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A monitoring program for Patagonian foxes based on power analysis

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Abstract Culpeo fox (*Pseudalopex culpaeus*) and gray fox (*Pseudalopex griseus*) are heavily culled in Patagonia. Fox populations seem to persist thanks to spatial refuges from which hunted areas are repopulated, following a source–sink dynamics. Sustainable use of Patagonian foxes warrants the design of a monitoring program in nature reserves and areas subjected to predator control. During 7 years, we used visitation indices to bait stations in a national park and neighboring sheep ranches of southern Argentina. We operated bait stations during three consecutive nights and calculated seven indices of relative abundance. For each fox species, we compared the power of different monitoring designs and scenarios that combined visitation indices, effort (number of bait station lines and survey frequency) while controlling for type I error, and magnitude of population change during a given period. We looked at the combinations that produced high power ($\beta \leq 0.24$). The operation of bait stations during several nights markedly increased statistical power. Index 7 (recording visits 72 h after activation) exhibited the lowest variation and improved expected power to detect a population trend. Both fox species could be monitored

simultaneously, with power >0.76 in the short term (5 years), activating 24 bait station lines. We conclude that monitoring programs for culpeo fox and gray fox based on bait stations are able to detect marked declines but are less useful to reliably detect moderate increases in abundance, especially in sheep ranches.

Keywords Argentina · Bait stations · Culpeo fox · Gray fox · Population management · Sustainable use

Introduction

Culpeo fox (*Pseudalopex culpaeus*) and gray fox (*Pseudalopex griseus*) are heavily persecuted throughout Patagonia, where they are simultaneously considered pest and valuable species (Novaro and Funes 1994; Novaro 1995). Fox pelts constitute an important source of income for rural people (Funes and Novaro 1999). On the other hand, sheep husbandry is a major land use, and culpeo fox prey regularly upon lambs and young sheep (Bellati 1986; Bellati and von Thungen 1990; Novaro 1997a; Novaro et al. 2000). Therefore, management of sheep ranches includes intensive control of culpeo fox (Travaini et al. 2000), which may remove up to 75% of local populations each year (Novaro 1995). Control methods are mostly nonselective (Travaini et al. 2000), and gray foxes as well as other predators and scavengers are killed too (Olrog 1980). Recently, Novaro et al. (2005) suggested that such extraction rates would drive populations extinct in the absence of spatial refuges from which hunted areas can be repopulated through immigration and that culpeo dynamics might be described by a source–sink model with attractive sinks. Since high levels of culpeo fox extraction are representative for most sheep ranches across Patagonia,

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source–sink dynamics with attractive sinks might be widespread (Novaro 1997a). Potential refuges for culpeo fox include cattle ranches (Novaro et al. 2005), abandoned ranches, and protected areas. After 1985, sheep husbandry was progressively abandoned in two thirds of Santa Cruz province (250,000 km²), southern Argentina, due to a combination of socioeconomic and environmental factors. However, since 2003, sheep farming is being restored in many of those abandoned ranches, threatening the culpeo populations that could act as sources. The attractive sink model predicts that population size will decline first on sources (Delibes et al. 2001), which warrants close monitoring of fox populations in protected areas and other refuges if sustainability criteria are to be incorporated to predator control. Moreover, assuming that lamb losses augment with culpeo density, detecting an increase of fox abundance in sheep ranches may help to anticipate control using nonselective methods (and their ecologically detrimental side effects) before predation on lambs reaches ranchers' tolerance levels (5% of lambs produced; Travaini et al. 2000).

The fundamental feature that makes useful a monitoring program is its ability to detect biologically significant changes in abundance (Taylor and Gerrodette 1993; Zielinski and Stauffer 1996; Gibbs et al. 1998). In this context, statistical power (Mapstone 1995) equals the probability that monitoring detects a specified population change (Lougheed et al. 1999), the “signal” among the “noise” in the field data (Gibbs et al. 1999). For any population index, designing a monitoring program basically implies maximizing statistical power to detect a pre-established level of change while minimizing sampling effort, in terms of spatial and temporal replicates, and its associated costs (Steidl et al. 1997; Gibbs et al. 1998). However, with some exceptions (e.g., Zielinski and Stauffer 1996; Rice et al. 2001), many monitoring programs have not been preceded by proper power analysis (Peterman 1990). Further, the relative sensitivity of power to different components of sampling effort may help to optimize the design of a monitoring program (Di Stefano 2003; Stem et al. 2005; Salzer and Salafsky 2006).

Scent stations and bait stations are standard methods to survey carnivores at broad spatial scales (Harrison et al. 2002; Sargeant et al. 2003; Zielinski et al. 2005). These methods can detect population trends when substantial changes in numbers occur across wide areas (Diefenbach et al. 1994; Sargeant et al. 1998). One of their drawbacks, however, is that a high proportion of visitation rates equal to zero produces concomitant high variability and reduces statistical power to detect trends (Gibbs 2000). Low or zero visitation rates partly depend on intrinsic attributes of the species surveyed at the behavioral and population levels and are unavoidable. For example, conditioning from

previous contacts of individuals with stations, low density of the target species, or high food availability might all result in low attraction to scents or baits. A high proportion of zeros in the population index may also arise if monitoring effort is insufficient or the monitoring protocol is unsuitable for the target population. In this case, power partly depends upon variables that can be managed by researchers when designing a monitoring program (Field et al. 2005).

We wanted to design a monitoring program for culpeo and gray foxes based on bait stations in an area including protected land (potential source) and sheep ranches (potential sink). We sought to minimize sampling effort while maintaining a high probability to detect a given level of change. In this study, we first compared the statistical properties of seven different visitation indices, with especial attention to the number of zeros and its influence on index variability. Then, we assessed the relative performance of different indices to maximize power. Finally, we analyzed the sensitivity of power to relevant components of the monitoring program. Specifically, we examined the influence of spatial replication, survey frequency, and season in different simulated scenarios of population decrease in sources and population increase in sinks.

Study area

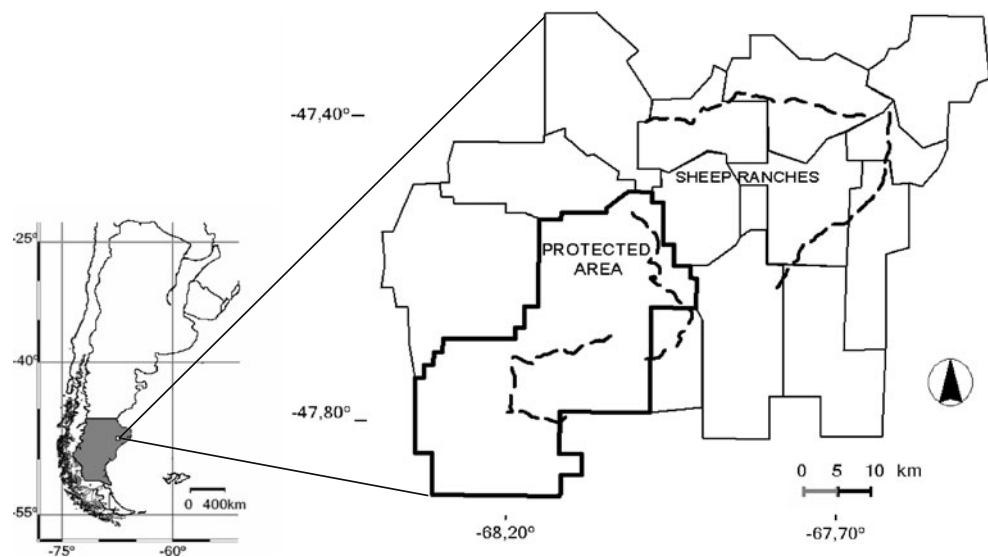
The study was conducted at the Monumento Natural Bosques Petrificados National Park (MNBP; 56,000 ha) and five neighboring sheep ranches totaling 100,000 ha (Santa Cruz province, Argentina; Fig. 1). Annual rainfall ranged between 100 and 300 mm, and snow is rare. Summer temperatures averaged 17°C, and winters were relatively mild for this region, with an average of 12.4 freezing days per year. A moderate to strong west wind blows almost constantly (Harris 1998). Most of the area was covered with tussock grasses and low, dome-shaped, and spiny shrubs (Soriano 1983), whose cover ranged from less than 10% in the most arid areas to 60% (Ares et al. 1990; Bertiller and Bisigato 1998).

Methods

Field methods

A bait station consisted of a 1-m-diameter circular surface of sifted, smoothed soil with a 30-g bait buried at 2–3-cm depth in its center (Linhart and Knowlton 1975). Bait composition was minced meat (80.6%), hydrogenous oil (9.7%), corn starch (8.1%), and a commercial trap lure (1.6%; Cat Passion, O'Gorman Enterprises Inc.; Travaini et

Fig. 1 Bait station lines inside the Monumento Natural Bosques Petrificados National Park (1999–2005) and neighboring sheep ranches (2000, 2002–2005) in Santa Cruz province, southern Patagonia. Short segments represent bait station lines, formed by groups of six bait stations. Since the few lines outside but adjacent to the park boundaries are placed in public lands where fox control is banned, they were treated as if they belonged to the protected area



al. 2001). We placed lines of six stations, spaced 0.5 km, on alternate sides along secondary, unpaved roads. Lines were at least 1 km apart. We assumed that individuals of both species would rarely encounter more than one line per survey and that each line was an independent sampling unit.

We set 16 lines inside the protected area, which were surveyed in spring during 7 years (from 1999 to 2005) and in fall during 5 years (2000, from 2002 to 2005). We established 16 lines in the adjacent sheep ranches where spring surveys were conducted in 2 years (2002 and 2005; Fig. 1).

In each survey, we operated bait stations during three consecutive nights. Each morning, we recorded whether fox tracks were printed on the surface. Since gray fox tracks are narrower and much shorter than culpeo fox tracks (Travaini et al. 2001), we could easily tell the difference between species. Strong winds and poor printing precluded unequivocal track identification in some stations which were not considered operative. These records were excluded from the analyses. We erased tracks, added more soil if necessary, and replaced the bait regardless of whether it was or was not consumed the night before. We conducted all surveys during dry weather. After each survey, we removed all uneaten baits.

Visitation indices

Bait station methodology is based on the assumption that rates of visitation by a fox species constitute an index of its relative abundance (Sargeant et al. 2003). We assumed that variations in fox detectability could be partly neutralized in the long term by the standardization of sampling conditions. For each fox species, we calculated indices of

relative abundance as the ratio between number of visits and number of operative station nights $\times 1,000$ (Linhart and Knowlton 1975). We defined seven different visitation indices from our three-night test. We computed visitation indices for the first (index 1), second (index 2), and third (index 3) night separately. Index 1 was identical to the one used in most single-night scent station studies (Sargeant et al. 1998; Travaini et al. 2003a, b). As resident foxes could encounter bait stations on successive nights, index 2 and index 3 could be positively or negatively affected by previous experience with baits. Multiple-night indices have been recommended for species that occur at low density (Conner et al. 1983). Therefore, we calculated visitation index 4 by treating the first two nights as if they were independent events, that is, computing the mean daily visitation rate. Index 5 was the mean daily visitation rate for all three nights. In the last pair of visitation indices, multiple sampling days were treated as a single period. Index 6 was the number of visited stations during any of the first two nights divided by six operative stations in the line, i.e., it was equivalent to checking stations after 48 h. Likewise, index 7 was equivalent to recording fox visits once, 72 h after activation.

For each survey, we computed the mean and coefficient of variation (CV) of each visitation index for the 16 lines inside the protected area. We also calculated the proportion of lines that received zero visits. Using the index value of each survey as a temporal replicate ($n=12$), we tested the null hypothesis that the proportion of zeros was equal for all visitation indices. Finally, we examined whether CV increased with the proportion of zeros at the same rate for the different visitation indices by checking for homogeneity of the slopes of the regression lines.

Power estimates and sources of variation

We estimated the power of different monitoring designs for Patagonian foxes with the aid of the freeware MONITOR (Gibbs 1995; Thomas and Krebs 1997; available at <http://nhsbig.inhs.uiuc.edu/wes/populations>). MONITOR uses Monte Carlo simulations to model count surveys (visitation indices in our case) over time and generates detection rates derived from route-regression analyses (Geissler and Sauer 1990; Gibbs and Melvin 1997). This simulation procedure is useful for evaluating the tradeoffs between sampling effort, logistical constraints, and power to detect trends (Gibbs et al. 1998). To estimate statistical power, we supplied the program with initial estimates of each visitation index and its variance for each fox species, sampling effort in terms of number of lines, survey frequency, and type I error. We specified the size of the effect as the percentage of population change during a given period. We also ran different simulations for bait station data obtained in different seasons. Combinations of parameter values for these variables produced different scenarios. For each scenario, we estimated one value of statistical power after 1,000 replications. To select scenarios that we considered suitable for the design of a monitoring program, we arbitrarily set the minimum acceptable power at $(1-\beta)=0.76$, i.e., the highest probability of failing to detect a specified trend was 0.24.

As initial values, the program needs the estimates of the mean and CV of the visitation rates. Gibbs et al. (1998) suggested to feed the program with tentative estimates of variability obtained from the literature, which were compiled for many taxa by Gibbs (2000). We opted, however, for deriving empirically these initial values in our study area (Table 1). To examine the effect of variability of visitation rates in different seasons inside the protected area, we fed the program with initial values calculated separately for spring surveys and fall surveys.

In simulations, we set the number of sampling units (bait station lines) between 14 and 26. In preliminary analyses, we found that highly variable visitation indices precluded reaching a statistical power of 0.8 if the number of lines was <14 (Travaini et al. 2003a, b). The upper limit of 26 lines was imposed by road availability inside the protected area. The period between successive surveys was set at values of 0.5, 1, and 2 years, the latter only when initial values of visitation rates were derived from bait station data recorded over a period of 6 years. To test the null hypothesis of no population change, type I error was set at values of $\alpha=0.05$, $\alpha=0.10$, and $\alpha=0.20$. We used one-tailed tests, as the predicted direction of change was established a priori (decrease in the protected area, increase in sheep ranches). We considered three levels of effect size or magnitude of population change: a 50% decrease after

5 years (6 years if field surveys were considered to be conducted every other year), a 50% decrease after 10 years, and a 30% increase after 3 years.

We used generalized linear models to analyze the relative effect of visitation index, sampling effort, and sampling frequency on estimated statistical power. To explore these effects, we used the subset of power values obtained within the protected area. For both fox species, power values followed a lognormal distribution, and we modeled log-transformed power using normal errors and the following predictors: (1) season, (2) sampling frequency (once a year or once every 2 years), (3) number of spatial replicates or lines, and (4) visitation index. Since changes in power cannot be considered in isolation of “effect size” and “alpha level,” we fitted these two factors as covariates in order to control for their effects. The contribution of each factor to the explained variance in power was assessed through sequential backward removal from the maximal model (Crawley 1993).

Results

We ran MONITOR for 4,998 scenarios corresponding to different combinations of parameters, 3,822 for the protected area (76%), and 1,176 for neighboring sheep ranches (24%).

Proportion of zeros and performance of visitation indices

Inside the protected area, visitation indices derived from the operation of bait stations during 2 or 3 days showed a tendency to have a lower proportion of zero values. The mean proportion of lines without visits was highest for index 1 (0.61 for culpeo fox; 0.40 for gray fox) and lowest for indices 5 and 7 (culpeo fox 0.44–0.46; gray fox 0.21–0.22). Using index 5 instead of index 1 produced a maximum reduction in the mean number of zeros of 27% for culpeo fox and 48% for gray fox. However, index variance was high enough to preclude that differences in the proportion of zeros between visitation indices were significant (Kruskal–Wallis, $n=79$; culpeo fox: $H=8.04$, $p=0.235$; gray fox: $H=9.44$, $p=0.151$). Index variance was higher for culpeo fox than for gray fox; for all indices combined, the maximum CV was 2.8 and 1.7, respectively.

The positive effect of the proportion of zeros on index variance was highly significant, and it was adequately described by a linear relationship (culpeo fox: slope=1.99, $R^2=0.854$; $F_{1, 77}=456$, $p<0.001$; gray fox: slope=2.21, $R^2=0.850$; $F_{1, 77}=444$, $p<0.001$). Therefore, index variance was also lower for indices calculated as the mean rates of several consecutive nights or as if stations were checked after two or three nights (Table 2). The highest mean CV

Table 1 Mean and CV of visitation indices used as initial values to run simulations in MONITOR

	Periodicity	Season	Index	Culpeo fox		Gray fox	
				Mean	CV	Mean	CV
Protected area							
	1 year, 2 years	Spring	1	159	1.132	182	1.088
	1 year, 2 years	Spring	2	161	1.000	255	1.109
	1 year, 2 years	Spring	3	220	1.045	222	1.455
	1 year, 2 years	Spring	4	160	0.994	214	1.065
	1 year, 2 years	Spring	5	191	0.859	213	1.188
	1 year, 2 years	Spring	6	253	0.826	306	0.944
	1 year, 2 years	Spring	7	338	0.787	343	0.983
	1 year, 2 years	Fall	1	183	1.164	248	1.016
	1 year, 2 years	Fall	2	188	1.505	322	1.047
	1 year, 2 years	Fall	3	214	1.299	334	0.790
	1 year, 2 years	Fall	4	182	1.324	292	0.942
	1 year, 2 years	Fall	5	195	1.277	308	0.864
	1 year, 2 years	Fall	6	266	1.068	386	0.966
	1 year, 2 years	Fall	7	328	0.987	454	0.817
	6 months		1	202	0.842	132	1.492
	6 months		2	243	0.831	143	1.336
	6 months		3	297	0.660	189	1.016
	6 months		4	221	0.701	138	1.304
	6 months		5	247	0.595	156	1.147
	6 months		6	361	0.598	228	1.162
	6 months		7	499	0.451	314	0.911
Sheep ranches							
	1 year, 2 years	Spring	1	42	1.619	120	1.317
	1 year, 2 years	Spring	2	68	1.691	68	2.015
	1 year, 2 years	Spring	3	47	1.936	120	1.267
	1 year, 2 years	Spring	4	52	1.269	94	1.447
	1 year, 2 years	Spring	5	49	1.388	103	1.320
	1 year, 2 years	Spring	6	94	1.244	151	1.192
	1 year, 2 years	Spring	7	110	1.200	198	1.030

Values were obtained from a sample of surveys in the protected area (spring 1999, 2000, and 2001; fall 2000, 2002, and 2003) and in the sheep ranches (spring 2002 and 2005). Periodicity means time elapsed between successive surveys in the simulations

corresponded to index 1 (culpeo fox 1.79; gray fox 1.28) and the lowest to index 7 (culpeo fox 1.22; gray fox 0.77). Contrasts (Tukey test) indicated that for both species the mean CV of index 7 was significantly lower than those of indices 1–4.

The effect of the proportion of zeros on the variability of visitation indices varied across indices (interaction term in

Table 2). Mean CV of indices obtained after checking bait stations during two or three nights increased with the proportion of zeros at a lower rate than single-night visitation indices. For the culpeo fox, extreme differences occurred between slopes above 2.2 for indices 1 and 2 and slopes below 1.8 for indices 4 to 7. For the gray fox, maximum differences were found between slopes in the

Table 2 Analysis of covariance for the effect of visitation index and the proportion of bait station lines without fox visits (“zero”) on the CV in visitation indices

	Culpeo fox					Gray fox				
	SS	df	MS	F	p	SS	df	MS	F	p
Intercept	2.832	1	2.832	85.52	<0.001	2.386	1	2.386	106.35	<0.001
Index	0.440	6	0.073	2.22	0.053	0.609	6	0.102	4.53	<0.001
Zero	16.600	1	16.560	501.29	<0.001	12.037	1	12.037	536.65	<0.001
Index × Zero	0.563	6	0.094	2.83	0.016	0.785	6	0.131	5.84	<0.001
Error	2.152	65	0.033			1.458	65	0.022		

The interaction term tests for homogeneity of slopes of regression lines for seven different indices

range 2.1–3.1 for indices 1, 3, and 4 and slopes below 1.8 for indices 5 to 7. In both species, index 7 exhibited the best behavior, that is, lowest CV and lowest rate of increase of CV with the proportion of zeros.

Statistical power in selected scenarios

All else being equal, the lowest variation in the visitation index was expected to yield the highest statistical power. Since index 7 was the visitation index that exhibited the lowest variation, we used this index to illustrate the scenarios that allowed us to detect trends with high power. For this purpose, power values were classified into three classes: low (<0.76), high (0.76–0.85; i.e., around 0.8, which is considered an acceptable power; Steidl et al. 1997), and very high (>0.85).

Power was low in most of the 273 scenarios considered in Fig. 2. The proportion of scenarios with low power was higher for culpeo fox (0.72) than for gray fox (0.64;

$\chi^2_c = 3.36, df=1, p=0.067$). It was possible to achieve high power with any sampling effort in terms of number of lines (Fig. 2). However, for the culpeo fox, the proportion of high-power scenarios increased from 0.20 with 14 lines to 0.39 with 26 lines, while for the gray fox this proportion increased from 0.15 to 0.49 (main effect of number of lines, $F_{1, 10}=105.61, p<0.001$). The positive effect of the number of lines had a steeper slope for the gray fox (interaction species \times number of lines, $F_{1, 10}=20.28, p=0.001$; Fig. 2).

For the culpeo fox, the proportion of scenarios with high or very high power was 0.07 for simulations of annual surveys ($n=126$) and 0.14 for surveys performed every other year ($n=84$); these proportions did not differ significantly ($\chi^2_c = 2.12, df=1, p=0.146$). However, they were significantly lower than corresponding proportions in surveys carried out twice a year, in spring and fall (0.89, $n=63$; $G=147.11, df=2, p<0.001$; Fig. 2a). For the gray fox, the proportions of scenarios where estimated power was >0.75 in annual and biennial surveys were similar

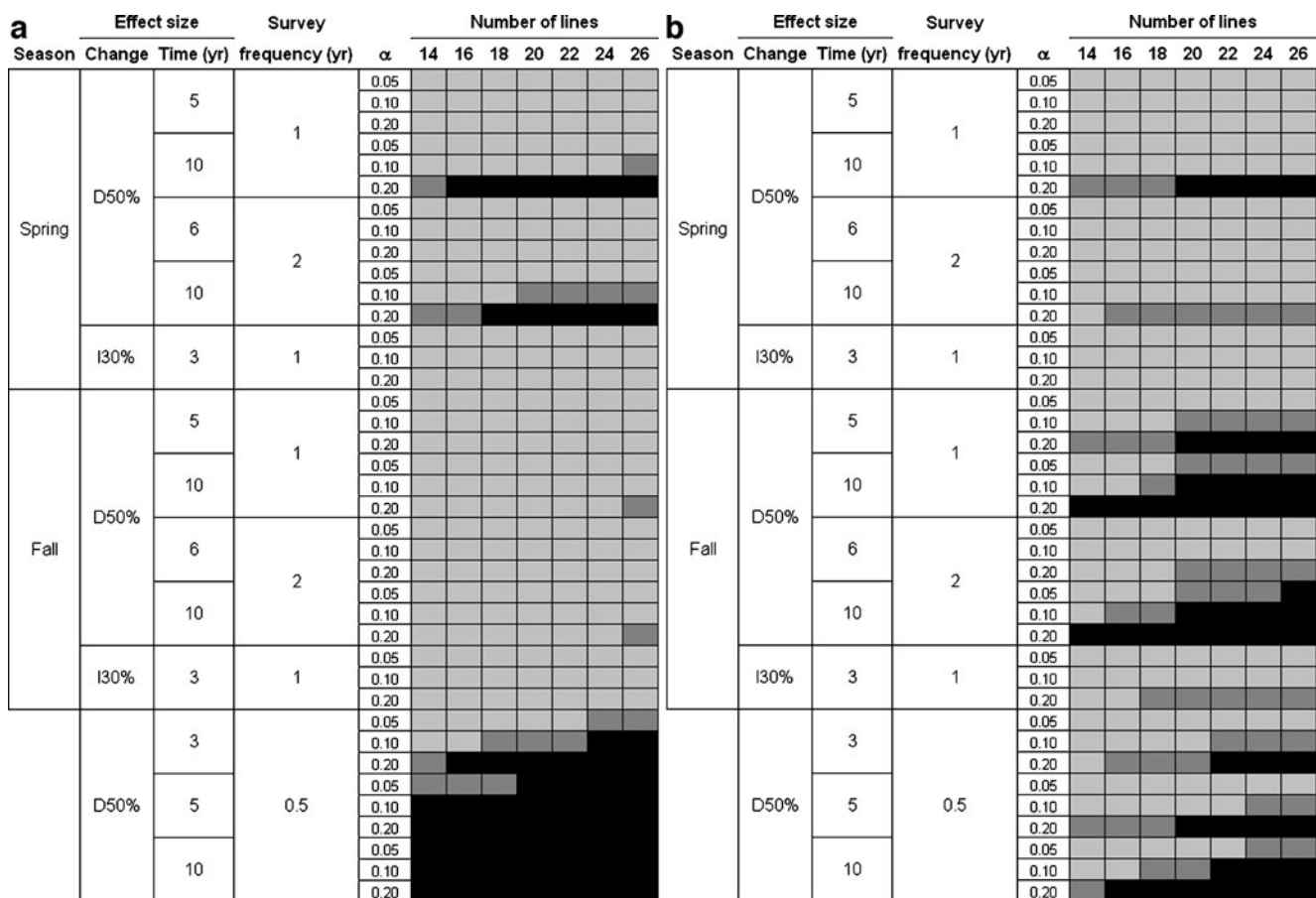


Fig. 2 Expected power for different scenarios of population change in **a** the culpeo fox and **b** the gray fox. We defined three classes of population change: (1) a 50% decrease in the visitation index over 5 years or over 6 years if surveys were conducted every other year, (2) a 50% decrease over 10 years, and (3) a 30% increase over 3 years.

Color indicates scenarios for which estimated statistical power was <0.76 (light gray), between 0.76 and 0.85 (dark gray), and >0.85 (black). Power analyses were made with visitation index 7, which simulates a single check after operating bait stations for 72 h

(0.31 and 0.32, respectively) and significantly lower than the proportion in biannual surveys (0.51; $G=7.71$, $df=2$, $p=0.021$; Fig. 2b).

If culpeo fox abundance was monitored twice a year, high power was attained regardless of variation in type I error (Fig. 2a). Using lower survey frequencies and setting $\alpha=0.05$ led invariably to low power, whereas high or very high power was expected in 7% of scenarios if $\alpha=0.10$ and 23% of scenarios if $\alpha=0.20$ ($G=19.11$, $df=2$, $p<0.001$; Fig. 2a). For the gray fox, the percentage of scenarios whose expected power was >0.75 increased from 11% if $\alpha=0.05$ through 28% if $\alpha=0.10$ to 69% if $\alpha=0.20$ ($G=74.08$, $df=2$, $p<0.001$).

For culpeo fox, it was not possible to detect a 30% increase of visitation index 7 over 3 years in any of the scenarios for the sheep ranches (Fig. 2a). A high or very high power was estimated inside the protected area for a 50% decrease over 5 years (6 years if surveys were performed every other year) in 20% of scenarios and over 10 years in 40% of scenarios (Fig. 2a). Differences in the fraction of scenarios with high power between these two temporal projections were significant ($\chi^2_c = 8.31$, $df=1$, $p=0.004$). Differences between the three effect sizes considered for the culpeo fox were significant too ($G=29.73$, $df=2$, $p<0.001$). For the gray fox, high power to detect a substantial population increase in the short term was possible in the sheep ranches (12% of scenarios; Fig. 2b). Inside the protected areas, the fraction of scenarios with high power to detect a population reduction notably increased by expanding the projected time from 5 or 6 years for surveys performed every other year (23%) to 10 years (57%; $\chi^2_c = 24.31$, $df=1$, $p<0.001$; Fig. 2b). Differences between the three effect sizes were also significant ($G=40.34$, $df=2$, $p<0.001$).

For culpeo fox, surveys in spring yielded high power in 18% of scenarios, a fraction significantly higher ($\chi^2_c = 13.54$, $df=1$, $p<0.001$) than the 2% we found for fall surveys (Fig. 2a). By contrast, high power was expected in 51% of fall scenarios for gray fox, and this percentage was significantly higher than the corresponding percentage of scenarios in spring (12%; $\chi^2_c = 33.61$, $df=1$, $p<0.001$).

Relative effects of components of monitoring on statistical power

Generalized linear models explained about 90% of the variance in statistical power for both fox species (Tables 3 and 4). All main effects were retained in the final models with the only exception of the survey frequency. That is, expected power was similar when simulations were run with visitation indices obtained either from annual surveys or from surveys carried out every other year. The effects we found in univariate analyses of power for visitation index 7

(Fig. 2) were, in general, reproduced when considering all indices and all effects together in a single model. It was clear that spring surveys of culpeo fox yielded higher power than surveys conducted in fall (Fig. 2). We found the opposite for gray fox (Fig. 2): power generally increased in fall but this increase was higher for indices 5–7 than for other visitation indices (Table 4). As expected, augmenting the effort in terms of number of lines improved power; this effect was more marked for gray fox (Table 4) than for culpeo fox (Table 3). For culpeo fox, the 0.8 threshold in power was rarely attained unless α was set to 0.20 (Table 3). For gray fox, however, an expected power of 0.8 could be obtained in many scenarios by setting $\alpha=0.10$ and in some scenarios by setting $\alpha=0.05$ (Table 4). Models corroborated that effect sizes of a 30–50% population change in the short term (3–6 years) yielded power values relatively similar between them and clearly lower than population changes projected in the long term (10 years). Finally, visitation indices that simulated a single checking of bait stations after 48 h (index 6) or especially 72 h (index 7) were associated with power values clearly higher than those of other indices. This distinction was sharp for culpeo fox (Table 3) and more gradual for gray fox, with intermediate power values obtained with indices that averaged the visitation rates of two or three nights (Table 4).

The magnitude of population change and the period over which change takes place (the effect size), as well as type I error, are factors that are arbitrarily defined by the researcher or the question of interest. For culpeo fox, these factors accounted for 73.1% of the variance in power that was explained by the model; the remaining 26.9% was accounted for by variables that can be manipulated as components of effort in the monitoring program. Among the latter, visitation index was the most important, contributing a further 13.9% of explained variance, either as a main effect or modulated by season or the number of lines in interaction terms (Table 3). For the gray fox, the attributes defined by the objectives of the monitoring program contributed less (47.3%) to the variance explained by the model (Table 4). Again, the effect of the type of index employed to describe population change, alone or interacting with season, had the highest influence among the components of monitoring effort (36.9% of explained variance).

Our models predicted that monitoring culpeos once a year or once every other year could reliably detect a population trend in the short term (3–6 years) only if surveys are conducted in the favorable season (spring), if type I error is set at the maximum value we allowed (0.20), and if at least 26 lines of bait stations are operated during three nights and checked after 72 h (index 7, Fig. 3). A 50% decrease in the population can be reliably detected in the long term with lower effort (Fig. 3).

Table 3 Generalized linear model of power to detect population trends of culpeo fox

Predictor ^a	Estimate	SE	<i>F</i>	<i>df</i>	<i>p</i>	% exp ^b
Intercept	-1.452	0.019				
Type I error ^c $\alpha=0.20$			3,169.9	1,974	<0.001	46.92
Effect size			1,770.1	1,974	<0.001	26.20
Long term (10 years)	0.286	0.006				
Lines	0.019	0.001	548.5	1,974	<0.001	8.12
Season			328.6	1,974	<0.001	4.87
Fall	-0.067	0.007				
Index			768.2	2,975	<0.001	11.37
Index 6	0.141	0.046				
Index 7	0.350	0.046				
Lines \times index			5.4	2,971	0.005	0.08
Index 6	0.005	0.002				
Index 7	-0.001	0.002				
Season \times index				3,965	<0.001	2.43
Index 6	-0.188	0.018				
Index 7	-0.189	0.018				
R^2						89.37
Total variance 81.86						

^a Levels not shown are included in the intercept

^b Contribution (%) of each predictor to the total variance explained by the model

^c Two levels: $\alpha=0.10$ (intercept) and $\alpha=0.20$

Using visitation index 7, a 30% increase or 50% decrease of the gray fox population in the short term can be detected with lower effort (24 lines) and setting $\alpha=0.10$. Increasing type I error to 0.20 or the temporal framework of population change to 10 years would greatly reduce sampling effort if index 7 is used and would also

allow us to conduct surveys in springtime, in order to monitor both species simultaneously. Establishing these settings for the gray fox would also maintain the same spatial effort if other indices that require operating stations only during two nights were employed (e.g., index 6; Fig. 4).

Table 4 Generalized linear model of power to detect population trends of gray fox

Predictor ^a	Estimate	SE	<i>F</i>	<i>df</i>	<i>p</i>	%exp ^b
Intercept	-2.090	0.021				
Type I error ^c $\alpha=0.10$			910.6	1,971	<0.001	22.73
Effect size			982.7	1,971	<0.001	24.53
Long term (10 years)	0.384	0.008				
Lines	0.035	0.001	556.2	1,971	<0.001	13.88
Season			77.1	1,971	<0.001	1.93
Fall	-0.023	0.014				
Index			871.7	4,976	<0.001	21.76
Index 4	-0.016	0.017				
Index 5	-0.059	0.017				
Index 6	0.151	0.017				
Index 7	0.347	0.017				
Season \times index			1,617.5	4,966	<0.001	15.17
Index 4	0.206	0.024				
Index 5	0.449	0.024				
Index 6	0.384	0.024				
Index 7	0.332	0.024				
R^2						91.70
Total variance 153.85						

^a Levels not shown are included in the intercept.

^b Contribution (%) of each predictor to the total variance explained by the model

^c Two levels: $\alpha=0.05$ (intercept) and $\alpha=0.10$.

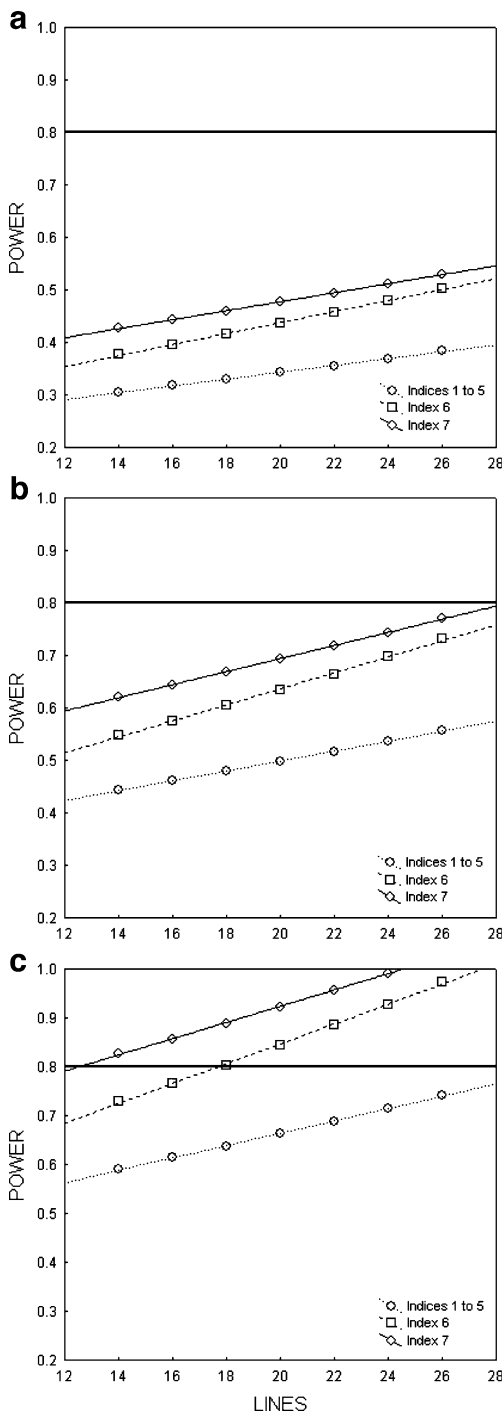


Fig. 3 Predicted power for selected scenarios of population change in the culpeo fox from visitation indices obtained during spring surveys. **a** Short term (5 years), $\alpha=0.10$. **b** Short term (5 years), $\alpha=0.20$. **c** Long term (10 year), $\alpha=0.20$

Discussion

A threshold in power around 0.8 to discriminate between suitable and unsuitable scenarios may be reasonable for species that do not face serious conservation problems

(Thomas and Juanes 1996; Hayes and Steidl 1997; Steidl et al. 1997). Although heavily persecuted, gray fox and culpeo fox may fall in this category as they occupy large geographic ranges (Redford and Eisenberg 1992), are locally abundant, exhibit high reproductive rates (Novaro

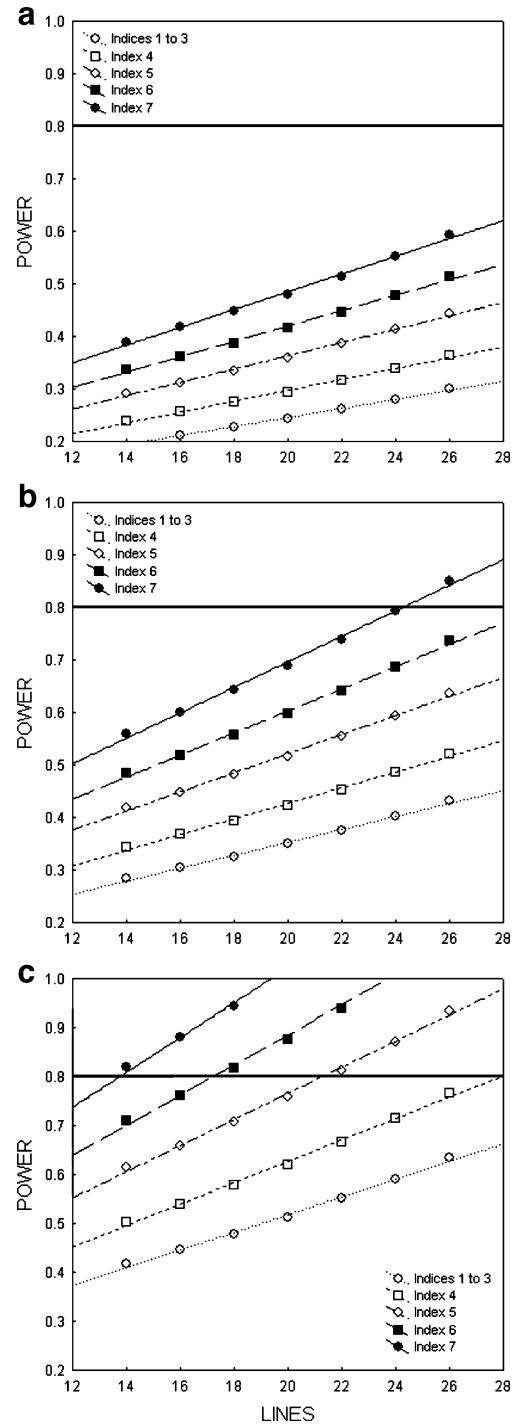


Fig. 4 Predicted power for selected scenarios of population change in the gray fox from visitation indices obtained during fall surveys. **a** Short term (5 years), $\alpha=0.05$. **b** Short term (5 years), $\alpha=0.10$. **c** Long term (10 years), $\alpha=0.10$

1997b), and have demonstrated a high potential for quick recovery after severe population decline (Ojeda and Mares 1982; Mares and Ojeda 1984; Novaro 1993, 1997b; Novaro et al. 2005). On the other hand, setting a higher threshold for statistical power would probably imply logistical and budgetary constraints that would compromise the practical implementation of the monitoring program. We relaxed type I error up to a maximum of $\alpha=0.20$. When testing the null hypothesis of absence of fox population decline in protected areas, from a conservation standpoint, a false alarm (type I error) is more tolerable than the consequences of failing to detect a population crash (Thompson et al. 1998; Elzinga et al. 2001).

Performance of visitation indices

Minimizing the average number of zeros in visitation indices by choosing the less zero-prone index was more effective for the gray fox (48% reduction of zero values) than for the culpeo fox (26% reduction). Moreover, maximum values of the CV for any index were higher for culpeo fox than for gray fox. Since the number of zeros was strongly correlated with index variance and index variance affected power, index behavior predicted that it will be more difficult to detect a trend for culpeo fox than for gray fox.

As recommended by Roughton and Sweeny (1982), scent stations and bait stations have been operated just for one night in most studies (Linscombe et al. 1983; Smith et al. 1994; Travaini et al. 1996; Sargeant et al. 1998). Single-night operation may restrict the chances of individuals to encounter at least one station during its activity period that particular night, especially if their home ranges are large compared with station spacing. This contributes to the decrease in visitation rates within lines and to the increase in the number of lines without visits. In turn, zeros may greatly inflate the variance in visitation rates and reduce the power of bait stations to detect a population trend. The absence of visits in some lines may also reflect gaps in the distribution of animals, but variance inflation in visitation rates due to spatial heterogeneity in territory occupancy is unavoidable. The amount of zeros due to short exposure of stations, however, can be minimized. All visitation indices computed with records obtained during more than one night had the purpose of reducing the proportion of lines not visited and the variance of the index by extending the period of exposure to stations. The operation of bait stations during several nights increases monitoring effort but also helps to increase statistical power. Moreover, in periods with favorable weather (dry and calm), bait stations could be checked only once after three consecutive nights, and total field effort would be the same as that of a single-night operation.

The probability of contagion in visits has been emphasized for adjacent stations or even clustered lines (Sargeant et al. 1998). Temporal contagion is also likely since individuals may visit a station with higher probability if they have previously obtained a bait as a reward. Neutral or negative reactions to baits might also be possible, and lines operated during successive nights may not constitute independent trials. However, visitation indices, regardless the way they are derived, are estimates of relative abundance. The fundamental assumption for the validity of the index to detect changes in fox abundance is that detectability and the average response of individuals (frequency of attraction or reluctance to baits after the first encounter) remain reasonably constant between surveys. To our knowledge, this assumption has not been tested in the context of bait station methodology.

Statistical power in selected scenarios

Power was low (<0.76) in most scenarios for both species even when we employed the visitation index that showed the lowest variance. To save space, we have not reported the results for other indices, including the widely used index 1. Their performance was even worse than that for index 7, i.e., power <0.76 was expected in a higher proportion of scenarios.

High power could be achieved with any number of lines between 14 and 26. This removes unavoidable spatial restrictions due to road availability and therefore proper line spacing, as a limiting factor for monitoring population trends in the MNBP.

For culpeo fox, high power was common in biannual surveys, but it also was restricted to a few scenarios (projections over 10 years and $\alpha=0.20$) if survey frequency was lower. Survey frequency was less influential for achieving high power in the gray fox. The annual peak of gray fox density usually occurs in fall, during juvenile dispersal and before winter mortality. High fox density might result in higher visitation rates with lower variability, and our results support this expectation. The opposite was observed for culpeo fox, and we have no clear explanation for this. A possibility is that the continuous decrease in visitation rates observed for this species throughout the study period could have masked the expected pattern.

Relative effects of components of monitoring on statistical power

The components of the monitoring program that were directly related to sampling effort explained a substantial fraction of the expected power to detect population trends in both fox species. Among these components, it was particularly relevant choosing a visitation index whose

statistical properties included a relatively low variance. In this regard, index 6 (a single check after 48-h operation) and especially index 7 (one check after 72 h) showed the best behavior and performed much better than the other indices, including index 1 (one check after 24 h) which is widely used in scent station and bait station surveys of many carnivores (Sargeant et al. 1998). The superior performance of index 7 seems to be density dependent. Outside the protected area, where average fox densities tend to be lower, a higher proportion of lines received no fox visit, and variance in visitation indices increased. As a result, obtaining a given power to detect fox trends in sheep ranches requires considerably more effort than inside the national park. Despite variation of index performance in areas subjected to different management regimes, the relative properties of visitation indices may be general and deserve consideration in bait or scent station surveys, as suggested by Conner et al. (1983) who found that operating scent stations during several nights improve abundance estimations of low-density carnivores. Wherever maximizing power will be an objective, researchers may want to consider an increase in the operation time of stations while keeping sampling effort constant.

A monitoring program for Patagonian foxes

Setting type I error to $\alpha=0.20$ allows reliable monitoring (power > 0.76) of both fox species in the short term (5 years) as long as 24 bait station lines are operated and visitation index 7 is used. With this design, similar power is expected if surveys are performed either every year or every other year. To save resources, surveys can be made only in spring which enhances power for culpeo fox, while increasing the number of lines will compensate any eventual loss of power for gray fox associated with spring surveys.

Based on MONITOR simulations, we suggest the following recommendations:

Inside the protected area

- (a) To detect a 50% decrease in 5 years or a 30% increase in 3 years for both species, spring surveys can be conducted every other year, activating 26 lines and keeping $\alpha=0.20$. Visitation indices 6 or 7 should be used, although the latter is preferred.
- (b) To detect a 50% decrease in 10 years, spring surveys could be conducted biennially, activating 18–20 lines and with $\alpha=0.20$ for both foxes. Visitation indices 6 or 7 are recommended.

Outside the protected area

- (a) Bait stations could not be used to reveal any substantial increase in culpeo fox numbers in the short term. To detect a 30% increase in 3 years with high

power, at least 26 lines should be operated twice a year, with $\alpha=0.20$ and using index 7. Clearly, this is not a viable alternative for sheep ranchers or wildlife management authorities in Santa Cruz. Nevertheless, the importance of early detection of fox increase, the concomitant ability to use selective control methods, and thereby enhanced protection of nontarget species deserve further attention.

Management implications

The monitoring program we propose may be applied to other protected areas and abandoned ranches over southern Patagonia, in order to detect fox population declines due to extractive or control activities in neighboring ranches. Our study involved about 100,000 ha of sheep ranches. Nevertheless, Santa Cruz province covers 25 million hectares. The use of predictive models of fox occurrence (cf. Travaini et al. 2007) should be a valuable tool for identifying representative areas where monitoring should be more efficient.

On the other hand, since methods of fox control used by sheep ranchers are not selective and have important side effects on nontarget species of conservation value (Olrog 1980), detecting an increase of low magnitude in fox abundance, as a signal for a potential positive trend in the long term, is important for wildlife agencies to anticipate a prescribed control with selective methods. Furthermore, it is important to detect a positive trend early, before the magnitude of damage to lambs will be considered unacceptable by ranchers. However, bait stations seem to be a weak method to detect, timely and with high power, a population increase as large as 30% in sheep ranches, especially for culpeo fox. In the ranches of our study area, this could be due in part to the fact that culpeo fox densities were lower than inside the national park, making higher the proportion of lines without visits, increasing the variance of visitation indices and, therefore, reducing power. To achieve an early detection of positive trends, the power of monitoring programs based on alternative indices, such as fecal density counts (Cavallini 1994; Webbon et al. 2004), spotlight counts (Ruelle et al. 2003; Sobrino et al. 2009), and culling indices (Hewson and Kolb 1973; Myrberget 1988; McDonald and Harris 1999), should be tested.

Simultaneous monitoring in adjacent protected and farmland areas may allow the integral management of fox populations subjected to spatial heterogeneity in mortality levels or in resource availability that translates into other population parameters. In a context of source–sink dynamics, a decreasing trend in the protected area, but not in sheep ranches, might draw attention to fox control levels in

ranches if these act as attractive sinks (Delibes et al. 2001; Robinson et al. 2008; Dexter and Murray 2009). The operation of other processes could also be suspected. For example, a severe reduction of food in ranches could lead to crowding effects in the protected area, as has been suggested for other taxa after substantial habitat removal (Hagan et al. 1996). Finally, similar monitoring approaches could be useful to manage the widespread predator–livestock conflict, as long as predator populations occupy refuges or constitute conservation targets (Herfindal et al. 2005; Fleming et al. 2006).

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