Thirty-Five-Year Management Plan for the Darwin's Fox (*Lycalopex fulvipes*) on Chiloé Island and Nahuelbuta National Park in Southern Chile

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Executive Summary

The Darwin's fox (*Lycalopex fulvipes*) is a small canid existing in southern Chile in South America. Two populations exist: a population estimated to be around 500 on Chiloe Island, and a smaller, mainland population in Nahuelbuta National Park, estimated to be made up of around 78 individuals. They are opportunistic omnivores that require dense native forests to shelter, forage, and breed. Very little is known about this species due to its small, and decreasing, population size. The Darwin's fox is threatened by many conservation issues, as well. These issues include disease spread, attacks, and spatial displacement from poorly managed free-ranging domestic dogs (*Canis lupis familiaris*), ignorance of park visitors and residence through off-leash dogs in protected areas and unrestricted feeding of foxes resulting in naivety of foxes to humans and dogs, and loss of native forests for replacement by exotic plantations. This management plan aims to increase the Darwin's fox population in Chile to sustainable levels in 35 years. The objectives to reach this goal include: (1) Reduce domestic dog dispersal into fox areas by 80% in 15 years, (2) Decrease disease prevalence in the Darwin's fox population by 50% in 15 years, (3) Increase local human population awareness of the Darwin's fox by 87% in 5 years (4) Increase survival of 3-year old and younger foxes by 80% in 15 years, and (5) Increase suitable habitat by 75% in 15 years. These actions will be carried out through satellite surveillance and radio tracking to better understand fox population numbers, fox movements, and mortality, as well as to monitor dogs in the park. Surveys will be conducted, and educational seminars and pamphlets will be provided to park visitors and local Chilean residence. This will be done to get a better understanding of the actions of dog owners and increase visitors awareness of these fox' existence, why they shouldn't feed or interact with them, and why to keep their dogs out of protected areas. New legislation will be put in place to further this. Legislation will help to keep dogs out of the park and prevent people from feeding them through increased fines and penalties for breaking these laws. This will also help to prevent the spread of diseases such as canine distemper virus from dogs to foxes, which would be catastrophic to this already small population. Suitable habitat will be increased through providing dense understory in exotic plantations so that these converted landscapes will still be usable. This management plan has the potential to increase fox survival and increase overall awareness of them, resulting in a reverse in the downward trend of this population and, instead, increasing the population to a sustainable level in Chile.

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Introduction

The Darwin's fox (*Lycalopex fulvipes*) is listed as endangered by the International Union for Conservation of Nature (IUCN) Red List. This classification is a result a small population size, which is continuing to decline (Silva-Rodriguez et al. 2016). These foxes are endemic to southern Chile, with the main population existing on Chiloe Island and a smaller mainland population in Nahuelbuta National Park (Jimenez and McMahon 2004, Silva-Rodriguez et al. 2016) and are the focus areas of this plan. Estimates of population size vary, but most studies suggest a population around 500 in Chiloe Island and 78 individuals in Nahuelbuta National Park (Jimenez and McMahon 2004). The Darwin's fox prefers dense, native Chilean forests as its primary habitat (Silva-Rodriguez et al. 2016, Jaksic et al. 1990). The major threats being faced by this species include the spread of disease through domestic dogs (Jimenez and McMahon 2004, Silva-Rodriguez et al. 2016), negligible dog ownership, resulting in free ranging domestic dogs which attack and kill foxes in protected areas (Silva-Rodriguez et al. 2016, Hidalgo-Hermoso et al. 2020), ignorance from park visitors who feed or try to interact with foxes, resulting in naivety of foxes to humans and dogs (Jimenez and McMahon 2004), and loss of native forests for exotic plantations (Miranda et al. 2015, Zamorano-Elgueta et al. 2015, Silva-Rodriguez et al. 2016). Due to the many threats being faced by this species, along with its already small and decreasing population size, and little being understood about this species, management action is needed. As a result of little information existing on many aspects of this species, two surrogate species were needed for this plan (Figure 3). This included the red fox (*Vulpes vulpes*) and the gray fox (*Urocyon cinereoargenteus*). These species were chosen for the many relevant natural history traits that these two species shared with the Darwin's fox, making them suitable surrogates for this management plan. The Darwin's fox is a unique species and brings guests to Nahuelbuta National Park as an ecotourism attraction. The Darwin's fox is also an important part of its ecosystem as a seed disperser. A large portion of this foxes diet consists of seeds, and because of this, many plant species may rely on this fox for seed dispersal (Jimenez and McMahon 2004). Without management, this fox may be extinct in 15 years (Figure 4).

Natural History

Species Identification

The Darwin's fox (*Lycalopex fulvipes*) is considered to be one of the world's rarest and least studied canids, while also being considered one of the most threatened. Little morphological data exists on this fox, as there are no individuals in zoos and only seven skins exist in museums (Jimenez 2007). The Darwin's fox is described as a small canid. The fox is morphologically distinct in comparison to other Chilean mainland foxes, having shorter legs, a smaller body size and darker coloration (Vila et al. 2004). Jimenez and McMahon (2004) also described the Darwin's fox as having short legs, as well as an elongated body and bushy tail. Their fur is a combination of black and gray with red markings on the ears and on the lower parts of the legs. Under the chin and along the underbelly, white markings are visible (Jimenez and McMahon 2004). On average, the Darwin's fox weighs 2.72 kg (5.99Ib). The average length is 228 mm (20.79Ib). Data does not support evidence of sexual dimorphism in this species (Jimenez and McMahon 2004). However, males do have a separation between the upper canines leading to the males appearing to have a broader muzzle compared to females (Jimenez 2007).

Distribution and Home Range

The Darwin's fox is endemic to Chile, with at least two distinct existing populations. One of these populations is found in the temperate rainforests of Chiloe Island, in southern Chile (Vila et al. 2004, Jimenez 2007, Silva-Rodriguez et al. 2016) with the second existing on the coastal range on the Chilean mainland (Silva-Rodriguez et al. 2016). Recent records have shown the presence of the fox in the Valdivian coastal range, which contains at least three protected areas: Alerce Costero National Park, the Valdivian Coastal Reserve, and the Oncol Park. In 2014, a few individuals were detected north of Llanquihue Lake, located on the foothills of the Andes. This means that the range of this species may be larger than originally thought (Silva-Rodriguez et al. 2016). Vila et al. (2004) also notes a mainland population in Nahuelbuta National Park, north of the island of Chiloe. This small, isolated population was discovered in the 1990s and it is estimated that a total between 50 and 78 individuals inhabit this park (Jaksic et al. 1990, Vila et al. 2004, Jimenez 2007). This fox is thought to be an obligate forest species and this park is surrounded by highly degraded habitat, meaning the population of this Park is completely isolated (Vila et al. 2004). This species still has one of the smallest known distributions of all extant canids, as it is limited to forested areas on the island of Chiloe and to a small continental population (Vila et al. 2004, Jimenez 2007). Home range size varies widely among individuals in this species, with there being high amounts of overlap within the population. This variability was not correlated with gender of the individual (Jimenez and McMahon 2004). These foxes are non-territorial and have been observed to share their home ranges with other foxes. Parents also share their home range with their offspring. Offspring dispersal is often affected by availability of open ranges, leading to young staying with parents in their home range until an opportunity to claim its own range becomes available (Jimenez and McMahon 2004).

The presence of this species on Chiloe Island and in mainland parks is possibly explained by these populations being left-over from a once more-widely distributed species. In the late Pleistocene, Chiloe Island was connected to the mainland by a land bridge. This bridge disappeared about 15,000 years ago after the last glaciation caused sea level to rise (Yahnke et al. 1996, Vila et al. 2004). The Darwin's fox likely left the mainland with the loss of the native forests, and currently only exist in the few National Parks where the forests still act as suitable habitat (Vila et al. 2004). Only recently was this fox recognized as its own species, as before it was believed to be an island subspecies of the larger gray fox or chilla fox (*Pseudalopex griseus*). This was changed with the discovery of the mainland population in sympatry with the chilla and the culpeo fox (*Pseudalopex culpaeus*), which is the largest of the three Chilean foxes (Jimenez 2007). Genetic analysis also confirmed that the small mainland population was distinct from the Chiloe population, and not a human-released group from the island population. This data further suggests that this fox is a remnant of an ancestral phylogenetic line that was more widely distributed in southern temperate forests of the past (Jimenez 2007).

Figure 1. Distribution of Darwin's fox (*Lycalopex fulvipes*) in Chile (Silva-Rodriguez et al. 2016)

Habitat

Early research in Nahuelbuta National Park suggested that the Darwin's fox was found in dense forests (Silva-Rodriguez et al. 2016, Jaksic et al. 1990). Nahuelbuta National Park's vegetation is primarily defined by undisturbed forests of *Nothofagus* beeches and *Araucaria* pines (Jaksic et al. 1990). More recently, with the help of radio-telemetry data, it is suggested that these foxes are more often found in dense deciduous forests and occasionally open pastures. Data has also shown Darwin's foxes positively associated with native forest availability and negatively associated with roads (Moreira-Acre et al. 2015*a*, Silva-Rodriguez et al. 2016). There has also been a positive response to fine grain habitat structure, which suggests that commercial plantations may be providing suitable habitat and food resources for this fox (Moreira-Acre et al. 2015*b*, Silva-Rodriguez et al. 2016). In the coastal mainland populations, the Darwin's fox has been observed mainly in old-growth and secondary evergreen forests. Near the Llanquihue Lake, the fox was recorded in highly fragmented forests with intensive dairy farms with large pastures and linear patches of degraded Valdivian forest along streams (Silva-Rodriguez et al. 2016). On Chiloe Island, Darwin's fox used secondary growth forests and scrublands depending on availability (Jimenez 2007, Silva-Rodriguez et al. 2016). Sandy beaches are also utilized by this species, as suggested by the consumption of crustaceans and direct observation (Elgueta et al. 2007, Jimenez 2007, Silva-Rodriguez et al. 2016).

Diet

The Darwin's fox has a diet that is highly opportunistic, feeding on mammals, birds, reptiles, amphibians, insects, shellfish, algae, carrion, berries, seeds, and even anthropogenic sources such as garbage (Jaksic et al. 1990, Jimenez and McMahon 2004, Vila et al. 2004). With the Darwin's fox often existing alongside humans and domesticated dogs (*Canis Lupus familiaris*), they are not expected to show high levels of avoidance of humans. In Chiloe, they often are found entering homes in the night in search of food (Vila et al. 2004). The Darwin's fox's diet changes as food availability changes in the environment, which can be seen through seasonal changes (Jimenez and McMahon 2004). Mainland foxes are reported to eat mainly small mammals, reptiles, insects, birds, and arachnids, with the consumption rates fluctuating with the seasons. Recent analysis suggests that insects were the most abundant prey in their diet, followed by small mammals and reptiles (Jimenez and McMahon 2004). The mainland foxes also rely heavily on the seeds of monkey-puzzle trees from March to May. On Chiloe Island, insects were most abundant in the foxes diet during the warm months, followed by amphibians, mammals, birds, and reptiles (Jimenez and McMahon 2004). During the winter, small mammals made up a majority of their diet. In the late summer and fall, the diet was mostly fruits of the *Mirtaceae* tree. A small amount of diet also consisted of carrion, suggested by hair remains of sheep, pigs, cattle, and horse in the foxes feces (Jimenez and McMahon 2004).

Foraging Behavior

Radio telemetry data provided by Jimenez and McMahon (2004) suggest that up to four foxes may gather around a carcass for a few days, but other than this behavior, they are usually solitary hunters. Some reports suggest that these foxes will scavenge opportunistically (Jaksic et al. 1990, Jimenez and McMahon 2004, Vila et al. 2004). Local Chileans have reported that lone Darwin's foxes will sometimes kill southern pudu deer (*Pudu puda*) by biting at their ankles, and then at their throat when the opportunity arises (Jimenez and McMahon 2004). Coastal foxes have also been observed eating shellfish and shorebirds, with individuals being observed consuming large brown algae on the beaches. In the Nahuelbuta National Park, where the mainland population exists, this fox is seen foraging in habitats abundant with small mammals, with the hunting mainly taking place during the night. During the day, these foxes are seen feeding on reptiles, amphibians and forest-floor dwelling bird species such as the tapaculos (Rhinocryptids) (Jimenez and McMahon 2004). On Chiloe Island, this fox is reported to kill poultry, however, some studies show this fox will not display this behavior. They have also been reported invading garbage dumps. On the mainland, farmers do not report these behaviors from this fox (Jimenez and McMahon 2004).

Reproduction

The Darwin's fox is monogamous, breeding once a year and can live for up to 7 years (Jaksic et al. 1990, Jimenez and McMahon 2004). In mainland populations, female lactation has been noted to occur in October, with pups being documented leaving the den with both parents in December. Litter sizes have been estimated to be 2-3 pups (Jimenez and McMahon 2004). The weaning of the young takes place in February, and during this time the females will be spending less time with the pups, with a greater amount of their interactions becoming antagonistic. The males during this time spend most of their time playing with and grooming their pups (Jimenez and McMahon 2004). The dens of the mainland Darwin's foxes are defined as being a rock cavity located in the forest with a bamboo understory (Jaksic et al. 1990, Jimenez and McMahon 2004). Reproduction in the Chiloe Island population occurs between October and January, when females have been observed lactating. During mating, males and females will spend a short period of time together and after the pups are born, females stay in the den with their young. Pups have been observed denning in a rotten and hollow log on the ground in late December on the Island (Jimenez and McMahon 2004), as well as a hollowed-out rock cavity with a bamboo understory (Jacksic et al. 1990).

Two surrogates, the red fox and the gray fox (Figure 3), were used to replace unknown knowledge about the Darwin's fox. Age classes (Figure 2) were derived from data on the gray fox. The age classes seen in the life stage diagram for this plan (Figure 2) were created based of skull structure, tooth wear, vomer development, baculum, and weight of 375 gray foxes, as these are the most accurate methods for aging gray foxes. Tooth wear has shown the be the most accurate (Wood 1958). The survival rates of less than 1-year old foxes and the percentage of offspring surviving their first year was also derived from gray fox data (Farias et al. 2005). Annual survival rates and survival into the next age class for 2-years old, 3-year old, and 4-years and older (Figure 2) were derived from life table data of 564 red foxes (Saunders et al. 2002). Fecundity (Figure 2) was created from multiplying the 50:50 (0.5) sex ratio of 818 gray foxes (wood 1958) by (0.61*3*1). A gray fox pups probability of dying in their first winter is represented by 0.61 (Wood 1958). The number of offspring produced in each birth was 3 for this equation. This number came from Darwin's fox data (Jimenez and McMahon 2004). Gray foxes breed once yearly and is represented in this equation (Fuller and Cypher 2004). Fecundity was determined to be 0.563895349 at each age category, excluding the "less than 1-year old" category (Figure 2). This number was used at each life stage as it is suggested that that there is no fecundity variation between age classes in the gray fox (Wood 1958).

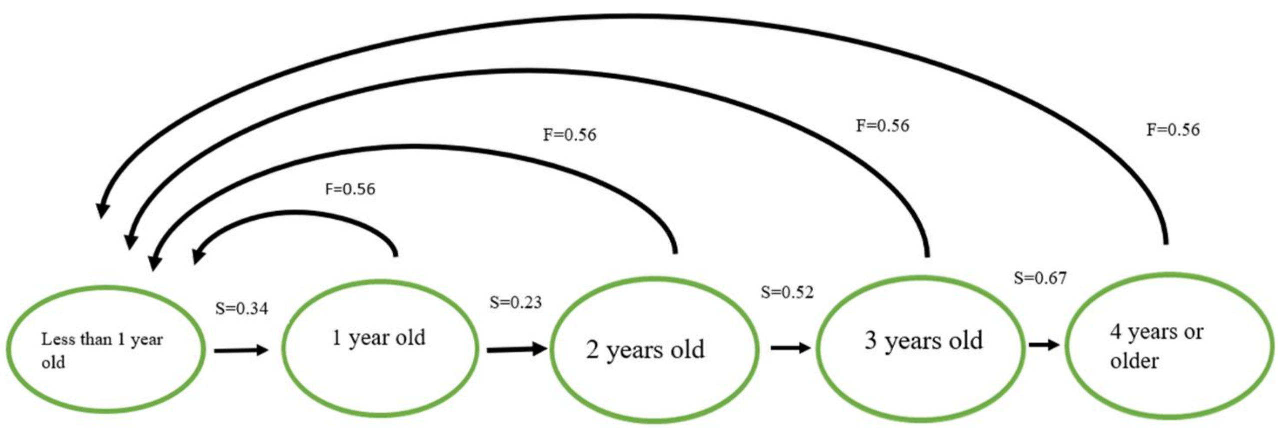

Figure 2. Stage based Darwin's fox life-cycle model with survival rates (S) and fecundity (F). Age classes and survival rates derived from surrogate gray fox and red fox available data (Wood 1958, Fuller and Cypher 2004, Jimenez and McMahon 2004).

Mortality

A major risk of mortality to the Darwin's fox comes from disease, mainly spilled over from domestic dogs (Silva-Rodriguez et al. 2016, Hidalgo-Hermoso et al. 2020). One of these diseases is canine distemper virus (CDV). This disease is highly contagious and mainly spread through airborne transmission. The breakout of this disease in many species of fox originate from free-ranging domestic dogs (Acosta-Jammet et al. 2015, Silva-Rodriguez et al. 2016, Hidalgo-Hermoso et al. 2020). An eight-year survey conducted by Hidalgo-Hermoso et al. (2020) did not find any signs of CDV in Darwin's fox populations currently. This may be due to this species being a forest dwelling specialist and CDV having a low environmental survival with dog-to-fox transmission opportunities being rare, however, infected foxes may have been missed as a result of unnoticed mortality. Although this disease is not currently affecting this species, it is a possibility, and with such low population numbers, and outbreak would be catastrophic (Hidalgo-Hermoso et al. 2020). Acosta-Jammet et al. (2015) also noted CDV as a risk, as well as canine parovirus, suggesting transmission likely to occur in lowland areas, and that wildlife in these areas of Chile, such as the Darwin's fox, may be at risk from spillover transmission from domestic dogs.

Along with these diseases, Jimenez et al. (2012) suggests that the Darwin's fox may also be at risk from endoparasites. After conducting studies on 189 fecal samples, 40 samples showed positive for ten different kinds of endoparasites, representing five genera (two nematodes, two cestodes, and one protozoan). All of these endoparasites were also found in domestic dogs. In several areas of Chiloe, these foxes live intermixed with dogs, resulting in a very high chance of parasite transmission. Parasite loads were found to be higher in areas with more domestic dogs, as well as being higher during the winter (Jimenez et al. 2012). The ear mite *Otodectes cynotis* has also been found to infect the Darwin's fox. This mite is found in domestic and wild cats (*Felis catus*) and dogs. Infection of the Darwin's fox likely comes from interactions with these species, and in small and endangered populations such as this fox, infectious disease can lead to extinction (Briceno et al. 2020). This mite produces inflammation and itching of the ear canal and accumulation of earwax that may block the ear canal and produce ceruminous gland hyperplasia. Severe untreated cases can lead to emaciation, self-induced trauma, and even seizures. This mite can also lead to secondary infections by fungi (Briceno et al. 2020). Gammaherpesvirus has also been detected in the Darwin's fox. This is the first report of a gammaherpersvirus infecting a canid worldwide, as well as of one infecting a South American carnivore. Lesions can result from this disease;

however, they have not yet been detected in this fox. This virus may predispose the host to secondary bacterial infections (Cabello et al. 2013).

In Nahuelbuta National Park, where the mainland population of the Darwin's fox is located, natural sources of mortality for the Darwin's fox is potential prey for the puma (*Felis concolor*), the culpeo fox, and the chilla fox (Jimenez and McMahon 2004). On Chiloe Island, locals have reported that they have killed Darwin's foxes due to the threat they pose to their poultry. Many individuals have also been reported to have been killed by domestic dogs (Jimenez and McMahon 2004, Silva-Rodriguez et al. 2016). Attacks by domestic dogs has been reported both on the mainland and on Chiloe Island. The Island population is rare or completely absent from old-growth forests that are heavily visited by domestic dogs, but are regularly seen in scrublands, where dogs are absent, suggesting spatial displacement as a result of dogs. These attacks come mainly from poorly managed free-ranging dogs and not feral dogs (Silva-Rodriguez et al. 2016). Human-caused mortality is also happening through locals killing foxes for attacking their dogs (Silva-Rodriguez et al. 2016). Tourists in the Park also act as a threat to this fox. Reports show an adult, lactating female was killed in a parking lot by a tourist. Many of these foxes have also become too comfortable around humans due to constant and unrestricted feeding by tourists. This has led to foxes spending time under parked cars, sometimes resulting in death by being run over. Some foxes have even been observed climbing into people's cars (Jimenez and McMahon 2004).

Competition

There is currently no data suggesting competition from other carnivores on Chiloe Island. The only other carnivores on the island that are potential competition for small mammals are the kod-kod (*Oncifelis guigna*), the hog-nosed skunk (*Conepatus chinga*), the little grison (*Galictis cuja*) and the sympatric rufous-legged owl (*Strix rufipes*) (Jimenez and McMahon 2004). The mainland population has some geographic overlap with six carnivore species, including the puma, the culpeo and the chilla foxes, the kod-kod, the hog-nosed skunk, and the grison. The puma, chilla fox, and culpeo fox are larger carnivores and are potential competitors, as well as potential predators. The Chilla fox also has some overlap in home range and activity patterns, creating the potential for competition. On the mainland, the Darwin's fox has been recorded moving to open forest and grassy areas mainly at night, when small mammals are active, and competitors are less active. This nocturnal behavior suggests avoidance of competitors and potential predators (Jimenez and McMahon 2004).

Ecological

A large portion of the Darwin's fox's diet consists of seeds and it has been suggested that these foxes may help in seed dispersal for several species of plant (Jimenez and McMahon 2004). Forest loss is a serious ecological threat to the Darwin's fox, with the highest rates of loss occurring in the coastal range of the Araucania Region, where the Nahuelbuta National Park is located. The annual loss rate from 1999-2008 reached 4.8%, which is the second highest reported Chilean temperate forest loss (Miranda et al. 2015, Silva-Rodriguez et al. 2016). In the Nahuelbuta range, human-induced forest fires are also always a threat to the Darwin's fox, which would be displaced by these new open areas (Silva-Rodriguez et al. 2016). Land use change and habitat fragmentation is a big component of global change, which has effects on biodiversity. Land use change is currently happening in Chile, and studies show that top predators affect ecosystem functions through prey consumption and are very vulnerable to these changes and fragmentation (Farias and Jaksic 2011). Studies by Farias and Jaksic (2011) showed strong effects of deforestation on biodiversity, which will potentially affect the functioning of the remaining native temperate forest ecosystems, which in turn will have a negative effect on the Darwin's fox.

Surrogate Natural History	Darwin's fox (*Lycalopex fulvipes*)	Red fox (*Vulpes vulpes*)	Gray fox (*Urocyon cinereoargenteus*)
Habitat Preference	Dense deciduous forests, mixed forests, brush and shrublands, access to beaches	Diverse habitat including mixed forests, scrub and woodlands	Deciduous and southern pine forests, woodlands, brushlands, shrublands
Diet Type	Opportunistic omnivore	Opportunistic omnivore	Omnivore
Activity Patterns	Active day and night, nocturnal activities important	Nocturnal	Nocturnal
Mating	Monogamous	Monogamous	Monogamous
Social Structure	Mated pair and offspring of the year	_	Mated pair and their offspring of the year
Offspring Dispersal	_	6-12months	9-10 months
Sexual Maturity	_	9-10 months	10 months
Number of Offspring	2-3	4-5	1-4
Live Span	7 years	9 years	4-5 years
Diseases Affected By	Canine distemper, endoparasites, ectoparasites, gammaherpesvirus	Rabies, parasites, sarcoptic mange, canine distemper	Canine distemper, internal parasites

Figure 3. Natural history comparison of the Darwin's fox (*Lycalopex fulvipes*) and the two surrogates chosen for this plan: the red fox (*Vulpes vulpes*) and the gray fox (*Urocyon cinereoargenteus*)

Conservation Issues

Ecological

A major ecological threat to the Darwin's fox is disease, mainly spread by the domesticated dog (Jimenez and McMahon 2004, Silva-Rodriguez et al. 2016). The main disease that the Darwin's fox is at risk from is canine distemper virus (Silva-Rodriguez et al. 2016, Hidalgo-Hermoso et al. 2020). Hidalgo-Hermoso et al. (2020) did not currently find signs of canine distemper virus in Darwin's fox populations but suggest that spill-over from dogs is likely and would be catastrophic to the Darwin's fox population. It is also concerning, as not only dogs in proximity of Nahuelbuta National Park have been confirmed to have the disease, but it has also been reported in the invasive American mink (*Neovison vison*) population, as well as in the Chilla and Culpeo foxes (Silva-Rodriguez et al. 2016, Acosta-Jammet et al. 2015). Acosta-Jammet et al. (2015) also reported a risk of canine distemper, as well as canine parovirus. Along with these diseases, endoparasites, mites, and gammaherpesvirus may also be diseases posing a threat to this species (Jimenez et al. 2012, Briceno et al. 2020, Cabello et al. 2013). Silva-Rodriguez et al. (2016) suggest that the lack of information about the Darwin's fox may be the true cause for lack of conclusive evidence of CDV in Darwin's fox.

Sociocultural and Economic

Another ecological threat faced by the Darwin's fox, which also fits into the categories of both sociocultural and economic is forest loss. The highest rates of forest loss are occurring in the coastal range of the Araucania Region, which is where the Nahuelbuta National Park is located. From 1999-2008, the annual loss observed for this period reached 4.4%, which is the second highest reported for Chilean temperate forest, the main habitat type of the Darwin's fox (Miranda et al. 2015, Silva-Rodriguez et al. 2016). Much of the native forest in Chile is being converted to forestry plantations (Miranda et al. 2015, Zamorano-Elgueta et al. 2015, Silva-Rodriguez et al. 2016). The Darwin's fox has been reported in these plantations, studies suggest that the foxes select for native forests (Moreira-Acre et al. 2015*a*, Silva-

Rodriguez et al. 2016). However, Moreira-Acre et al. (2015*b*) suggest that if these plantations are managed through an increase of understory cover, they can then provide suitable habitat and food resources. Simonetti et al. (2013) also suggested that a well-developed understory may serve as a surrogate habitat in these plantations.

Dogs are not only a threat through disease spread but are also a threat due to negligible ownership. Local surveys have suggested that vaccination and sterilization for domestic dogs is low, with traces of pathogens such as CDV high in local dog populations (Hidalgo-Hermoso et al. 2020). Domestic dogs can also be directly responsible for the death of these foxes through attacks. In many protected areas, including areas where the Darwin's fox is seen, domestic dogs pose a threat through intra-guild killing. Fox deaths have been reported on both the mainland and on Chiloe Island as a result of attacks by dogs (Silva-Rodriguez et al. 2016). Moreira-Acre et al. (2015*a*) also reported a negative correlation between areas that are used by both foxes and dogs in Nahuelbuta National Park. On Chiloe Island, these foxes are rare or completely nonexistent in old-growth forests that are frequently visited by dogs, despite this being prime habitat, yet are being recorded in scrublands when dogs are absent, suggesting spatial displacement of Darwin's foxes due to dogs. It has also been found that most of these cases are the result of poorly managed free-ranging dogs, and not feral dogs (Moreira-Acre et al. 2015*a*, Silva-Rodriguez et al. 2016). Tourists in the park often allow their dogs to run loose in the park, with one documented case of a park visitors dog attacking a female fox while she nursed two pups (Jimenez and McMahon 2004).

Human tourists in the park also pose a threat to the species. Due to constant and unrestricted illegal feeding of the foxes in the park, they have become too comfortable around humans. This has led to a case of a lactating female being killed by a tourist in the park's parking lot. Many foxes are also spending time underneath peoples vehicles, risking being run over. Foxes have even been reported climbing into people's cars, as well as visitors purposefully trying to leave the park with a fox in their car (Jimenez and McMahon 2004). Local Chileans have also reported killing foxes because they supposedly attack their domestic animals. Foxes are often trapped and then either killed or translocated by famers in an effort to protect their poultry. Many local peoples consider them to be problem animals, however, in the Nahuelbuta range, the Darwin's fox is not commonly persecuted or killed and its conservation would likely show high social support (Silva-Rodriguez et al. 2016). A study conducted by Moreira-Acre et al. (2015*b*) also found that human diurnal activity, as well as domestic dogs, can affect the occurrence of carnivores, such as the Darwin's fox, in human-dominated landscapes. It was found that these foxes exist in habitats covered by large amounts of native forest, while displaying diurnal behavior in an effort to avoid encounters with humans and dogs. In landscapes where forest loss and degradation have been increasing, many carnivores are concentrating into the few remaining patches of native forest, resulting in spatial overlap of many species.

Some locals have also reported on killing foxes for their fur. There is not a big commercial use for this species, however, some individuals have been illegally kept in captivity as pets, and there is a small demand for these furs (Silva-Rodriguez et al. 2016). Jimenez and McMahon (2004) reported that this fox is easily and repeatedly trapped, but there is no known hunting and trapping for fur specifically. Iriarte and Jaksic (1986) reported on the history of the fur trade in Chile and noted how the Chilean fur trade has pushed species to the verge of extinction, such as the sea lion (*Otaria byronia*). It was also reported that population levels of many species that were hunted for furs were unknown and the exact amount of fur being cropped is difficult to determine (Iriarte and Jaksic 1986). With the ability for this trade to push species to extinction, along with unknown population numbers and exact amounts of fur being traded, this could pose a potential threat to the endangered Darwin's fox if there is, in fact, more of a fur trade for this species than is currently known.

Legal

The Darwin's fox is considered to be endangered and is listed as so by the IUCN Red List (Silva-Rodriguez et al. 2016). This species currently lacks any sort of management plan, however the Institute of Zoological (2005) tried to conduct a project for this species. Unfortunately, it didn't take off, as the author believed that one of the most important outputs of the project had been completely overlooked, which was the development of a conservation action plan. It was also stated that the project seemed to suffer from lack of coordination and direction. Along with poor efforts to create management plans for this species, the biggest threat comes from domestic dogs and the disease that comes with them. While there are protected areas such as the Nahuelbuta National Park, dogs are still able to run rampant around these protected areas.

Certain laws that are currently in place in Chile will be beneficial to the Darwin's fox. The 1931 Forest Law was made to protect forests and halt the destructive processes affecting forests, while also giving the president the ability to create national parks and reserves (Forest Legality Initiative 2014). The Native Forest Law regulates the use of native forests and promotes sustainable forest management (Forest Legality Initiative 2014). Article 2 DL. 701, the reforestation section of this law, is an action of repopulating forests with tree or shrub species through the management of forests that had been previously subjected to extractive exploitation actions (Forest Legality Initiative 2014). Law 20,283 on Native Forest Recovery and Forest Development gives incentives to stakeholders, such as small forest owner, to grow native trees and ensure forest sustainability. Along with these laws and actions of the Chilean government, the CITES Agreement is an international agreement among governments, including Chile, to ensure that international trade of wildlife and plant species do not threaten the survival of those specie (Forest Legality Initiative 2014).

Statement of Need

As described above, a wide variety of ecological, sociocultural, economic, and legal conservation issues exist, showing the necessity of a management plan for the Darwin's fox in Chile. With so limited being known about this species, along with a small population size, understanding the diseases that threaten it is vital (Jimenez et al. 2012, Briceno et al. 2020, Cabello et al. 2013). Knowledge is also limited about some of the diseases that affect the Darwin's fox, such as the gammaherpesvirus. As a result, these diseases need to be taken into serious consideration when devising conservation strategies, such as translocating individuals (Cabello et al. 2013). Control and health management of domestic dogs in Chile is just as vital. With domestic dogs being the greatest risk of disease transmission, as well as attacking and killing foxes, and displacing foxes from primary habitat, controlling these dogs is necessity to protect the Darwin's fox (Jimenez and McMahon 2004, Jimenez et al. 2012, Moreira-Acre et al. 2015*a*).

The Darwin's fox needs native forests for shelter, breeding and hunting (Moreira-Acre et al. 2015a, Silva-Rodriguez et al. 2016). Replacement of native forests by plantations will result in a decline of small mammal populations, potentially modifying prey selection by mesocarnivores, like the Darwin's fox (Moreira-Acre et al. 2015*a*). Understory is needed to provide for small mammals, which in turn acts as a food source for the Darwin's fox, suggesting that along with native forest, suitable understory in exotic plantations is needed (Moreira-Acre et al. 2015*b*, Simonetti et al. 2013). It will also be important to increase the size of the native forest that remain and to re-forest unused forestry roads and paths (Moreira-Acre et al. 2015*a*).

Conservation action is needed for this species. The previously stated laws (Forest Legality Initiative 2014) need to be followed, as these will provide the Darwin's fox with suitable habitat through understory enhancement and sustainable forestry practices. These laws will also help to protect the fox and its habitat from being taken in unsustainable numbers, and with the Darwin's fox population already being low, they will be protected from being taken and traded altogether. Due to the many conservation issues facing this species, this management plan, along with the utilization of these already in-place laws, will be necessary for long term success of the Darwin's fox in Chile. Without management, the Darwin's fox will be extinct in 15 years (Figure 4).

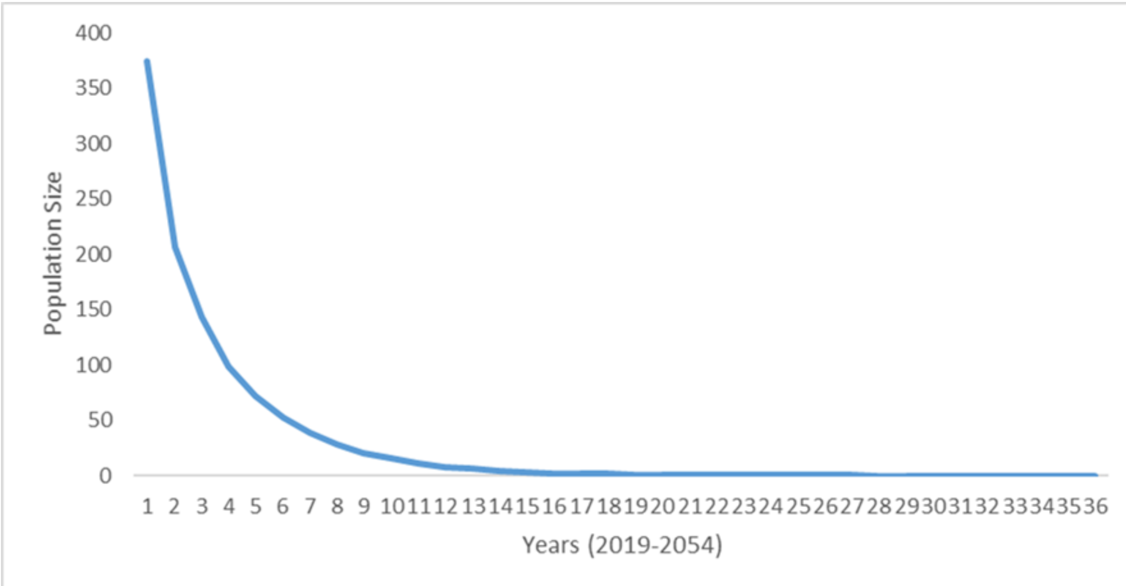

Figure 4. Darwin's fox (*Lycalopex fulvipes*) population size by year determined from survival rate data of the Darwin's fox, red fox (*Vulpes vulpes*), and gray fox (*Urocyon cinereoargenteus*). Extinction in 15 years without management.

Goals and Objectives

<u>Goal:</u> Increase the Darwin's fox (*Lycalopex fulvipes*) population in Chile to a sustainable level.

***Objective 1* –** Reduce domestic dog dispersal into fox areas by 80% in 15 years.

Action 1.1: Identify domestic dogs utilizing protected areas. Domestic dog movement into protected fox areas creates the highest risk for interactions with wildlife (Sepulveda et al. 2015). Only a small portion of the dog population demonstrated this behavior, making it most beneficial to focus management on just this portion of the population, instead of the entire local population (Sepulveda et al. 2015). Identifying these dogs will be necessary for reducing their movements into fox areas. These types of dogs can be identified through dog owners reporting dog movement in protected areas, such as

Nahuelbuta National Park, when observed. After learning that domestic dogs may negatively be affecting the Darwin's fox and other wildlife, owners may be more likely to report these actions and keep their dogs out of protected areas (Sepulveda et al. 2015). Public outreach and educational programs may be beneficial (Objective 3).

Action 1.2: Create movement barriers. Conservation programs to create movement barriers could potentially reduce dog access into forest ecosystems by reducing access into these ecosystems. By reducing the presence of or access to unused trails or roads, and through forest restoration efforts along roadways, especially those close to rural communities, domestic dogs presence in fox areas will be reduced. (Sepulveda et al. 2015).

Action 1.3: Implement tighter regulations that do not allow for domestic dogs in protected wilderness areas, such as Nahuelbuta National Park, as well as strict enforcement of these regulations, as this would likely help reduce negative fox-dog interactions from dog dispersal into fox areas. Dogs are currently not allowed into Nahuelbuta National Park or on Chiloe Island, however, dogs are still often allowed into the park with visitors despite the laws. These visitors then often let their dogs loose. Dogs from local farms are also often brought into the park to help look for the farmers cattle. Park rangers have even been seen with dogs in the park, including the park administrator (Jimenez and McMahon 2004). Overall control of dog management through leash requirement laws in parks where the fox is present may be beneficial as well, if entirely banning them from the park is not possible (Sepulveda et al. 2015).

No Action: The Darwin's fox displays the non-adaptive behavior of being naïve towards people and their dogs. No action being taken to reduce these dog movements into the park will likely result in continued mortalities of the Darwin's fox (Jimenez and McMahon 2004, Sepulveda et al. 2015).

Final Courses of Action: Actions 1.1 and 1.3 will be implemented immediately and continued throughout the 15-years allotted to achieve this objective. Actions 1.2 will be implemented as soon as it is possibly to get these programs together, preferably within 5 years of this objectives implementation.

Rationale: Actions 1.1 and 1.3 will be implemented within the first year and throughout the 15-year objective. These actions should take the least amount of time to implement and are relatively simple. Actions 1.2 will not be implemented immediately because this action requires building conservation programs and habitat buffers. This could take time to put together and may receive some public backlash.

ASSESSMENT PROTOCOL: Objective 1 will be considered a success if domestic dog dispersal into fox areas are reduced by 80% in 15 years. The implementation of the suggested actions, including identifying domestic dogs who regularly utilized protected fox areas, creating movement barriers, and implementing tighter legislation of dog allowance in the park, will make this objective a success. If these actions are implemented, occurrence of dogs in the park will be greatly reduced, which will contribute to the overall goal of increasing the Darwin's fox population, making this objective a success. While reducing domestic dog occurrence in protected areas by 80% is ideal to allow for the protection the Darwin's fox needs to get the population healthy and increasing, any reduction of domestic dogs in protected areas that contributes to reverting or slowing the downward trend projected for this population will be beneficial to this species.

After the actions of this objective have been completed, determining if there has been a decrease of domestic dogs in the park will be assessed using surveys handed out to dog-owning park visitor and local dog-owning residence to determine if they continue to bring their dogs into the park and if they have contributed to reporting dog movements. Park managers can visually assess if less dogs are roaming the park through walkthroughs of trails. This can begin after the completion of action 1.3. Assessing whether foxes in these areas have increased will be done through satellite monitoring of the population (Hidalgo-Hermoso et al. 2020). Capturing foxes and equipping them with radio collars for monitoring will also be done. This will allow us to monitor the survival of individuals and track their movements to determine if they are re-entering areas they have previously been displaced of due to domestic dog movements.

If dog occurrence in the park has not decreased by 80% in 15 years, management actions will be adjusted. Adjusting the timeline for this objective is a possibility. If dogs are still entering the park, public outreach to prevent dog dispersal (Action 1.1 and Objective 3) may have to be increased and expanded further throughout Chile. Public outreach is suggested in Action 1.1, but heavily covered by Objective 3. Objective 3 may need to be implemented sooner than objective 1 to help reduce dog dispersal. The tighter legislation suggested in action 1.3 may have to be altered as well. This may include creating higher fines and stricter punishments for ignoring this legislation.

Objective 2 – Decrease disease prevalence in the Darwin's fox population by 50% in 15 years.

Action 2.1: Monitor canine distemper virus in the Darwin's fox with increased health surveillance of the populations, as well as through the use of satellite tracking. This would allow for better understanding of mortality causes in the Darwin's fox population (Hidalgo-Hermoso et al. 2020). This disease has not yet reached the Darwin's fox, and with such a small population, an outbreak would be devastating to this species. The small population size and lack of existing knowledge will make health surveillance necessary to understand causes of mortality in the Darwin's fox, as well as to ensure transmission of this disease to foxes has not be overlooked (Hidalgo-Hermoso et al. 2020).

Action 2.2: Reduce the risk of disease spillover to the Darwin's fox from domestic dogs. Canine distemper and endoparasites have both shown to be transferred from dog populations (Jimenez et al. 2012, Hidalgo-Hermoso et al. 2020). Canine distemper is highly contagious and mainly contracted through airborne transmission. The outbreak of this disease in many species of fox originate from free-ranging dogs (Acosta-Jammet et al. 2015, Silva-Rodriguez et al. 2016, Hidalgo-Hermoso et al. 2020). Ten different types of endoparasites have been found in domestic dogs, with parasite loads being higher in areas with more domestic dogs, suggesting a high change of parasite transmission (Jimenez et al. 2012).

As suggested in objective 1, reduced interactions with domestic dogs and the management of dogs around fox areas will be significant in increasing fox survival rates. Dog sterilization, vaccination campaigns, responsible pet ownership programs and excluding dogs from conservation areas will be useful to help prevent the spread of these diseases from domestic dogs to the Darwin's fox (Jimenez et al. 2012, Hidalgo-Hermoso et al. 2020).

Action 2.3: Control the invasive American mink populations in Chile. This species carries canine distemper virus and poses a risk of spillover to the Darwin' fox (Silva-Rodriguez et al. 2016, Acosta-Jammet et al. 2015). In Chile, the American mink is the top predator, free of predation or competition. This lack of predation or competition may result in the mink further expanding its spatial and temporal niche across Chile, creating more opportunity for disease transmission (Crego et al. 2018). Strategic trapping methods have shown to be successful in trapping minks. Identifying areas that are heavily used by minks will be vital to prevent the capture of non-target species as well as to have a high capture rate. Mink rafts will be placed in water bodies to track mink movements to understand where to place traps. Once minks are trapped, they will be euthanized immediately (Reynolds et al. 2013).

Action 2.4: Conduct further research into ear mite transmission and gammaherpesvirus. Ear mites have been found to infect the Darwin's fox, as well as domestic dogs and cats, suggesting interaction with these species may allow mite transmission. Researching ectoparasites and their prevalence in these other species will allow for better understanding of infection sources and the long-term impacts on endangered and insular fox populations (Briceno et al. 2020). In 2013, there was the very first report of a gammaherpesvirus infecting a canid worldwide, as well as one infecting a South American carnivore (Cabello et al. 2013). This disease has not yet been detected in the Darwin's fox and there is still a lot of unknowns about this virus. Research into this disease is vital to help prevent the spread to the Darwin's fox. This disease also needs to be taken into serious consideration when creating conservation strategies, such as translocating individuals (Cabello et al. 2013).

2.5: Control for ear mites. Action 2.4 will act as a preliminary step, as understanding these diseases will be necessary to properly control them. Control will be done through the steps suggested in action 2.2. Ear mites are often transmitted though domestic dogs and cats (Briceno et al. 2020), suggested that the steps in action 2.2, to prevent disease spillover, will be useful. The actions outlined in objective 1, to reduce domestic dog dispersal in fox areas, will also be useful to control for ear mites in the Darwin's fox.

No Action: No action will result in increased disease transmission and likely higher mortality in the Darwin's fox population. With no monitoring of disease in this population, disease such as canine distemper will continue to spread and likely reach the Darwin's fox population, resulting in catastrophic mortality and possibly extinction in this already small population (Hidalgo-Hermoso et al. 2020). Without control of domestic dog populations (Objective 1), they will continue to spread disease throughout wildlife areas and to the Darwin's fox. This uncontrolled inter-species disease transmission will be devastating to the endangered Darwin's fox (Jimenez et al. 2012, Hidalgo-Hermoso et al. 2020). Without research into other disease, they will be left unchecked and left out of conservation strategies, contributing to the spread of disease throughout Chile (Cabello et al. 2013).

Final Course of Action: Actions 2.1, 2.2, 2.3, 2.4, and 2.5 should be implemented immediately and continued through the 15 years allotted for this objective.

Rationale: All actions will be implemented immediately because they are crucial to understanding disease spread and stop disease transmission to the Darwin's fox. Surveilling fox health is very important and will not be difficult to begin within the first year of this plan. Controlling dog populations to prevent disease spillover is extremely important, as they pose the greatest threat to foxes in terms of disease transmission. Objective 1 is entirely about controlling dog populations, so the implementation of this objective as soon as possible will be vital in completing this objective and reducing disease spread. Research into diseases where less is known can be implemented within the first few years. This will be necessary to prevent these diseases from being devastating to the Darwin's fox, however, it will take time to gather personnel and supplies for these studies, as well as secure grants, if needed. Action 2.3 will be implemented immediately because the control of this invasive species will be necessary in reducing the risk of diseases spread. Trapping efforts will begin in this plan, but it is recommended that further management goes into American mink control after this plan ends. This is an invasive species that can have negative impacts on the whole ecosystem it has invaded (Reynolds et al. 2013, Crego et al. 2018).

ASSESSMENT PROTOCOL: Objective 2 will be considered a success if disease prevalence in the Darwin's fox population is reduced by 50% in 15 years. The suggested actions of monitoring canine distemper in foxes, decreasing disease spillover from dogs, control the invasive American mink population, conducting further research into ear mites and gammaherpesvirus, and managing for ear mites, will make this action a success. If these actions are implemented, disease spread to foxes may be decreased, contributing to the overall goal of increasing the Darwin's fox population, making this action a success. While a 50% reduction in disease prevalence is ideal to get the population healthy and increasing, any reduction of disease that contributes to reverting or slowing the decreasing trend projected for this population will be considered beneficial.

After the actions of this objective have been completed, determining if there has been a decrease of disease spread will be assessed using satellite monitoring (Hidalgo-Hermoso et al. 2020), as well as the suggested assessments in objective 1, as dogs contribute greatly to disease spread and controlling domestic dogs will greatly contribute to disease control. Capturing foxes and equipping them with radio collars to monitor them will also be done. This will allow us to monitor the survival of individuals in the target age group. We will also assess these foxes and test for disease. Areas that American minks frequent will also be monitored to determine if their numbers have been reduced and if there are less potentially harmful interaction between them and Darwin's foxes.

If disease prevalence has not been reduced by 50% in 15 years, then management actions will be adjusted. This may include expanding the timeline of this objective. Dog control may need to be increased, as suggested in objective 1. Action 2.3 may need to be focused on more heavily. Without predators or competitors, the invasive American mink provides high opportunity for disease transmission (Crego et al. 2018) and may require more significant control. More resources and time will also need to be given to disease research to better understand how these diseases affect the Darwin's fox.

***Objective 3* –** Increase local human populations awareness of the Darwin's fox by 87% in 5 years.

Action 3.1: Conduct surveys (Appendix A) to get a better understanding of park visitors awareness of the endangered Darwin's fox. A study was conducted in Donau-Auen National Park in Austria to determine what percentage of park visitors understand the effect they may be having on wildlife. This park was exposed to high-use pressure including off-trail use and off-leash dog walking (Sterl et al. 2008), which are also problems in parks where the Darwin's fox is found. It was determined that only 40% of visitors were aware that these actions disturbed wildlife, and only 12% believed they could have contributed to disturbing wildlife that day (Sterl et al. 2008). Based off the many negative human-fox interactions that happen in Nahuelbuta National Park, it is likely that park visitor awareness in this park reflects the awareness from this study, thus why conducting studies and raising awareness by 87% will likely be beneficial. Surveys will also be conducted as part of the assessment protocol for this objective to determine if our objective has been successful. The survey specified in this action is an initial survey taken at the beginning of this objective to better understand the level of already existing knowledge of the Darwin's fox. Understanding this will help to understand how to proceed to ensure this objective is completed.

Action 3.2: Create pamphlets (Appendix B) and educational seminars for guests of the park on why they need to keep their dogs on leashes, as well as why they should not try to feed or interact with foxes. Tourists in the park often allow their dogs to run loose in the park. This displaces the Darwin's fox and leads to fox deaths, with one documented case of a park visitors dog attacking and killing a female fox while she nursed two pups (Jimenez and McMahon 2004). Dogs also spread disease as reference in objective 2. Increasing park visitors knowledge on the dangers of letting their dogs run free and their effect on wildlife may lead to higher rates of visitors keeping their dogs on leash, or out of the park all together. Using kennels or leashes around farm animal enclosures may allow dogs to perform their primary guarding duty, while also minimizing roaming and hunting behaviors in areas where native wildlife will be at risk (Sepulveda et al. 2015). Topics such as this can be discussed in seminars. If people understand how and why they should take actions such as this, it will help to promote more responsible pet ownership

No Action: No action will result in park visitors continued disturbance of the Darwin's fox through off-leash dogs and illegal feeding. As many park visitors understanding of what their actions do to wildlife is very low (Sterl et al. 2008), without implementing educational programs, this behavior will continue and will continue to harm foxes.

Final Courses of Action: Actions 3.1 and 3.2 will be implemented immediately and continued through the 5 years allotted for this objective.

Rationale: Actions 3.1 and 3.2 can be implemented within the first year of this plan. Conducting a survey on park visitors knowledge about this fox is critical for continuing this objective. Creating educational pamphlets and seminars for guests and locals is also critical for increasing public awareness and can be implemented within 6 months to a year.

ASSESSMENT PROTOCOL: Objective 3 will be considered a success if Darwin's fox awareness by local and park visiting humans is increased by 87% in 5 years. The suggested actions of conducting survey and creating pamphlets and educational opportunities will contributing to making this objective a success. If these actions are implemented, awareness by humans of the Darwin's fox and the threats it is facing will be raised, potentially contributing to an increase in the Darwin's fox population. If these actions are implemented and awareness is increase by 87% in 5 years, this action will be considered a success.

After the actions of this objective have been completed, determining if awareness has been raised can be done by conducting further surveys. Surveys can be taken at the beginning of this management plan (Action 3.1) and then another survey can be conducted at the end of this objective to determine if awareness has changed. Surveying park visitors and local to determine if they have visited any of the educational seminars or read educational pamphlets will help to determine if these actions have had any impact.

If awareness has not been raised by 87% in 5 years, then adjustments will be made. More funding may need to be acquired that will allow us to have more educational opportunities and hire more personal to expand and increase our surveys and educational opportunities.

Objective 4 – Increase survival of 3-year old and younger foxes by 80% in 15 years (Figure 5).

Action 4.1: Create incentives to stop farmers from trapping and killing foxes. Local Chileans have reported killing foxes because they supposedly attack their domestic animals. Foxes are often trapped and then either killed or translocated by famers in an effort to protect their poultry. Many local peoples consider them to be problem animals, however, in the Nahuelbuta range, the Darwin's fox is not commonly persecuted or killed and its conservation would likely show high social support (Silva-

Rodriguez et al. 2016). Some reports suggest that it is very unlikely that these foxes are responsible for killing livestock, so it may be beneficial to also provide educational seminars or pamphlets to farmers, as well as those outlined in objective 3. This may be beneficial in stopping prosecution of foxes by farmers. If they refuse to believe that these foxes are not posing a threat, then providing incentives, such as money or tax cuts, may be beneficial to preserving foxes that wander near farmland.

Action 4.2: Reduce attacks from domestic dogs. Along with disease spread, domestic dogs have been reported attacking and killing Darwin's fox. There is one documented case of a park visitors dog attacking and killing a female fox who was nursing two pups (Jimenez and McMahon 2004). Conducting the suggested actions in objective 1 to reduce domestic dogs in the park will be beneficial to achieving the goal if this action.

Action 4.3: Implement strict legislation that penalizes park visitors for interacting with foxes and create educational opportunities for park visitors and locals about why they should not feed wildlife, as suggested in objective 3. Due to constant and unrestricted illegal feeding of the foxes in the park, they have become too comfortable around humans. This has led to a case of a lactating female being killed by a tourist in the park's parking lot. Many foxes are also spending time underneath peoples vehicles, risking being run over. Foxes have even been reported climbing into people's cars, as well as visitors purposefully trying to leave the park with a fox in their car (Jimenez and McMahon 2004). If people learn that feeding foxes is leading to a development of naivety to people and dogs, which is resulting in foxes being hit by cars, and attacked by people and dogs, they may be less likely to engage in these actions (Objective 3). Many people will still not follow appropriate park behavior, and, for this reason, strict legislation and enforcement will be useful. If there are hefty fines or banning from the park for feeding foxes or trying to remove them from the park, many people may be deterred from this behavior. This will ideally result in foxes losing some of their naivety to dogs and humans, resulting in higher rates of fox survival.

No Action: If no action is taken to increase survival of foxes in the 3-year and younger age groups, then this species population will continue to decline. Figure 4 shows the future of the Darwin's fox with no management, suggesting extinction in 15 years. The other objectives of this plan will contribute to increasing survival rates, but without focus on increasing 3-year old and younger foxes by 80%, we will not see the population spike shown in figure 5.

Final Course of Action: Action 4.1 and 4.3 will be implemented within the first 5 years. Action 4.2 will be implemented through objective 1, so this action should be implemented immediately.

Rationale: Actions 4.1 and 4.3 can be implemented within the first 5 years. Getting legislation passed in the park that creates penalties for interacting with foxes my take time, however after implementing action 3.1 and 3.2, public awareness may already be raised. This may make it easier to get this sort of legislation passed. Creating legal incentives to farmers will also take time, but it is likely that we will see high social support from farmers in the Nahuelbuta range, potentially helping to get support from farmers on Chiloe Island, where they are considered to be a problem animal. Many famers believe that these foxes kill their poultry (Silva-Rodriguez et al. 2016), suggesting that not implementing educational opportunities (Objective 3) and incentives to farmers will lead to continued, unnecessary, killing of the Darwin's fox. Action 4.2 heavily relays on the actions of objective 1. As those actions are implemented to reduce domestic dogs in fox areas, attacks from domestic dogs should also be reduced.

ASSESSMENT PROTOCOL: Objective 4 will be considered a success if the survival of 3-year old and younger foxes is increased by 80% in 15 years. The suggested actions of creating incentives for farmers, reducing attacks by domestic dogs, and creating legislation that penalizes people for feeding or interacting with foxes will contribute to making this objective a success. If these actions are implanted successfully over 15 years, the survival rates of foxes in this age group will be increased by 80%, making this objective successful and contribute to the overall goal of increasing the population to sustainable numbers.

Action 4.1 can be assessed through following up with farmers to determine if they have been receiving the incentives and if they have still been killing foxes, if farmers who have been getting the proposed incentives have stopped killing foxes, then this action will be successful. Action 4.2 is largely dependent on objective 1 and the assessment protocol suggested in objective 1 will help to determine the success of this action. Action 4.3 can be assessed by speaking with park visitors to determine if they have been interacting with foxes or received any type of ticketing for this behavior. Ticket records can also be observed to determine if less ticketing has been occurring after people learn of the new legislation.

If 3-year old and younger fox survival has not been increased by 80% in 15 years, then this objective will be a failure and will be harmful to this plan. The Darwin's fox likely faces extinction in 15 years (Figure 4), so if this objective is not met, it may be too late for these foxes. If this objective is not as successful as it is intended to be by halfway through our allotted 15 years, then the actions in this objective will have to be altered to ensure we meet our goal within the allotted time of this objective. This could include providing even better incentives and creating even stricter legislation that is heavily enforced.

Objective 5: Increase suitable habitat by 75% in 15 years

Action 5.1: Increase understory in exotic plantation. Much of the native forest in Chile is being converted to forestry plantations (Miranda et al. 2015, Zamorano-Elgueta et al. 2015, Silva-Rodriguez et al. 2016). The Darwin's fox prefers to select for native forests, but with so much forest being replaced by plantations, these foxes have been seen utilizing the plantations (Moreira-Acre et al. 2015a, Silva-

Rodriguez et al. 2016). The replacement of native forests by plantations without suitable understory will result in a decline of small mammal populations, potentially modifying prey selection by mesocarnivores, like the Darwin's fox (Moreira-Acre et al. 2015*a*). However, if these plantations are managed through an increase of understory cover, they can then provide suitable habitat and food resources (Moreira-Acre et al. 2015*b*). Well-developed understory may serve as a surrogate habitat in these plantations. When understory was removed, the frequency of mammal occurrence decreased significantly, where in control stands, where understory had not been removed, frequency did not change. Providing dense understory in exotic plantations also creates more connectivity between fox populations and helps to combat habitat fragmentation (Simonetti et al. 2013).

Action 5.2: Use wildlife-sensitive forest harvesting techniques. This will be done through multiple methods, including the retention of a percentage of decaying and dead trees and woody debris, a retention of old-growth forest stands, and reducing fragmentation effects through wildlife corridors (Yahner et al. 2012). There are multiple laws in place in Chile that could be used to help implement these practices. The 1931 Forest Law, which gives protection to forests and can halt destructive processes affecting forests, the Native Forest Law, which regulates the use of native forests and promotes sustainable forest management, and the CITES Agreement, an international agreement among governments to ensure that international trade of wildlife and plant species does not threaten the survival of these species (Forest Legality Initiative 2014), can all be used to ensure that wildlife-sensitive practices are carried out.

Rationale: Tree cavities of decaying and dead trees and woody debris provide many species of wildlife with shelter, dens, foraging sites, nests, and cover (Yahner et al. 2012). Darwin's fox have been known to den in hollowed out logs on the ground or dead or decaying woody debris (Jimenez and McMahon 2004). Leaving enough woody debris in forests utilized by the Darwin's fox would allow for better opportunities for denning for this fox, as well as potentially being beneficial for enhancing their foraging sites. In the U.S., since European settlement, only about 3-5% of the original old growth forest remain (Yahner et al. 2012). This trend is also being seen today in Chile, with much of its native forests, including old-growth forest, being replaced by forestry plantations (Zamorano-Elgueta et al 2015). Temperate old-growth forests are the most often utilized forest type by the Darwin's fox (Jaksic et al. 1990, Jimenez and McMahon 2004), so management that ensures there is a sufficient amount of old-growth forest left intact may be beneficial to this fox. Parts of the Darwin's fox population exist in fragmented habitat (Jimenez and McMahon 2004). Fragmentation of habitat is one of the greatest threats to wildlife throughout the world and can have severe effects on wildlife communities (Yahner et al. 2012). Reduction of the effects from fragmentation may benefit the Darwin's fox population through connecting potentially separated populations and increasing their range and ability to spread out, potentially allowing for population increases.

Action 5.3: Expand Nahuelbuta National Park. While foxes are protected in the park, mortality becomes a much greater risk when foxes move to lower, unprotected areas in search of milder conditions in the winter. Some foxes will also use these areas to breed (Jimenez and McMahon 2004). Expanding the park will create more habitat for the Darwin's fox and give them safer opportunities to breed, contributing to a population increase. This could be achieved through the help of the Wildlife Conservation Society. This organization works to assist governments and local communities to plan protected area networks and to develop management plans for these protected areas, as well as ensure local communities see the benefits of conservation (Wildlife Conservation Society 2020*a*). In March 2020, this organization helped to provide funding to protect the endangered cross river gorilla (*Gorilla gorilla diehli*) by expanding protected areas to all of Cross River National Park, where this gorilla inhabits. This is the most endangered ape in Africa and this protection will protect the gorilla from habitat loss and poaching (Wildlife Conservation Society 2020*b*). This organization could help provide funding to expand Nahuelbuta National Park, which would then protect the Darwin's fox from habitat loss and persecution. The Darwin's fox is a unique species that acts as an ecotourism attraction in Nahuelbuta National Park (Jimenez and McMahon 2004). A fund could be set up with the park that allows for part of the park entrance fee, or a donation from park guests upon entrance, that acts as additional funding that goes towards achieving this action. As this fox is an ecotourism attraction, many guests would likely participate. Current laws would also likely be helpful in achieving this action. The 1931 Forest law gives the President the ability to create national parks and reserves (Forest Legality Initiative 2014). This could be potentially helpful in expanding the park. The Native Forest Recovery and Forest Development law provides incentives to stakeholders, such as small forest and private landowners, to grow native trees and ensure forest sustainability (Forest Legality Initiative 2014). While this law would not help in officially expanding the park, it may be useful in helping to get private landowners who own land surrounding the park to ensure the forest around the park are healthy and useable by the Darwin's fox.

No Action: Increasing understory in exotic plantations has shown to improve this habitat, making it useable to the Darwin's fox by providing suitable habitat, food resources, and habitat connectivity (Simonetti et al. 2013, Moreira-Acre et al. 2015*b*). Taking no action to ensure these converted forests are suable by native wildlife will likely lead to a decline of the Darwin's fox in Chile by pushing them further into unprotected areas.

Final Course of Action: Action 5.1, 5.2, and 5.3 will be implemented as soon as it is possible, preferably within 5 years and continued throughout the 15 years allotted to this objective.

Rationale: Action 5.1, 5.2, and 5.3 will be implemented as soon as it is possible too. These actions require passing new laws and legislation. Passing these laws, getting forestry companies to follow new understory guidelines, and securing the funding to properly implement these actions will likely take time, but should be completed in no more than 5 years, allowing these actions to continue throughout the 15 years of this objective.

ASSESSMENT PROTOCOL: Objective 5 will be considered a success if suitable fox habitat is increased by 75% in 15 years. The suggested actions of increasing understory in exotic plantations, using wildlife-sensitive forest harvesting techniques, and expanding the parks boarders will contributing to making this objective a success. If these actions are implemented, safe, usable habitat and food resources in the form of small mammals (Moreira-Acre et al. 2015*b*) will be increased, contributing to an increase in the Darwin's fox population. If these actions are implemented and suitable habitat is increase by 75% in 15 years, this action will be considered a success.

After these actions have been implemented, assessing whether this objective was a success will be done through studying restored plantation sites. Monitoring will be done through tree-mounted cameras and placed in restored and unrestored plantations. This will allow us to monitor fox frequency in plantations and determine if the understory enhanced plantations have a higher use frequency by foxes, compared to the unrestored plantation. Forestry plantations can also be monitored to ensure the suggested forestry techniques are being used. If the park is expanded, these new protected areas will be monitored to determine if foxes are utilizing these areas and that they are safe for them to do so.

If suitable habitat has not been increased by 75% in 15 years, then this objective will be adjusted. We may be required to extend the timeline on this objective to allow for more time for legislation to pass that allows the expanding of the park. If understory is not being adequately enhanced in plantations, this may require the passing of new laws forcing forestry companies to be accountable for maintaining a specific percentage of understory in their plantations, as well as the forestry techniques they use.

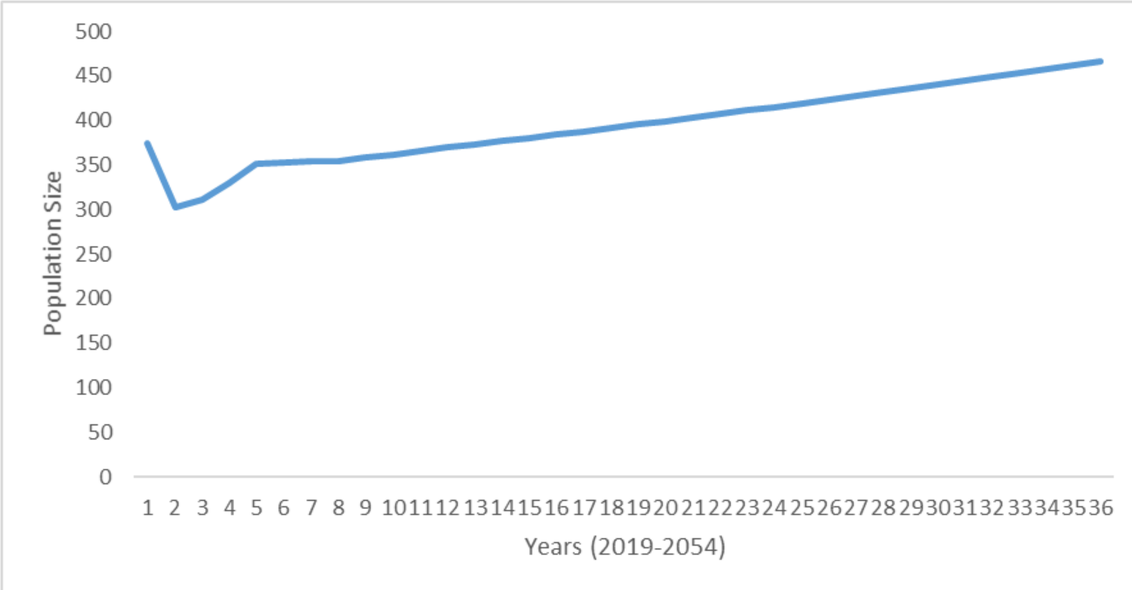

Figure 5. Darwin's fox population when increasing survival rates of foxes in the age groups less than 1-year old to 3-years old by 80%.

Conclusion

This Darwin's fox management plan for Chiloe Island and Nahuelbuta National Park in southern Chile could potentially increase the Darwin's fox population to sustainable levels and remove the threat of extinction. Plantations should be enhanced with dense understory, foxes should be monitored, domestic dogs in protected areas should be monitored and restricted, and locals and park visitors should be educated on the negative effects their dogs and direct contact with foxes may have on this endangered species. Disease spread and spatial displacement by domestic dogs, interaction with humans, and native forest loss all act as threats to the Darwin's fox. Through the knowledge collected on the Darwin's fox from existing studies, what is know about other fox species, such as the gray fox and the red fox, the models created for this plan, a set of actions and assessments have been developed. This goal may be difficult to achieve due to the foxes small population size and its secretive nature. In Chile, allowing dogs off-leash to roam freely and trying to feed or interact with the Darwin's fox is common (Jimenez and McMahon 2004, Silva-Rodriguez et al. 2016), so changing these human behaviors will be challenging. However, if the suggested courses of action described in this plan are implemented successfully, managers will be able to achieve the goal of increasing the Darwin's fox population in southern Chile to sustainable levels in 35 years. The consequences of failure to implement this plan successfully will result in extinction of this species in 15 years (Figure 5). It is vital that this plan is implemented and followed though successfully in Chile. Extinction of this canid would be a significant loss to Chile, not only because of this species uniqueness, but also because of this foxes role as a seed disperser in its ecosystem, but also for the economic benefit it has to Chile through acting as an ecotourism attraction (Jimenez and McMahon 2004). Limited information currently exists on this unique fox, presenting many opportunities for further research, as there is still an abundance of knowledge to be discovered about the Darwin's fox.

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Appendix A –

A survey created to better understand park visitors awareness of the Darwin's fox, how they are potentially interacting with foxes, if they are bringing in dogs, and if they believe that these actions disturb wildlife. This will be distributed to visitors entering the park.

Thirty-Five-Year Management Plan for the Endangered Darwin's Fox (Lycalopex fulvipes) in Nahuelbuta National Park and Chiloe Island in Southern Chile

Survey Questions 2019

The Darwin's fox is a small canid existing on Chiloe Island and in Nahuelbuta National Park in southern Chile. This fox is currently listed as endangered due to it having a small and decreasing population. This mainly comes from negative interactions with domestic dogs in protected areas through attacks and disease. Park visitors interacting directly with foxes also puts this fox at risk. Interacting with a fox creates a naivety to humans in foxes, which can result in foxes getting hurt. These foxes are also suffering from a loss of their native habitat. This survey will help us to get a better understanding of park visitors awareness of these foxes and what actions may threaten them, and hopefully you can learn a little more about the Darwin's fox while taking it! Thank you for participating in the conservation of the Darwin's fox!

1. Are you aware of the Darwin's fox presence in areas of Southern Chile such as Nahuelbuta National Park and on Chiloe Island? (Choose one)

   a. Yes

   b. No

2. Are you familiar with the Darwin's fox conservation efforts to increase the small and decreasing population in Chile? (Choose one)

   a. Yes

   b. No

3. Do you believe that the Darwin's fox has value in Chile? (Choose one)

   a. Yes

   b. No

   c. Unsure

   d. Other (Explain):

4. Have you ever had a personal experience with a Darwin's fox, such as seeing, feeding, or trying to interact with one?

a. Yes (Explain):

b. No

5. Are you a permanent resident in Southern Chile? (Choose one)

a. Yes

b. No

c. Other (Explain)

6. How often do you visit Nahuelbuta National Park? (Choose best answer)

a. One-five times a week

b. One-five times a month

c. One-five times a year

d. This is my first visit

7. If you are a dog owner, do you ever let your dog off the leash in the park? (Choose one)

a. Yes

b. No

8. Do you believe actions such as off-trail use, and off-leash dog walking can disturb wildlife, such as through spatial displacement? (Choose one)

a. Yes

b. No

c. Unsure

9. Do you believe you have contributed to wildlife disturbance through acts such as spatial displacement, letting your dog off-leash, or walking off-trail at your last visit to the park?

a. Yes (Explain):

b. No (Explain):

c. Unsure (Explain):

Appendix B –

A pamphlet created as an educational piece of literature that will be easy to read and understand on why dogs should be kept out of the park. This will also be distributed to visitors entering the park as an attempt to educate them on why they should not bring their dogs, with the goal of resulting in a decline of dog presence in the park

Why should you not bring your dog to the park?

PAUL SMITH'S COLLEGE

RED LIST

Wildlife Conservation Society

Darwin's fox (*Lycalopex fulvipes*)

Thirty-Five-Year Management Plan for the Endangered Darwin's Fox in Nahuelbuta National Park

DOGS DISPALCE WILDLIFE

The Darwin's fox loves to spend it's time in old growth temperate forests, like Nahuelbuta National Park! Unfortunately, when dogs are prsent in these areas, foexes are forces to leave. These foxes have been recorded more frequently visiting scrublands, when dogs are absent. Most cases of these incidents are caused by poorly managed free-ranging dogs and not feral dogs.

DOGS ATTACK FOXES

Fox deaths as a result of dog attacks have been reported in both Nahuelbuta National Park and on Chiloe Island, the two main places the fox is found.

Did You See a Darwin's fox?

The Darwin's fox (Lycalopex fulvipes) is considered one the world's rarest and least studied canids, while also being considered one of the most threatened

- Short legs, long body, bushy tail
- Their fur is a combination of black and gray with red markings on the ears and lower parts of the legs
- Under the chin and along the underbelly, white markings are visible
- Average mass: 2.72 kg (5.99 Ib.)
- Average length: 528 mm (20.79 in.)

DISEASE SPREAD

Domestic dogs can spread diseases such as:

- Canine Distemper Virus
- Endoparasites such as nematodes, cestodes, and protozoans
- Ear mites
- Gammaherpesvirus

DO NOT FEED FOXES

If you see a fox, it may look cute or hungry, but do not attempt to feed or touch foxes! These are wild animals and feeding them makes them too comfortable near people. This can lead to foxes getting hurt by people who fear an approaching fox, foxes sitting under cars in the parking lot, where they can get hurt, or breaking into people's cars!

WHAT CAN YOU DO TO PROTECT FOXES?

- Leave your dog at home
- Stay on the trails
- Do not feed wildlife
- Do not try to touch foxes

MORE INFORMATION

https://www.iucnredlist.org/species/41586/107263066

https://animaldiversity.org/accounts/Lycalopex_fulvipes/