declination of rodent relative abundance along the year, from summer 2014 to summer 2015.

Table 10. Relative abundance of small rodents in four different habitat types estimated during summer 2014, winter 2014, spring 2014, and summer 2015 on Navarino Island, Chile.

Habitat	**Trap nights**	**Summer 14 Captures * 100 trap**	**Trap nights**	**Winter 14 Captures * 100 trap**	**Trap nights**	**Spring 14 Captures * 100 trap**	**Trap nights**	**Summer 15 Captures * 100 trap**
Primary Forest	500	0.4	250	0	500	0.2	500	0.2
Secondary Forest	500	0.2	250	0	500	0	500	0.4
Coast – Shrubs	500	6.8	250	4.8	500	2.2	500	3.6
Meadow	500	0.2	250	1.6	500	0	500	0.6
Total	**2000**	**1.9**	**1000**	**1.6**	**2000**	**0.6**	**2000**	**1.2**

Birds

I also estimated abundance of birds using the point counting technique. I used 16 circular plots during summer 2014 and 2015, and spring 2014, and 8 during winter 2014 for 5 days to identify all birds detected during 15 min at 4 different habitat types. I differentiated between birds that were within 2 m of the ground or above 2 m assuming birds that spend time closer to ground level are potential prey of mink. As an estimator, I used the mean number of birds per 1 h of observation. I considered species that could be potential mink prey based on mink diet studies.

Relative abundance of birds within 2 m of ground level was higher for coast-bush habitat, relative to other habitat types for the three seasons (Tables 11,12, 13, and 14). As expected, given that some species are migrants, relative abundance of birds diminished during winter season, thus the abundance of potential prey for mink likely decreased as well. Abundance increased during the spring when migrant species arrive for the breeding season, thus, increasing potential prey for mink.

Table 11. Relative abundance of birds (individuals/hr) in four different habitat types below and above 2 m of ground level, estimated in February and March, 2014, on Navarino Island, Chile.

Species	Primary Forest		Secondary Forest		Meadow		Coast-Bush	
	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m
Elaenia albiceps	0.00	0.60	0.00	1.00	0.20	0.00	1.00	0.00
Aphrastura spinicauda	2.40	17.90	0.25	15.35	1.60	0.00	12.25	0.25
Zonotrichia capensis	0.00	3.80	0.00	3.40	0.40	0.50	18.20	0.00
Phrygilus patagonicus	0.00	0.40	0.00	1.00	0.00	0.00	5.35	0.00
Carduelis carduelis	0.00	0.70	0.00	0.00	0.00	0.00	0.60	0.00
Tachycineta leucopyga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Turdus falcklandii	0.40	0.65	0.00	1.20	0.00	0.00	1.60	0.25
Enicognathus ferrigineus	0.20	0.00	0.00	0.40	1.65	0.00	0.00	0.60
Troglodytes aedon	0.00	0.40	0.50	0.25	1.50	0.00	11.45	0.00
Xolmis pyrope	0.00	0.40	0.20	0.25	0.00	0.00	0.00	0.25
Campephilus magellanicus	0.00	1.40	0.00	1.10	1.60	0.00	0.00	0.00
Chloephaga picta	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00
Theristicus melanopis	0.00	0.00	0.00	0.00	0.00	0.00	0.25	1.00
Cinclodes spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Curaeus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25
Total (ind/hr)	**3.00**	**27.45**	**1.55**	**24.95**	**6.95**	**0.50**	**51.20**	**10.25**

Table 12. Relative abundance of birds (individuals/hr) in four different habitat types below and above 2 m of ground level estimated in June and July, 2014, on Navarino Island, Chile.

Species	Primary Forest		Secondary Forest		Meadow		Coast-Bush	
	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m
Aphrastura spinicauda	2.00	28.00	0.00	15.00	0.40	2.00	14.40	5.50
Phrygilus patagonicus	0.00	3.50	0.00	1.50	0.00	0.00	1.20	0.00
Carduelis carduelis	0.00	1.50	0.00	0.50	0.00	0.00	2.00	1.00
Turdus falcklandii	0.80	4.50	0.00	0.50	0.00	0.00	0.00	0.00
Enicognathus ferrigineus	0.00	1.00	0.00	1.00	0.00	0.00	5.20	0.00
Troglodytes aedon	1.20	0.00	0.00	0.00	0.80	0.00	2.00	0.00
Xolmis pyrope	0.00	0.00	0.40	0.00	1.20	0.00	0.00	0.00
Campephilus magellanicus	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
Cinclodes spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Total (ind/hr)	**4.00**	**39.00**	**0.40**	**20.50**	**2.40**	**4.00**	**25.60**	**10.50**

Table 13. Relative abundance of birds (individuals/hr) in four different habitat types below and above 2 m of ground level, estimated in October and November, 2014, on Navarino Island, Chile.

Species	Primary Forest		Secondary Forest		Meadow		Coast-Bush	
	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m	↓2m	↑2m
Elaenia albiceps	0.00	0.60	0.00	1.00	0.20	0.00	1.00	0.00
Aphrastura spinicauda	2.40	17.90	0.25	15.35	1.60	0.00	12.25	0.25
Zonotrichia capensis	0.00	3.80	0.00	3.40	0.40	0.50	18.20	0.00
Phrygilus patagonicus	0.00	0.40	0.00	1.00	0.00	0.00	5.35	0.00
Carduelis carduelis	0.00	0.70	0.00	0.00	0.00	0.00	0.60	0.00
Tachycineta leucopyga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Turdus falcklandii	0.40	0.65	0.00	1.20	0.00	0.00	1.60	0.25
Enicognathus ferrigineus	0.20	0.00	0.00	0.40	1.65	0.00	0.00	0.60
Troglodytes aedon	0.00	0.40	0.50	0.25	1.50	0.00	11.45	0.00
Xolmis pyrope	0.00	0.40	0.20	0.25	0.00	0.00	0.00	0.25
Campephilus magellanicus	0.00	1.40	0.00	1.10	1.60	0.00	0.00	0.00
Chloephaga picta	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00
Theristicus melanopis	0.00	0.00	0.00	0.00	0.00	0.00	0.25	1.00
Cinclodes spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Curaeus curaeus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.25
Pygarrhicas albogularis	0.00	1.15	0.00	0.00	0.00	0.00	0.00	1.25
Anairetes parulus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
Lessonia ruffa	0.00	0.00	0.00	0.00	3.55	0.20	2.10	0.20
Sturnella loica	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00
Gallinago	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Vanellus chilensis	0.00	0.00	0.00	0.00	0.60	0.80	0.00	0.00
Lophonetta specularoides	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00
Anas sibilatrix	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00
Anas flavirostris	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00
Total (ind/hr)	**2.20**	**58.40**	**0.00**	**43.60**	**14.75**	**8.45**	**47.40**	**11.15**

Table 14. Relative abundance of birds (individuals/hr) in four different habitat types below and above 2 m of ground level, estimated in February and March, 2015, on Navarino Island, Chile.

Species	**Primary Forest**		**Secondary Forest**		**Meadow**		**Coast-Bush**	
	↓ 2m	↑ 2m	↓ 2m	↑ 2m	↓ 2m	↑ 2m	↓ 2m	↑ 2m
Elaenia albiceps	0.00	2.25	0.00	3.90	0.00	0.00	1.25	0.25
Aphrastura spinicauda	1.35	22.9	0.00	18.25	0.40	0.00	10.9	0.00
Zonotrichia capensis	0.00	3.20	0.00	1.70	2.95	0.00	16.50	1.75
Phrygilus patagonicus	0.00	9.35	0.00	9.40	0.00	0.00	3.55	0.20
Carduelis carduelis	0.00	15.55	0.00	10.70	0.90	0.00	0.90	4.95
Tachycineta leucopyga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Turdus falcklandii	0.20	1.85	0.50	3.65	0.25	0.20	0.00	0.00
Enicognathus ferrigineus	0.00	0.25	0.00	0.40	0.00	0.00	0.00	0.00
Troglodytes aedon	0.25	0.45	0.00	0.00	1.05	0.00	12.30	0.00
Xolmis pyrope	0.00	0.50	0.00	0.40	1.45	0.20	1.00	0.00
Campephilus magellanicus	0.25	3.50	0.00	0.60	0.00	0.00	0.00	0.00
Chloephaga picta	0.00	0.00	0.00	0.00	1.20	0.00	0.00	1.00
Cinclodes spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
Curaeus curaeus	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
Pygarrhicas albogularis	0.00	2.75	0.00	0.50	0.00	0.00	0.00	1.25
Anairetes parulus	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.20
Lessonia ruffa	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00
Churrin	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Gallinago gallinago	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00
Dormilona tontita	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00
Anas sibilatrix	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00
Anas flavirostris	0.00	0.00	0.00	0.00	5.40	1.00	0.00	0.00
Total (ind/hr)	**2.05**	**63.75**	**0.50**	**50.90**	**14.75**	**3.40**	**47.80**	**11.80**

Muskrats

I assessed presence/absence of muskrats by sampling their tracks and scats along 75 200-m transects separated by a minimum distance of 100 m. While walking through the diverse habitats, I determined transect starting points where I crossed a stream or a beaver dam. Transects were walked by two observers, one on each side of the stream, or walking together along the shore in case of beaver ponds. When a transect fell along a beaver dam, we searched for recent beaver activity, such as fresh tree cuts near the dam or tracks, to determine beaver presence in the dam.

Based on field observations, I classified transects in four types of systems: active beaver dams with a lentic system (i.e. active beaver dams that have a pond or a wetland system), inactive beaver dams with a lentic system (i.e. inactive beaver dams that still preserve a pond or a wetland system), beaver dams with a lotic system (i.e. inactive beaver dams where the stream recovered the flow), and lotic streams with no beaver. I fitted generalized linear model (GLM) with binomial distribution and logit function to investigate how muskrat presence was related to different habitat types.

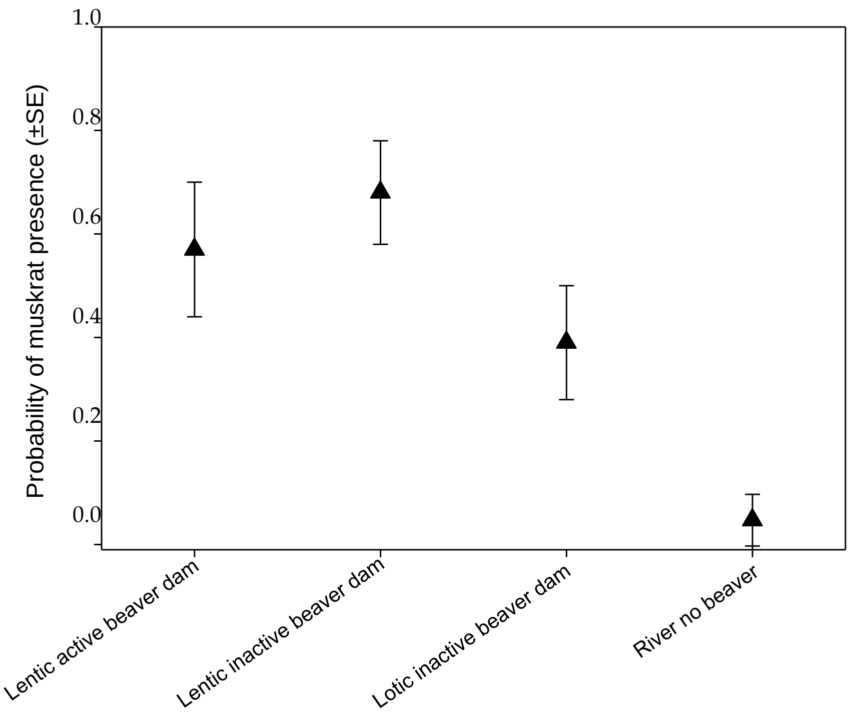

Fig. 11. Predicted muskrat presence in the northern region on Navarino Island, Chile (February-March 2014 and February-March 2015), in relation to lentic active beaver dams (i.e. active beaver dams that have a pond or a wetland system), lentic inactive beaver dams (i.e. abandoned beaver dams that still preserve a pond or a wetland system), lotic beaver dams (i.e. inactive beaver dams where the stream recovered the flow), and lotic streams with no beaver.

I detected muskrat signs at 41% of transect. The probability of finding muskrats was higher for inactive beaver dams that still conserved a pond system, followed by active beaver dams, lower for beaver-modified habitats where the river recovered the flow, and almost null in rivers with no beaver intervention (Figure 11).

American mink diet

To study American mink diet composition, I collected a total of 174 scats throughout the year. I initially planned to use stomach contents. However, most of mink stomachs I analysed were empty and SAG agents did not trap mink intensively this past year. Therefore, I decided to collect scats to assess mink's diet to increase my sample size. Also, given that I could not be sure how long a scat has been on the ground or in a latrine, I decided to analyse data annually and not seasonally.

I identified prey items to the lowest taxonomic group possible, using different techniques: for arthropods, I used local guides; for small mammals, I compared hair with hair of local small rodents, and bones and teeth with voucher specimens and photographs; and for birds I

compared feathers and bones with keys and references. I estimated frequency of occurrence (FO) expressed as a percentage (number of scats with a prey category divided by the total number of scats), and percentage of bulk (PB) of a prey category (proportion of volume of a scat with a prey category multiplied by dry weight of the scat, divided by total dry weight of scats). Diet composition was differentiated between faeces found in inland wetlands and forest (n= 96) and marine coast (n=
78) (Table 15).

Table 15. Diet composition of American mink based on faeces (n = 174) from March to November on Navarino Island; FO = frequency of occurrence expressed as a percentage, PB = percentage of bulk.

Prey item	**Inland Wetlands and Forests**		**Marine Coast**		**Total**	
	FO	**PB**	**FO**	**PB**	**FO**	**PB**
Abrothrix xanthorhinus	18.8	9.6	7.7	2.2	13.8	6.3
Mus musculus	1.0	0.4	0.0	0.0	0.6	0.2
Neovison vison	0.0	0.0	2.6	3.9	1.1	1.7
Oligoryzomys longicaudatus	3.1	3.9	6.4	11	4.6	7.5
Ondatra zibethicus	32.3	47.3	2.6	6.8	19.0	29.4
Castor canadensis	1.0	0.2	0.0	0.00	0.6	0.1
Unidentified mammals	3.1	0.2	2.6	0.00	2.9	0.4
Total mammals	**57.3**	**61.9**	**21.8**	**25.3**	**41. 4**	**45.8**
Anseriformes	4.2	1.4	1.3	0.3	2.9	0.9
Ardeiformes	0.0	0.0	2.6	0.7	1.1	0.3
Piciformes	1.0	0.1	0.0	0.0	0.6	0.1
Passeriformes	25.0	14.5	12.8	6.0	19.5	10.8
Pelecaniformes	1.0	0.1	3.8	0.4	2.3	0.2
Eggs	1.0	0.1	0.0	0.0	0.6	0.1
Unidentified birds	2.1	0.1	9.0	0.5	5.2	0.2
Total birds	**33.3**	**16.4**	**28.2**	**7.9**	**31.0**	**12.6**
Fish	**8.3**	**1.8**	**79.5**	**49.7**	**40.2**	**23.2**
Coleoptera	30.2	5.5	6.4	2.4	19.5	4.1
Odonata	5.2	1.6	0.0	0.0	2.9	0.9
Unidentified insects	0.0	0.0	3.8	0.1	2.9	0.1
Total insects	**33.3**	**16.7**	**10.3**	**2.4**	**23.0**	**10.4**
Crustaceans	**0.0**	**0.0**	**20.5**	**10.5**	**9.2**	**4.7**
Seeds	**15.6**	**3.8**	**11.5**	**3.4**	**13.8**	**3.7**

Conclusions

Overall, mammals represented the main prey item of the American mink, followed by fish. However, fish was an important prey item for mink that inhabited the coast representing near 50% of the bulk, while mammals represented almost 62% of the bulk for mink that inhabited inland. The proportion of native rodents in the mink diet corresponds to their relative abundance, with *A. xanthorhinus* being almost 3 times more frequent than *O. longicaudatus*.

This proportion is similar to previous studies (Schüttler et al. 2008). Ibarra et al. (2009) reported that these two native rodents represented 29% of mink diet in inland ponds, while I found 22% in this study. However, muskrats, on the other hand, represented 30% of the bulk of mink diet, and 47.3% in inland forests and wetlands. Overall, birds represented 12.6% of the bulk of the diet; however they were present on 30% of the scats. This is much lower compared to 40% of the bulk reported by Schüttler et al. (2008). Passerines were the most important bird prey. Compared to previous studies (Schüttler et al. 2008; Ibarra et al. 2009), I found that mammals are now being more frequently consumed, with muskrats representing 70% of mammal biomass. Also, fish are more important for mink in coastal habitat. These results may be explained by decrease in native rodents and birds abundances (Crego et al. 2014).

Muskrats were more likely to be found in beaver modified habitats, where conditions were more suitable than in naturally-occurring habitats. Beavers dam building seems to facilitate muskrats by creating suitable habitat were muskrats establish colonies. Highest probability of muskrat presence was in abandoned dams that still preserved a pond system and active beaver dams. Thus, the association between the muskrat and the presence of beaver seems to be facultative, where the pond is what seems is needed for the muskrat establishment. As muskrats prefer lentic waters to establish (Engeman and Whisson 2005), the transformation of lotic mountain rivers with small river beds and fast flowing water (Anderson et al. 2006) into ponds by beavers, is what creates the suitable habitat for muskrats. Moreover, muskrats represented almost 50% of the bulk of mink diet in inland forests and wetlands. In turn, muskrat presence provides a stable prey base for mink on inland territories. Today, beavers, muskrats, and mink seem to synergistically interact to invade and impact the pristine ecosystems, affecting local biodiversity and habitats at the southernmost archipelagos of the Americas.

It is interesting that two scats presented high content of mink hair, what may be explained by cannibalism. Cannibalism in mink has been previously observed on the island (Cristian Soto, SAG officer, pers. comm.).

D- Anti-predatory behaviour

** To investigate rodent prey naivety to American mink predation**

The "naïve prey" hypothesis suggests that the evolutionary history between non-native predators and the invaded community results in a lack of behavioural responses from prey to avoid predation (Sih et al. 2010). Many mammalian prey recognize predator odour as a way to avoid predator encounters (Kovacs et al. 2012). However, such behaviours generally are developed in a long process of co-evolution between the prey and the predator. Given that mink are a novel terrestrial predator on Navarino Island, I hypothesize that small rodents will not perceive mink odour as a direct cue of predation risk. However, since raptors are native co-inhabitants, I hypothesize that small rodents will use indirect cues of raptor predation risk. To study this, I conducted two experiments. Before running the experiments, I surveyed rodent presence over 5 nights using a grid of 111 Sherman traps. I only captured individuals of the species *Abrothrix xanthorhinus,* thus we extended our results for this species.

For the first experiment, I set 40 stations, 30 m apart. Each station consisted of 4 Sherman traps, 2 placed under vegetation cover (shrubs) and 2 in open habitat, 1 m from the closest shrub. I randomly applied mink-gland odour to 20 of the 40 stations, and water to the other 20 as a control. Odour was applied to cotton balls at 2-3 cm from the trap door. Traps were active during 5 nights and baited with rolled oats. Traps were revised every morning and if successful, it was replaced with a new, clean trap to avoid rodent odour affecting the treatment. For each treatment at each station I considered one capture if at least one of the 2 traps captured a rodent. The design attempted to assess predation risk from raptors by having half traps under the cover of vegetation, and to assess predation risk from mink. Data were analysed using a two-way ANOVA.

The second experiment was based upon e Optimal Foraging Theory (MacArthur and Pianka 1966), which evaluates the perception of predation risk on food trade-offs. If an animal perceives predation risk it should be a point in which the animal will leave a source of food when the cost of predation becomes higher than the benefits accrued from harvesting the food resource (Brown 1988; Altendorf et al. 2001; Hanes 2012). Thus, I also investigated predation risk perception by small rodents by quantifying giving-up densities (GUD's) and comparing between safe and risky areas (covered or uncovered, without and with American mink odour, respectively). Following the previous design, I used the 40 stations with the same configuration to avoid odour from the previous experiment affecting the second. Trails consisted of 11 x 11 x 9 cm plastic boxes, with two opposite, circular entrances of 2.5 cm, designed to exclude birds from feeding.

At each station, one trail was set under vegetation cover and the other in open habitat, 1 m from the closest bush. Similarly, at 20 stations I set mink odour at each entrance to the trail, and water in the other 20. Each trail was filled with 600 cc of soil and 20 g of dried-wheat seeds. After 3 nights, remaining seeds were sieved from the soil and collected. Trails were reset with 20 g of dried seeds. This process was repeated 3 times. At the laboratory, seeds were dried in the stove for 5 h at 60° C and weighed. GUD was calculated as the proportion of seeds remained. Only trails where rodent activity was evident were used for analysis. Five days before beginning the odour treatment, I set the trails and let rodents feed in trails with no treatment to become acclimated. Data were analysed using a mixed-model ANOVA specifying time and site as random effects, and mink odour and tray type (covered or exposed) as fixed effects.

Results and Discussion

I live-trapped 10 individuals of *A. xanthorhinus* with 10 recaptures. Captures occurred only on covered traps (Fig. 12A) but there was no significant difference in the average number of captures per station between mink odour and the control treatments ($F_{1, 37}$=0.03, p=0.85) (Fig. 12B).

I examined 120 observations taken from 40 stations for a total period of 9 days (3 surveys). I detected foraging activity in 75 (62.5%) of the observations. Foraging activity by *A. xanthorhinus* was affected by microhabitat characteristics ($F_{1, 34}$=83.61, p<0.0001). Rodents removed an average of 61.5% seeds on trails with vegetation cover compared to 13.6% on trails placed in open microhabitat (Fig. 12C). However, seed consumption was not affected by the presence of mink cues on the trails ($F_{1, 13}$=2.406, p=0.14) (Fig. 12D).

Both experiments provided support for my hypothesis, suggesting that the *A. xanthorhinus* do not perceive direct cues of mink as a predator. However, they avoid open areas, suggesting that they may perceive indirect cues of raptor predation, thus preferring covered areas. These results are in accordance with other studies that showed similar rodent responses to novel terrestrial predators, supporting the thesis that short time periods are not long enough to allow prey to develop anti-predatory behaviours to novel predators (Orrock 2010; Kovacs et al. 2012). The lack of anti-predatory behaviours toward mink predation may also explain the relative high percentage of this species in mink diet and the low population density of *A. xanthorhinus* and *Oligoryzomys longicaudatus* found in this study (Crego et al. 2014).

To predict if native species extinctions are likely or not to occur in the near future, more research is needed to clearly understand how invasive species affect abundance patterns of native species, how these native species respond to the invasion, and which species are most affected (Sax and Gaines 2008). Besides the number of invasive species in Cape Horn region, most studies conducted were merely descriptive, with a lack of experimental research to better understand ecological mechanisms (Quiroz et al. 2009; Valenzuela et al. 2014). My study will fill part of this knowledge gap in the region and will bring attention to the threats faced by native rodent populations. These results show that the mink may be significantly impacting the rodent population with the risk of diminishing the populations, and indirectly affecting raptors that rely on this source of prey. Further research will be important to confirm indirect effects of mink on other raptor species in the region that prey upon rodents.

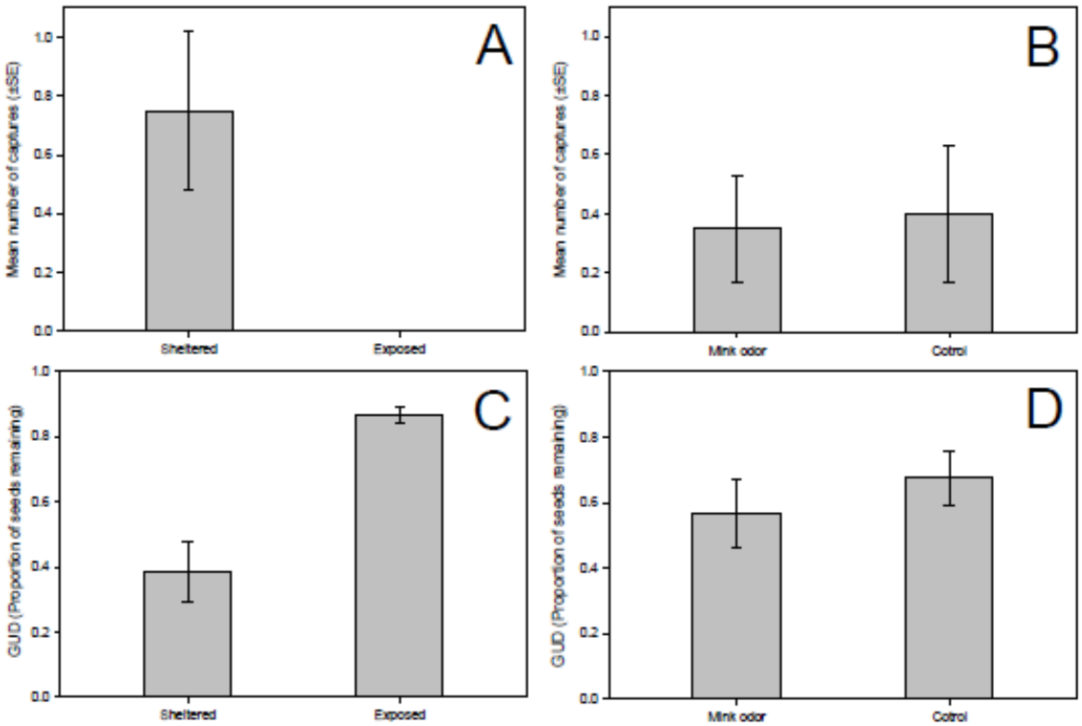

Fig. 12. Mean number (±SE) of *Abrothrix xanthorhinus* captured per station during September of 2014 on Navarino Island, Chile in sheltered and exposed microhabitats (A) and in traps with mink odour and traps with water odour as a control (B). Mean proportion of seeds (±SE) left in foraging trails by *A. xanthorhinus* set during September of 2014 on Navarino Island, Chile, in sheltered and exposed microhabitats (C) and in trails with mink odour and trails with water odour as a control (D).

E- Management

To propose a management plan to control or eradicate American mink from Navarino Island

The ultimate goal of this project is to conserve biodiversity and natural ecological processes on Navarino Island. American mink have no competitors or natural predators on Navarino Island, making them a new top predator in this fragile ecosystem where most prey species are likely naive to predation, as suggested by this research. Birds and small mammals evolved on this island isolated from terrestrial predators and it is likely they lack anti-predatory behaviours to ground predators. To protect native biodiversity, more research is crucial to provide sound information related with specific ecological characteristics of this invasive species, to later develop management actions to control or eradicate it on Navarino Island and protect local biodiversity (Silva and Saavedra 2008).

Many global studies show that control, or even eradication, of invasive species from islands is feasible (Bonesi and Palazon 2007). Trapping programs are effective when they are well-planned and are persistent over time. For example, studies in Europe show that mink can be controlled (Melero et al. 2010) or even eradicated (Bonesi and Palazon 2007; Bryce et al. 2011).

In Chile, national agencies are responsible for conserving and monitoring wildlife. On Navarino Island, the Chilean Agriculture and Livestock Bureau (SAG) is the agency in charge of managing the American mink population. As part of their control actions, SAG officers regularly remove mink using traps along the north edge of the island following the only dirt road that exists (Soto Volkart et al. 2007; Caicheo 2010; Davis et al. 2012). Unfortunately, the lack of human resources and deep understanding of American mink ecology undermines a successful control of this invasive species. Reports from the SAG about the mink control program in the Antarctic Province of Chile documented that 104 animals were eliminated between 2008 and 2013, with 52% juveniles (Soto Volkart et al. 2007; Caicheo 2010; Davis et al. 2012). Such trapping activities occur mostly during the summer, when weather conditions are better. Besides trapping efforts, the mink population appears to be growing (Crego et al. 2014). Moreover, future trapping programs were being planned over this same coast line and same season (Cristian Soto, SAG officer, pers. comm.).

In order to have a substantial effect on the population, reproductive adults should be removed. In this study, I have documented the high occupancy of mink on Navarino Island during the summer, occupying forested areas away from the shore line or even streams (see Objective 1). Occupancy dropped during the winter, with animals concentrating more closely to the shore line during the spring. These data suggest that currently, given that most of the trapping activities occur during the summer, when mink are more active with juveniles dispersing, most of the animals that are being removed likely will not survive winter famine. Therefore, trapping during the summer will not be effective in controlling the population if several animals remain inland and would subsequently recolonize the empty territories, at the time that adults are not removed. Therefore, I recommend allocating trapping efforts at the end of the winter and beginning of the spring when mink are occupying mostly shrub coastal areas, and reproductive adults are more likely to be eliminated from the population. In this way, SAG will likely have a better impact controlling mink population, and should avoid spending resources on trapping animals that likely will not survive the winter. I am currently working with SAG agent to develop an intensive trapping control during September and October of 2015. Even though the monetary recourses have not been realized yet by the national government, SAG is planning the control based on these recommendations.

In the near future, it would be important to implement a methodology to monitor the trend of the mink population on the island and evaluate the effect of trapping efforts. The use of trap cameras for such goal is effective for several reasons. They are economical and easy to operate, and can work for long periods of time, collecting large amounts of data with only having to visit them periodically (O'Connell et al. 2011). The benefits of implementing trap cameras quickly outweigh the costs as the traps provide information about changes in occupancy over time and they objectively quantify the success of trapping programs on the island. I highly recommended SAG to monitor assess the effectiveness of their mink control actions.

Data collected during this study demonstrates that the invasive species problem does not end with the mink. Several other exotic species have been documented during the year and deserve attention. For example, feral dogs have become more common throughout the year and may represent a threat for the native guanaco population. Also, I am currently studying the relationship among beavers, muskrats, and mink. These three invasive species seem to interact in a process known as invasive meltdown (Simberloff and Von Holle 1999). Considering management of all species may be beneficial in the long term to protect the pristine ecosystem of Cape Horn. I plan to further investigate this question.

American mink represent a threat for the native biodiversity of Cape Horn Biosphere Reserve. This study suggests that native rodents cannot perceive the risk that mink represent for them, thus are more likely to be depredated. Also, our previous work showed how mink depredate the Magellanic Woodpecker, a charismatic and important bird for the ecoregion (Jiménez et al. 2014). Furthermore, because there were no terrestrial predators on Navarino, many bird species developed ground-nesting and foraging strategies. This makes them vulnerable to mink depredation. I will further address this question as part of my dissertation work. Nevertheless, improving management control on this invasive species seems crucial to avoid the extinction of these and other native species. A management plan implemented during the late winter and spring, when the road is free in ice and snow, and conditions are favourable to work on the field, likely would have a higher impact on the American mink than trapping during the summer. Monitor population control programs would be also important to evaluate such conservation actions and improve them in the future.

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Annex A

Additional information

- Detected fauna visits (>60 min between detections) using trap cameras at 98 stations on Navarino Island, Chile during February and March, 2014.

Species	Coast-Shrubs	Primary Forest	Secondary Forest	Meadow	Total
Mammals					
Neovison vison	160	35	17	27	239
Canis lupus familiaris	8	0	5	1	14
Felis catus	1	0	0	0	1
Sus scrofa	0	4	3	0	7
Bos Taurus	182	22	50	15	269
Eqqus domesticus	30	0	3	0	33
Unidentified species	0	4	0	0	4
Birds					
Anas flavirostris	0	0	0	1	1
Aphrastura spinicauda	0	2	0	0	2
Campephilus magellanicus	0	0	3	0	3
Caracara plancus	18	2	10	2	32
Chloephaga picta	8	0	0	2	10
Cinclodes fuscus	5	0	0	2	7
Curaeus curaeus	3	0	0	0	3
Gallinago gallinago	2	0	0	0	2
Larus dominicanus	1	0	0	0	1
Milvago chimango	33	6	63	7	109
Phrygilus patagonicus	2	0	0	0	2
Sturnella loyca	1	0	0	0	1
Theristicus melanopis	20	0	0	1	21
Troglodytes aedon	1	0	0	0	1
Turdus falcklandii	19	21	14	11	65
Vanellus chilensis	3	0	0	0	3
Xolmis pyrope	0	0	0	2	2
Zonotrichia capensis	27	2	4	7	40
Unidentified species	1	0	0	1	2

- Detected fauna visits (>60 min between detections) using trap cameras at 49 stations on Navarino Island, Chile during June and July, 2014.

Species	Coast-Shrubs	Primary Forest	Secondary Forest	Meadow	Total
Mammals					
Neovison vison	3	34	11	1	49
Canis lupus familiaris	3	2	0	5	10
Felis catus	2	0	0	0	2
Sus scrofa	0	1	0	0	1
Bos Taurus	52	4	12	0	68
Eqqus domesticus	20	2	5	0	27
Unidentified species	0	0	1	0	1

Birds					
Caracara plancus	4	2	3	2	11
Milvago chimango	3	0	7	0	10
Phrygilus patagonicus	0	2	0	0	2
Turdus falcklandii	1	1	0	0	2
Unidentified species	0	0	0	1	1

- Detected fauna visits (>60 min between detections) using trap cameras at 98 stations on Navarino Island, Chile during October and November, 2014.

Species	**Coast-Shrubs**	**Primary Forest**	**Secondary Forest**	**Meadow**	**Total**
Mammals					
Neovison vison	19	1	6	1	27
Canis lupus familiaris	11	8	4	14	37
Felis catus	3	0	0	2	5
Sus scrofa	0	0	0	2	2
Bos Taurus	236	2	14	48	300
Eqqus domesticus	49	0	0	3	52
Abrothrix xanthorhinus	5	0	1	0	6
Oligoryzomys longicaudatus	4	0	0	0	4
Odontra zibethicus	0	0	1	0	1
Unidentified species	0	0	1	0	1
Birds					
Anas flavirostris	0	0	0	1	1
Aphrastura spinicauda	1	0	5	0	6
Campephilus magellanicus	0	0	0	1	1
Caracara plancus	27	1	2	6	36
Carduelis barbata	3	0	0	0	3
Chloephaga picta	100	101	1	0	202
Cinclodes fuscus	18	0	0	0	18
Curaeus curaeus	1	0	0	0	1
Gallinago gallinago	1	1	0	0	2
Larus dominicanus	3	0	0	0	3
Lessonia ruffa	3	5	0	0	8
Milvago chimango	54	3	11	26	94
Muscisaxicola macloviana	9	2	0	0	11
Phrygilus patagonicus	1	0	3	0	4
Strix rufipes	0	0	0	1	1
Sturnella loyca	2	0	0	0	2
Tachycineta meyeni	1	2	0	0	3
Theristicus melanopis	17	9	2	1	29
Troglodytes aedon	2	1	3	3	9
Turdus falcklandii	43	2	43	33	121
Xolmis pyrope	1	0	0	0	1
Zonotrichia capensis	152	27	10	13	202
Unidentified species	3	2	2	1	8

- Detected fauna visits (>60 min between detections) using trap cameras at 98 stations on Navarino Island, Chile during February and March, 2015.

Species	**Coast-Shrubs**	**Primary Forest**	**Secondary Forest**	**Meadow**	**Total**
Mammals					
Neovison vison	81	52	26	6	165
Canis lupus familiaris	5	4	4	5	18
Felis catus	1	0	1	0	2
Sus scrofa	1	3	5	0	9
Bos Taurus	116	8	41	21	186
Eqqus domesticus	25	0	4	0	29
Oligoryzomys longicaudatus	0	0	2	0	2
Odontra zibethicus	0	0	1	0	1
Unidentified species	0	0	0	1	1
Birds					
Anas flavirostris					
Aphrastura spinicauda	0	8	0	0	8
Campephilus magellanicus	0	0	1	0	1
Caracara plancus	11	2	6	1	20
Carduelis barbata					
Chloephaga picta	16	0	0	0	16
Cinclodes fuscus	11	0	0	2	16
Curaeus curaeus	17	0	0	0	17
Gallinago gallinago	6	0	1	0	7
Lessonia ruffa	1	0	0	0	1
Milvago chimango	34	1	33	3	71
Muscisaxicola macloviana	18	0	0	0	18
Phrygilus patagonicus	0	3	0	0	3
Tachycineta meyeni					
Theristicus melanopis	3	0	0	0	3
Turdus falcklandii	10	17	6	7	40
Xolmis pyrope	0	0	0	1	1
Zonotrichia capensis	36	18	10	2	66
Unidentified species	2	0	0	0	2

- Initially I planned to estimate prey abundance to use the information as covariates for the models. In my proposal I included rodents, birds, and insects. After discussing the project with my committee, they recommended that I only focus on birds and rodents, but also including muskrats. These species account for 70% of the mink diet on Navarino Island, and so the effort involved in estimating insects would not be worthwhile in comparison.

  However, the low density of rodents found and the difficulties while estimating avian abundance given bad climatic conditions during counting sessions, made this variable difficult to estimate without including large variation. I will continue estimating rodent abundance because the low abundances I found are surprising, so I want to know if mink depredation has an effect on it, or if it is a normal stage of rodent population fluctuations. I am planning to include avian information gathered with the trap cameras for future modeling, as avian photos better represent bird abundance at ground level than the point counts.

- Matias Barcelo was my field technician during the summer work. His participation in my project helped him to conduct his University practice, required for graduation in the Bachelor of Biology at the Pontificia Universidad Católica de Chile.

- Our manuscript to the *Boletín de la Red Latinoamericana para el estudio de Especies Invasoras* was accepted and published.

- While assessing abundance of the muskrat I realized there was a close relationship between the muskrat, an important mink prey item, and the beaver, another invasive mammal in this ecosystem. It is a unique and interesting relationship that might explain the success of mink in the island, as muskrats may be sustaining mink population as other native rodents abundances dropped, and muskrats may depend on beavers (see results of objective B). Ultimately, beavers may be playing a key role in the invasive system. After discussing the idea with my advisor, I decided to put more effort into this question and it will be a future chapter of my thesis. Actually, I am presenting a talk in the Annual Meeting of the Ecological Society of America this coming August.

Annex B

Having the grant and with it the opportunity to live in Puerto Williams, Navarino, while conducting my research, gave me the chance to get involved with the local community through talks in the local school and other local places organized by the Sub-Antarctic Biocultural Conservation Program.

- The 26th of February, 2014, I presented a talk to the local community explaining the goals and scopes of my project. Also, I discussed the problems associated with the invasive American mink and the importance of protecting biodiversity on Navarino Island. Following are some pictures of that activity:

- On the 9th of May I participated in an activity at the primary school of Puerto Williams: Liceo Donald Mc Intyre G. I presented a workshop about bird biodiversity on Navarino Island, entitled: "Celebration of the International Day of Migratory Birds". We taught students about migratory birds and the threat that the mink pose.

- On the 19th of June, Nicolas Carro, one of my assistants, and I participated in an activity at the primary school of Puerto Williams: Liceo Donald Mc Intyre G, as research assistants to observe and count birds in different habitats of the town. We discussed with students the threat that the mink and other invasive species pose to the birds in the ecosystem.

- During the months of February and March 2015, with my assistant Gabriel Nicolas Gomez, who is also a photographer, we dictated two workshops for the local community of Puerto Williams, combining invasive species and photography topics. They were free and open to all of the people from the town. The goal of the workshops was to educate people about the problem of invasive species and, at the same, allow them an opportunity to learn more about photography.

The activity was called “Through the eyes of the tree”. The idea behind this metaphor was to make people “see” and “feel” as a tree through the lenses of a camera (such as the trap cameras attached to a tree) how new exotic animals affect local biodiversity that historically co-inhabitated with the forests. Many trees are more than 200 years old and have been alive before beavers, mink, dogs, and cows, arrived to Navarino Island. People could perceive those new inhabitants and be aware of the threat they represent to the ecosystem.

Myself and Gabriel Gomez presenting during one of the free workshops provided to the local community of Puerto Williams.

Finally, and with support from the Sub-Antarctic Biocultural Conservation Program (SBCP), Puerto Williams Municipality, the Chilean Agriculture and Livestock Bureau (SAG), and local electricity company EDELMAG, we organized a photograph contest with the topic, exotic species. The municipality, EDELMAG and SCCP provided the awards, and SAG educational material about exotic species.

A total of 30 people from the local community participated in the workshops. We received several pictures and the three selected pictures are shown below: the first one corresponds to a beaver, the second one to a trout, and the third one shows the effect of beaver activity on the native forest.

Annex C

My project and activities related with the Sub-Antarctic Biocultural Conservation Program appeared on different Chilean news, showing the public the importance of managing the invasive American mink population on Navarino and other areas and the threat it poses to local biodiversity.

24 of August 2014, El Pinguino newspaper, Punta Arenas, Chile.

LLEGÓ PRIMERO A TIERRA DEL FUEGO POR LA INDUSTRIA PELETERA

Visón americano amenaza Reserva de la Biosfera Cabo de Hornos

El cambio climático no es el único factor que afecta al planeta, otra gran amenaza es la introducción de especies exóticas invasoras. En la Isla Navarino están estudiando cómo se adaptan a sus nuevos hábitats y qué efectos provocan en el proceso, con el objeto de mitigar su impacto negativo.

Por Paula Viano
Periodista

La Comuna de Cabo de Hornos incluye las islas y archipiélagos al sur de Tierra del Fuego que abarcan un área extensa y remota, donde se encuentra considerada una de las últimas 24 regiones más prístinas del planeta. Es una zona que ha permanecido ajena a los grandes cambios que la actividad humana provoca en los ambientes naturales. Alberga los ecosistemas forestales más australes del planeta, dominados por especies del género Nothofagus. Muchos seres conforman la diversidad de estos lugares, cohabitando desde diminutos musgos y líquenes, hasta grandes lengas y coihues que, a su vez, conforman el hábitat de animales, desde pequeños insectos hasta grandes aves y guanacos. Este entorno ha permitido la evolución de especies únicas.

Sin embargo, a pesar de su ubicación geográfica aislada, este ecosistema no ha estado exento de los efectos provocados por la actividad del hombre. Desde que la cultura occidental desarrolló el transporte a gran escala, numerosas especies han podido sortear las barreras biológicas naturales que impiden "colonizar" el territorio. Como resultado, muchas arribaron a la isla Navarino y al Cabo de Hornos, provenientes de diversas partes del mundo. Es el caso del visón americano (Neovison vison), que hoy está amenazando la biodiversidad del lugar.

Como las especies exóticas invasoras representan hoy una de las principales causas de extinción de las especies nativas a nivel mundial, el estudiante de doctorado de la Universidad de North Texas (UNT), Ramiro Crego, investiga la ecología del visón, para entender cómo se adapta a las nuevas condiciones ambientales, qué especies se ven más afectadas por él, y cómo estas responden a la nueva presión de depredación.

El doctorante es parte del Programa de Conservación Biocultural Subantártica, desarrollado en colaboración por las universidades de North Texas y de Magallanes, junto al Parque Etnobotánico Omora y al Instituto de Ecología y Biodiversidad. Trabaja con destacados profesores e investigadores como el Dr. Jaime Jiménez y el Dr. Ricardo Rozzi.

UNA GRAN AMENAZA PARA LAS RESERVAS DE LA BIÓSFERA es la introducción de especies exóticas invasoras.

Investigación

El visón americano fue una de las últimas especies invasoras que llegaron a la Reserva de la Biósfera Cabo de Hornos, introducido por la industria peletera en la isla Grande de Tierra del Fuego. Según cuenta el investigador, hace menos de 20 años este logró establecerse en la isla Navarino.

Este pequeño mamífero semiacuático, pariente de las nutrias, es un depredador muy eficaz que se alimenta de aves, pequeños roedores y peces. "El problema principal es que, por miles de años de evolución, muchas de las especies que habitan en las islas de esta región nunca tuvieron contacto con un depredador terrestre, por lo que no saben cuidarse de ellos. Muchas aves, por ejemplo, como las caranca, caiquenes y patos juarjual, anidan en el suelo, convirtiéndose en presa fácil del visón", comenta Ramiro Crego.

"En muchos casos pecan de ingenuas ante el peligro", agrega.

Para profundizar la comprensión de lo que está sucediendo, utiliza "cámaras trampa", equipos fotográficos que se activan, automáticamente, al detectar el movimiento de un animal, y que están distribuidos a través del bosque, las turbas y las costas. También lleva a cabo estudios de dieta y experimentos para entender si las aves y roedores reconocen al visón como un depredador.

El visón americano fue una de las últimas especies invasoras que llegaron a la Reserva de la Biósfera Cabo de Hornos, introducido por la industria peletera en la Isla Grande de Tierra del Fuego. Según cuenta el investigador, hace 20 años este logró establecerse en la Isla Navarino. Este pequeño mamífero semiacuático, pariente de las nutrias, es un depredador muy eficaz que se alimenta de aves, pequeños roedores y peces.

Si bien se sabe que este animal afecta a las aves asociadas a ríos y costas marítimas, nuevos estudios muestran que en isla Navarino -y a diferencia de lo que ocurre con otras regiones- no sólo se limitan a los hábitats semi acuáticos, sino que también incursionan en los bosques para alimentarse.

Gracias al monitoreo de aves que se lleva a cabo en el Parque Etnobotánico Omora hace 14 años, se han identificado patrones de disminución en algunas especies de aves, aunque si bien es difícil atribuirlo a la presencia de visón, "es probable que esté teniendo algún efecto. Lo mismo se ha apreciado en ratones nativos", añade el biólogo.

Cuenta que el caso más destacado es el descubrimiento de la depredación y amenaza al carpintero magallánico (Campephilus magellanicus), una especie considerada emblemática y de suma importancia por su papel ecosistémico y cultural a nivel regional. "Dada su baja tasa reproductiva, no es descabellado pensar que, en un futuro no muy lejano, la población se vea diezmada", dice Crego, "como probablemente sucedió con los guanacos de la isla debido a los perros asilvestrados. Hoy en día estamos haciendo estudios para evaluar la probabilidad de adaptación de las aves afectadas por este nuevo depredador terrestre, por ejemplo, defendiéndose, o comiendo y anidando a mayor altura en los árboles".

Otra especie que se cree afectada es el pájaro reloj o churrín, ave de hábitos terrestres que, según los habitantes de la isla, se escuchaba frecuentemente y hoy es muy raro oír u observar. De hecho, ellos perciben una disminución en la población general de aves. Y si bien no es posible saber qué va a pasar en 10 años más, "el panorama no es nada alentador".

Los resultados de la investigación estarán a fines del 2016. El equipo del Programa de Conservación espera que este estudio ayude con los planes de monitoreo y control de este exótico depredador, para proteger a los habitantes originarios del bosque. Pero los investigadores también realizan experiencias de campo y construcción de metáforas en el Parque Etnobotánico Omora, para que las personas puedan ampliar la visión hacia un entendimiento más holístico, y sientan empatía por el árbol o el pájaro que muere por culpa del animal invasor.

"Para sentir que la suerte de contar con un medio ambiente prístino, implica una gran responsabilidad: mantener el armónico flujo de la vida", finaliza Ramiro Crego.

EL CARPINTERO MAGALLÁNICO, una especie de suma importancia por su papel ecosistémico y cultural, se encuentra amenazada.

22 of June 2014, La Prensa Austral newspaper, Punta Arenas, Chile.

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Positiva acogida registran cafés científicos en Puerto Williams

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22 de junio de 2014

Con alta participación de la comunidad se han realizado los Cafés Científicos organizados por el Instituto de Ecología y Biodiversidad (IEB) y el Parque Etnobotánico Omora en Puerto Williams durante el primer semestre de este año.

A la fecha se han realizado cuatro Cafés Científicos entre febrero y mayo. El primero, a cargo de Ramiro Crego, estudiante de Doctorado de la Universidad de North Texas, trató el tema de la invasión de visones en Isla Navarino, mientras que en el segundo la doctora Tamara Contador mostró las peculiaridades de la mosca antártica, y la relevancia de su estudio. El tercer Café Científico, realizado el 22 de abril en conmemoración del Día de la Tierra, contó con el connotado geólogo Constantino Mpodozis, quien se refirió a la sismicidad de Chile. Mpodozis dio además una clase magistral sobre la historia de la Tierra para los estudiantes de séptimo y octavo básico del Liceo Donald McIntyre de Puerto Williams.

El cuarto Café Científico de la temporada citó a múltiples expositores en torno a las aves de isla Navarino. Un Café a Vuelo de Pájaro contó con Omar Barroso, ornitólogo y encargado del monitoreo de aves del Parque Omora, Lorenzo Aillapán, hombre pájaro mapuche; Julia González, artesana yagán y residente histórica de Puerto Williams; y la doctora Victoria Castro, arqueóloga de las universidades de Chile y Alberto Hurtado. Los asistentes pudieron conocer no sólo información científica recopilada por los investigadores del IEB y de Omora, sino también las perspectivas ancestrales de los pueblos originarios en su relación con el mundo de las aves. La sesión finalizó con un juego de adivinanzas "Si se la sabe cante", usando imágenes de aves locales.

En cada una de sus versiones, los Cafés Científicos han reunido sobre una treintena de personas, entre las que se cuentan autoridades civiles y uniformadas, además de miembros de la comunidad yagán y del Liceo Donald McIntyre.

La temporada de Cafés Científicos de Puerto Williams continuará el día sábado 28 de junio, con la conmemoración del Día del Arbol.

MÁS NOTICIAS

Convocan a adultos mayores a dar rienda suelta a su talento literario

13 of November 2014, CONAF magazine, Santiago, Chile.

FAUNA

Visón norteamericano: a 100 años de una visita *Non Grata*

Los primeros individuos fueron traídos desde Norteamérica hasta la Patagonia chilena y argentina para impulsar la industria peletera. Sus habilidades de gran cazador y nadador le han permitido adaptarse y reproducirse sin mayores problemas desde La Araucanía hasta el Cabo de Hornos.

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Chile Forestal / 11

23 of February 2015. TV program CLIMAX at NTN24. Biodiversity of Chile threaten by the presence of invasive species.

http://ntn24.com/video/biodiversidad-de-chile-en-amenaza-por-presencia-de-especies-invasoras- 41209

Radio interview about American mink invasion in Navarino Island. Educational program, six senses, Institute of Ecology and Biodiversity, Chile.

http://www.6sentidos.cl/podCast/Invasion_Vison_Navarino.mp3