THE IMPACT OF FOX AND FERAL CAT PREDATION ON THE POPULATION VIABILITY OF THE THREATENED, ENDEMIC SOCOTRA CORMORANT ON SINIYA ISLAND, UNITED ARAB EMIRATES

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SUMMARY

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Seabirds are vulnerable to a variety of threats occurring at breeding colonies, including disturbance, habitat degradation and predation from terrestrial predators. Socotra Cormorants *Phalacrocorax nigrogularis* are threatened, regionally endemic seabirds restricted to the Arabian Gulf and Gulf of Oman regions. Populations have been collapsing throughout their range, mostly in response to habitat loss from oil exploitation and disturbance at breeding sites. Almost half of the historically abundant colonies have disappeared, and the global breeding population has suffered catastrophic declines over the last 30 years. Siniya Island, Umm Al Quwain, hosts the largest colony in the United Arab Emirates with an estimated 15 500 breeding pairs. Predation by feral cats *Felis catus* and native red foxes *Vulpes vulpes* constitutes a major threat to this colony. We simulated population trends under different mortality levels using the software Vortex. The baseline model was parameterized using data on Socotra Cormorants or other cormorant species. Simulation of the baseline model showed a gradual increase in population, assuming carrying capacity of Siniya Island was 50 000 individuals. Compared with the baseline, within 50 years, a mortality of 900 individuals per year would reduce the population to fewer than 5 000 breeding pairs; mortality of 1 800 or 2 000 individuals per year would reduce the population to a few hundred pairs. Populations were more susceptible to adult mortality in all mortality scenarios (900, 1 800, and 2 000 individuals/year), leading to reductions to near-extinction levels. Our estimates of predation-related mortality were conservative, and the trends implied by the population model could potentially be catastrophic to the species. Eradication of feral cats and red foxes is recommended as a management tool to ensure long-term survival of this colony.

INTRODUCTION

Predation from terrestrial mammals, including introduced predators such as feral cats *Felis catus* or native predators such as foxes *Vulpes* spp., constitutes an important threat to seabird colonies, resulting in high annual mortality in the order of hundreds of thousands of seabirds (Sklepkovych & Montevecchi 1996, Keitt *et al*. 2002, Lavers *et al*. 2010, Medina *et al*. 2011, Towns *et al*. 2011). Life history traits such as long reproductive cycles, delayed maturity and low productivity make seabirds especially vulnerable to predation, and populations can be decimated in relatively short periods (Lavers *et al*. 2007, 2010; Medina *et al*. 2011, Mulder *et al*. 2011). For instance, periodic presence (once every two years) of Arctic foxes *Alopus lagopus* on the Gannet Islands (Labrador, Canada) resulted in the estimated abandonment of over 2 500 nests of Razorbills *Alca torda*, which represented more than 25% of the breeding population (Birkhead & Nettleship 1995). Jones (1977) estimated that 47 000 Antarctic Prions *Pachyptila vittata* and 150 000 White-headed Petrels *Pterodroma lessoni* were killed by feral cats on Macquarie Island. As high mortality from predation is known to have negative demographic consequences (Lavers *et al*. 2010), introduced predators have been systematically eradicated from many seabird colonies (Medina *et al*. 2011, Towns *et al*. 2011). Additionally, removal of native predators, such as Arctic foxes, has been practiced on some colonies to ensure the survival of threatened seabird species (Birkhead & Nettleship 1995, Rowe & Jones 2000, Lavers *et al*. 2007, 2009).

Socotra Cormorants *Phalacrocorax nigrogularis* are a globally Vulnerable cormorant species endemic to the Arabian Gulf and Gulf of Oman regions (BirdLife International 2010, Jennings 2010, EAD 2012). Breeding populations are declining globally, including colonies within the United Arab Emirates (Jenning 2010, Wilson 2012). The current global population is estimated at 110 000 pairs, with about 34% of the population occurring in the United Arab Emirates (UAE). Primary threats to the species include destruction or modification of colonies for oil exploitation, direct human disturbance, fishing line entrapment, predation by feral cats and red foxes (*V. vulpes*) and oil spills (Jennings 2010, Muzaffar *et al*. 2012). Feral cats have been reported on offshore islands in Abu Dhabi emirate and are regarded as a threat to nesting seabirds (Jennings 2010). Red foxes, on the other hand, are expanding in distribution throughout the region but have not been reported on any of the seabird colonies in UAE (EAD 2012). Since the species is native to UAE, their presence on islands with breeding Socotra Cormorants could introduce a wildlife management dilemma, since foxes are categorized as Least Concern by the World Conservation Union (IUCN 2008) while the Socotra Cormorant is Vulnerable (BirdLife International 2012). Since the species is declining rapidly (Jennings 2010), establishing the threats and their relative impacts on population persistence is of direct conservation value (Muzaffar *et al*. 2012).

Socotra Cormorants typically nest in gravel or sandy islands in large groups – sometimes with numbers exceeding tens of thousands of individuals (Jennings 2010). As open-ground nesters, parent cormorants generally meet any non-avian threat by departing, rather than through defensive aggression (Frid & Dill 2002, S.B. Muzaffar, unpublished data). The altricial chicks are defenseless against terrestrial predators. Historically, this vulnerability was less of a problem, as the natural breeding colonies did not include terrestrial predators of any type (Jennings 2010). However, feral cats and foxes are now established on Siniya Island, located off the coast of the Emirate of Umm Al Quwain (S.B. Muzaffar, unpublished data). This island is located close to the Umm Al Quwain shoreline, and temporary land bridges may form during low tide, allowing natural introduction of foxes to the island. The feral cats were introduced to the island when the Umm Al Quwain Municipality initiated management of the island in the 1980s. Socotra Cormorants may have been exposed to, and may have adapted to, terrestrial predators for at least a few decades, but there are no data on whether these predators were responsible for declines in the species. Predation by meso-predators such as foxes and cats may result in higher mortality rates, with the potential of long-term population collapse (Keitt *et al*. 2002, Lavers *et al*. 2007, Keitt *et al*. 2011, Medina *et al*. 2011, Towns *et al*. 2011). Thus, determining the effect of cat and fox predation on population viability on this colony is of great conservation value.

Population viability analyses have been used extensively in evaluating the impact of a variety of factors on seabird and other populations (Lacy 1993; Lavers *et al*. 2009, 2010). In the absence of long-term data on many seabird species, population viability analyses could help in prioritizing conservation action for threatened species (Lavers *et al*. 2009). To this end, we carried out population viability analyses with the following objectives: (i) to determine mortality of Socotra Cormorants due to fox and feral cat predation and (ii) to determine the effects of such mortality on population persistence using a stochastic population model.

STUDY AREA

Siniya Island, Umm Al Quwain, UAE (25°36′20.63″N, 55°36′28.85″E, Fig. 1) hosts the largest known colony of breeding Socotra Cormorants in the UAE, with a recorded 15 500 breeding pairs in 1995 (Jennings 2010). Located about 2 km northeast of the old town area of Umm Al Quwain, the island is surrounded by shallow water with areas of high sediment deposit. Tidal inlets are found around the island, as are several large lagoons containing shallow, muddy water. The colony of Socotra Cormorants is restricted to the north-central part of the island. The habitat consists of mixed desert scrub, loose sandy gravel, and plantations of *Prosopis juliflora* and *Acacia* spp. The periphery of the island is covered with mangroves *Avecennia marina*, occurring in patches, or *Haloxylon-Arthrocnemum macrostachyum* scrub complex bordering the edges throughout the island. Three individual foxes and three individual feral cats were recorded during the course of 2011 breeding season, although the island is large enough (approximately 26 km^2) to hold a much larger population of foxes and feral cats (MacDonald *et al*. 1999, Goszczyński 2002, Harper 2004).

METHODS

Estimation of predation rates

Six 200 × 10 m transects were selected in areas adjacent to the colony, near the scrub border. These areas were chosen because they were immediately outside the colony boundary and had evidence of predation. Transects were widely distributed on the north, southwest and southeast parts of the colony to limit disturbance to the colony. They were walked during two months of the breeding season (October 24, 26, and 31, and November 14, 20, and 27, 2011), and all dead birds with signs of obvious fresh predation (e.g., bite marks or partially consumed carcass) were counted. We tallied all the counts for the period and calculated daily mortality rates per square meter for the period based on mean numbers per transect. We calculated the area of scrub border and surrounding areas adjacent to the colony that were likely to have dead birds from predation using GPS points plotted on Google Earth. Scale templates were overlaid onto the Google Earth map, and total scrub border area was calculated using the offset method (Patton 2010), which gave an accurate total scrub area measurement. We then estimated total mortality by extrapolating the mortality rates to include the entire nesting, chick-rearing and fledging period (August–December) and multiplying that by the areas with dead birds. We independently determined mortality due to predation by calculating the mean number of cormorants that could be killed by three foxes and three cats (total minimum number of predators observed during the study

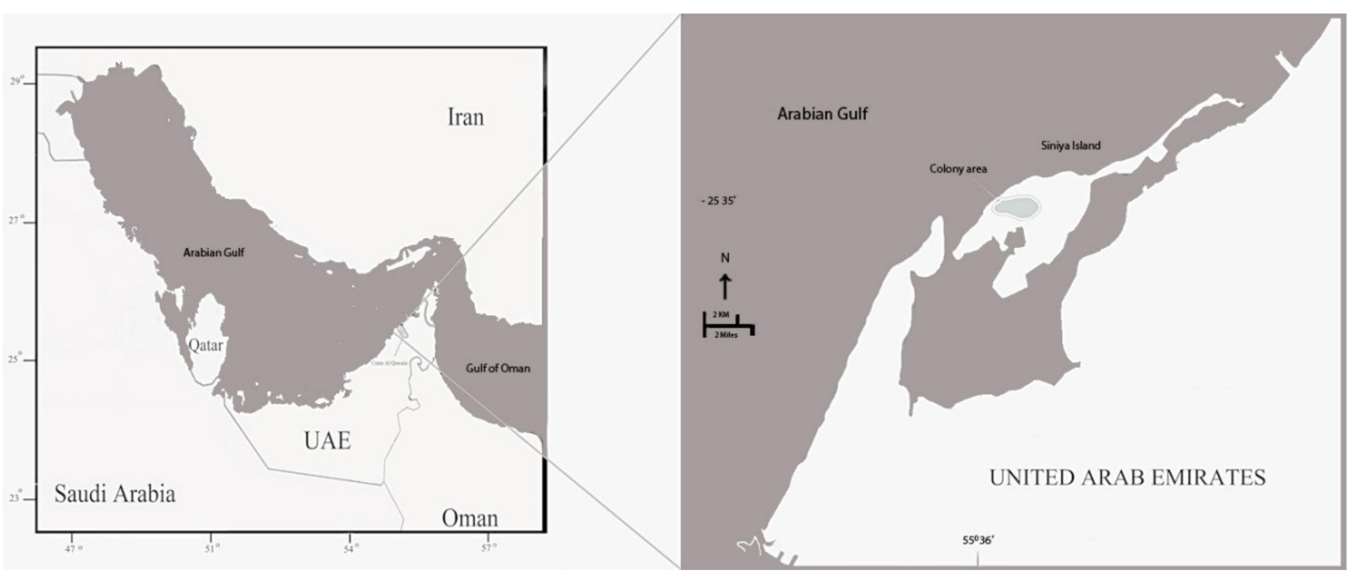

Fig. 1. Map of Siniya Island, Umm Al Quwain, showing the approximate location of the breeding colony in 2011.

period) based on estimates of fox and cat dietary requirements from the published literature. Red foxes may eat between 0.27 and 0.85 kg/d, depending on body size and food availability (Golighty *et al*. 1994, Webbon *et al*. 2004). We used the mean size of 3.1 kg for foxes in the Middle East (MacDonald *et al*. 1999). Similarly, feral cats could consume between 0.32 and 0.527 kg/d (Keitt *et al*. 2002). We used a mean weight of 2.7 kg based on published weights of insular feral cats (King 1990). The following allometric equation was used to calculate the daily biomass required by small mammals (Nagy 1987): $b = 3.35\ (2.86/18)\ (\text{weight})^{0.813}$, where b = biomass in kilograms.

We assumed that 90% of the diet of cats and foxes consisted of Socotra Cormorants, on the basis of the literature (Kelly 2000, Mulder *et al*. 2012). We assumed that foxes consume 30% of a carcass (foxes consumed only the breast meat in all examined kills, pers. obs.), and cats consume 50% (Keitt *et al*. 2002).

The number of birds captured (*Nc*) was then estimated using the following equation (Nagy 1987):

$Nc = b(153)/(\text{proportion eaten})(\text{weight})$, where 153 = number of days that breeding birds and chicks were assumed to be present on the island, based on the 2011 nesting season. We did not estimate additional kills made by foxes or feral cats that were hoarded or not eaten (Sklepkovych & Montevecchi 1996, Mulder *et al*. 2012).

Population viability analysis

We used Vortex software (ver 9.99; Lacy 1993) to model the impact of fox/cat predation on extinction probability of Socotra Cormorants. We parameterized the model using our data (Muzaffar *et al*. 2012) and best estimates from other cormorant species (Nelson 2005, Harris *et al*. 1994; Table 1). Vortex uses a stage-structured model to determine population persistence (Lacy 1993). Age classes were divided into 0–1, 1–2, and > 2 years (breeding age) based on other cormorant species (Nelson 2005). Mortality of 0–1-year-old birds was set at 39%, 1–2-year-old birds at 13% and > 2-year-old birds at 10% based on Great Cormorants (Nelson 2005). Clutch size (1–3), fledging success (1.34/nest) and proportion of nests with a given number of fledglings (e.g. 1, 2 or 3) were taken from Muzaffar *et al*. (2012). Since mortality estimates in Vortex are entered as percentages for different age categories, the subsequent reduction of egg and chick mortality (less than one year old) was not modeled. Sex ratio was assumed to be 1:1, and maximum age at breeding was set at 10 years (Nelson 2005). We used these parameters for the baseline model, assuming no mortality due to fox or cat predation. We imposed additional mortality due to predation based on the estimated mortality for the breeding season by creating three discrete scenarios (henceforth referred to as alternate scenarios), namely: 2000 kills/season (based on estimated mortality from transects), 1800 kills/season (based on predator energetic requirements) or 900 kills/season (arbitrarily chosen

TABLE 1
Key parameters and sensitivity analyses used to model population change in Socotra Cormorants on Siniya Island, UAE[a]

Parameter	Estimate for baseline model[b]	Range for sensitivity analyses	Source
Initial population size	31000	—	Jennings 2010
Sex ratio (assumed)	1:1	—	Nelson 2005
Number of broods	1	—	Muzaffar *et al*. 2012, Jennings 2010
Clutch size	1 to 3		Muzaffar *et al*. 2012
Proportion of clutches with 1, 2, 3 eggs (%)	35, 55, 10		Muzaffar *et al*. 2012
Mortality rates			
Ages 0–1 (%)	40		Muzaffar *et al*. 2012
Ages 1–2 (%)	13	20 30 40	Harris *et al*. 1994
Ages 2+ (%)	10	20 30 40	Nelson 2005
Maximum age at breeding (estimated)	10 years		Nelson 2005
Carrying capacity (estimated)	50000		This study
Mortality (per season)			
Scenario 1		900	
Scenario 2		1800	
Scenario 3		2000	

[a] Sources could include other cormorant species.

[b] No mortality from predation was assumed in the baseline model.

value approximately half the mortality of the lower estimate). We also tested the sensitivity of population persistence, under baseline parameter values and the alternate scenarios, to varying levels of mortality in different age classes. That is, we altered the proportions of mortality for each age class under each of the three scenarios (Table 1). The initial population size was set at 30000 breeding birds (from Jennings 2010, estimated in 1995). The carrying capacity of the island was set at 50000 individuals based on the observation that additional habitat was present on Siniya Island that could support a 40% increase in the population. We modeled the population for 50 years using 1000 simulations.

RESULTS

Predation rates

We recorded 29 individual kills (27 adults, 2 chicks) over a period of 35 days covering 12000 m^2 of transects (Table 2), which represented 6.3% of the total available area (190558 m^2) over which predation could be detected. Individual transects differed both temporally and spatially in the number of kills recorded, with a general trend of higher number of kills early in the season. The spatial variability was incorporated into the estimation of daily mortality rate (Table 2). The total number of birds killed by either foxes or cats was estimated to be 2013 individuals for the entire season. We estimated a total of 1883 birds (Golighty *et al*. 1994, Keitt *et al*. 2002, Webbon *et al*. 2004) for the entire period based on the presence of three foxes and three cats, which is comparable to the numbers estimated from the transects (approximately 2000 kills). Thus, we conservatively estimated the total kill arising from fox or feral cat predation to be 1800 birds for the 2011 breeding season.

Population viability analyses

The baseline model had a stochastic growth rate (*r*) of 0.004 (SD±0.032, Table 3) and assumed no mortality from fox or cat predation. The model showed a gradual rise in the population over the 50 years of simulation, with no chance of extinction (Fig. 2). The alternate models with 900, 1800 and 2000 birds predated/season showed different levels of population decline characterized by a fall in the stochastic growth rate (Fig. 2, Table 3). A kill rate of 900 kills/season resulted in substantial decline, with the population reduced to 2816±446 individuals within 50 years (Fig. 2). Fox predation rates of 1800 kills/season or more reduced the population to fewer than 10000 individuals in 10–15 years and fewer than 700 individuals in 50 years. Sensitivity analyses showed that populations were more vulnerable to decline when adult mortality was high (Fig. 3). Population simulation with high juvenile mortality but low adult mortality showed gradual declines,

TABLE 2
Bird kills recorded on transects and estimates of total kills

Date	Kills (all transects)	Estimate kills/ season/m^2
24 Oct	16	0.001333333
26 Oct	0	0
31 Oct	3	0.00025
14 Nov	9	0.00075
20 Nov	0	0
27 Nov	1	8.3333×10^{-5}
Total kills	29	0.002416667
Total area of transects, m^2	12000	
Area (predation), m^2	190558	
Mortality rate/m^2 (season)	0.01056	
Estimated total mortality (individuals: entire season)	2013	

TABLE 3
Comparison of instantaneous growth rate (r) and finite growth rate (λ) under baseline and alternate scenarios (900, 1800 or 2000 kills/season)

Scenario, number of kills/season	Stochastic *r*	SD	Estimated λ
Baseline	0.004	0.036	1.00400759
900	-0.048	0.039	0.95313853
1800	-0.079	0.041	0.92404749
2000	-0.108	0.047	0.89763765

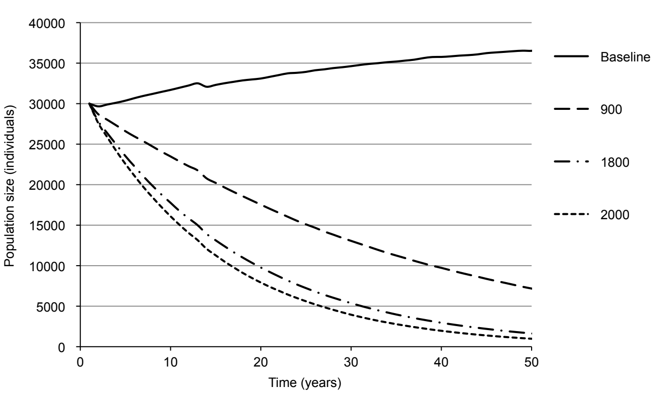

Fig. 2. Comparison of population trajectory under different overall mortality levels (900, 1800, or 2000 kills/season) with high juvenile mortality relative to adult mortality.

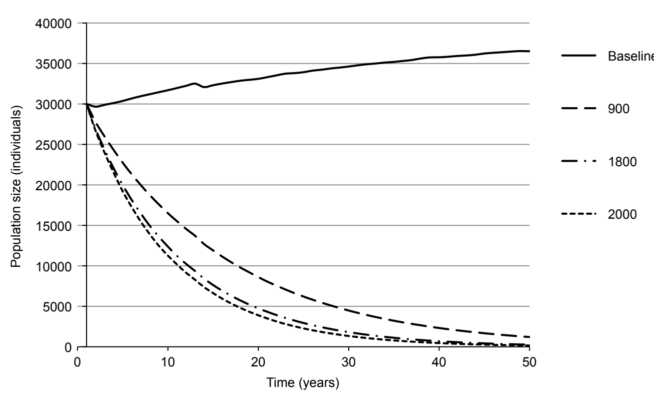

Fig. 3. Comparison of population trajectory under different mortality levels (900, 1800, or 2000 kills/season) with high adult mortality relative to juvenile mortality.

with a final population of 6961±1968 individuals after 50 years. Population simulations with 1800 and 2000 kills/season with high juvenile mortality also declined rapidly and had populations of approximately 10000 individuals within 20 years of simulation. Simulations of populations, with 900 kills/season having high adult mortality, were comparable to the populations with 1800 and 2000 kills/season with high juvenile mortality. Simulations for populations with greater than 1800 kills/season with high adult mortality were reduced to fewer than 10000 individuals within 13–14 years. The numbers were projected to decline to 239 individuals within 50 years.

DISCUSSION

Estimation of mortality from foxes and feral cats

Ground-nesting seabirds are especially vulnerable to predation, and this could result in substantial declines in populations (Schreiber & Burger 2002, Lavers *et al*. 2010, Mulder *et al*. 2012). Foxes can eat up to 0.85 kg/d (Webbon *et al*. 2004), which could involve predation of many individual seabirds (Sklepkovych & Montevecchi 1996). The diet of the red fox in the UAE consists of rodents and insects, with lesser percentages of hare, birds and reptiles (Stuart & Stuart 2003). Foxes in Saudi Arabia are reportedly small (~3.1 kg) compared with those of more northern latitudes, and this may represent an adaptation to extremely hot, dry environments (MacDonald *et al*. 1999). However, the species is opportunistic and is capable of hunting larger prey (Croft & Hone 1978, Jędrzejewski & Jędrzejewski 1992). Furthermore, the foraging behavior of the red fox is flexible, and, in situations with a superabundance of prey (e.g. in a seabird colony), the number of kills could increase several-fold (Birkhead & Nettleship 1995, Skelpkovych & Montevecchi 1996, Mulder *et al*. 2012). We observed foxes eating only the neck and breast meat of Socotra Cormorants, which represented approximately 30% of the total body weight (S.B. Muzaffar, unpublished data).

Similarly, the diet of feral cats generally includes small rodents and birds (Tidemann *et al*. 1994), and in seabird colonies can consist almost entirely of birds (Keitt *et al*. 2002, Peck *et al*. 2008). Overlapping distributions of feral cat and red fox diets result in feral cats preying on the young of an abundant prey whereas the larger foxes prey on adults (Catling 1988). During the Socotra Cormorant breeding season, carcasses of larger adults and fledglings were assumed to be fox kills while those of smaller chicks were assumed to be feral cat kills (both inferred from spoor around kills and bite marks), although this assumption needs to be validated with diet studies and observation of predation. The combination of the two predators could be detrimental to the breeding population of seabirds on an island, with the possibility of complex interactions (Russell & Le Corre 2009, Mulder *et al*. 2012).

In addition, foxes are known to hoard food using two distinct strategies. Larder hoarding involves a large number of prey hoarded in a limited number of locations clustered near the areas with high predation (Sklepkovych & Montevecchi 1996). Scatter hoarding involves placement of a much smaller number of prey over a wider area within the territory of the fox. Although we did not estimate the number of carcasses in hoards, we observed foxes hoarding food items during the study, mostly in larder hoards. Sklepkovych & Montevecchi (1996) recorded over 1000 individual seabird caracasses in fox hoards in a temperate seabird colony studied over a two-year period. This behaviour has the potential to further increase the mortality from fox predation. Additionally, we had very few chicks in our samples, partly because chicks were completely removed from the environment at a faster rate than adults (S.B. Muzaffar, unpublished data). Mortality estimates from cat predation were well within the limits observed in other studies (Keitt *et al*. 2002, Harper 2004). Thus, our estimate of predation of approximately 1800 birds (from three foxes and three feral cats) was likely an underestimate, since chicks were under-represented in the transect samples, partial consumption of carcasses was not used to validate the estimate, and fox hoarding behavior was not taken into account. Nevertheless, we consider the mortality estimates to be realistic and informative for population-level analyses.

Population viability analyses

We recognize that population viability analyses are inaccurate predictors of population trends in the absence of population parameter estimates (Lacy 1993). However, our approximation of survival of juveniles and adults from other species of cormorants was used to predict future trends of Socotra Cormorants. The estimates of egg and chick mortality were those observed in the current year (Muzaffar *et al*. 2012), and we lack other data to determine interannual variation of these parameters of this species. However, since the egg and chick mortality reported in Muzaffar *et al*. (2012) were well within the estimates for many other species of cormorants (Nelson 2005), we considered these parameter estimates to be reliable.

The baseline model showed a very gradual increase in the population in the absence of fox or cat mortality (Table 3). However, the stochastic r and lambda estimates declined as fox and feral cat predation increased, corresponding to declines in population size. Mortality as low as 900 individuals/year could reduce the population gradually to fewer than 3000 individuals, and mortality of 1800 individuals/year or more could cause the populations to decline to near-extinction levels. The more realistic total mortality of 2000 or more individuals/year is likely to reduce the population to a few hundred individuals in as few as 30 years. Moreover, adult survival has a very large impact on population dynamics of seabirds (Lavers *et al*. 2009, 2010). Our study was no exception: the cormorant population was more sensitive to adult mortality than to juvenile morality (Fig. 3). Since foxes were adept at killing adult Socotra Cormorants and most of the kills recorded were breeding adult birds, the population could be seriously threatened by fox predation in particular. Additionally, there is no information on the effects of density-dependent processes on reproductive success of Socotra Cormorants, which is why we did not use approximations to model this. Thus, the consequences of fox and feral cat predation could be devastating depending on the level of disturbance, extent to which reproductive success is lowered and other density-dependent processes.

Our assumption of three foxes and three cats could be very low. The density of red foxes during the study could have been as high as 0.33 foxes/km^2, while the density of feral cats may have been as high as 4.5 cats/km^2 (Harper 2004). Thus, eight or more foxes and more than 30 cats could have been supported on Siniya Island, given its size of 26 km^2. Additionally, red foxes in the Middle East apparently do not exhibit territoriality (MacDonald *et al*. 1999), indicating that higher densities could live in smaller areas when prey is abundant. Therefore, the threat to the Socotra Cormorant colony on Siniya Island could be higher than perceived.

Conservation implications and ethical management concerns

Clearly, fox and feral cats are likely having a detrimental effect on Socotra Cormorants on Siniya Island. Since the feral cats are introduced predators that do not belong to the island, their eradication can be justified (Keitt *et al*. 2011). Red foxes are found throughout the region in low density. They arrive on Siniya Island via land bridges that appear at low tide. The control of a native predator may be considered unethical, although such control is practiced in many countries depending on the comparative population status of the species concerned (Rowe & Jones 2000, Lenain & Warrington 2004, Lavers *et al*. 2009). For example, Arctic foxes have been controlled on offshore islands in Labrador to reduce their impact on the formerly threatened Razorbills (Rowe & Jones 2000, Lavers *et al*. 2009). Red foxes have been trapped and euthanized to reduce predation on re-introduced, globally Vulnerable Houbara Bustards *Chlamydotis macqueenii* since translocation may not be effective (Lenain & Warrington 2004). The red fox is categorized as Least Concern (IUCN 2008) because of its large geographic distribution and abundance. Furthermore, in the Middle East, the red fox has been increasing in density and distribution, aided by urbanization, agriculture and forestry (EAD 2012). The Socotra Cormorant, on the other hand, is Vulnerable (BirdLife International 2010). The reduction of its populations from hundreds of thousands in the 1980s and 1990s to less than 50% of the historic numbers (see Jennings 2010) may even justify upgrading its status to Endangered. Removal of a few foxes that are not threatened may save the largest known Socotra Cormorant colony in the UAE from extinction. Immediate measures should be implemented to eradicate foxes and feral cats from Siniya Island.

Keitt *et al*. (2011) reviewed the success of eradication programs from around the world. They suggested that both foxes and cats could be eradicated successfully and cost-effectively, provided the size of the island was less than 10 000 ha (Campbell *et al*. 2011). Since Siniya Island is only 26 km^2 (2 600 ha), it is likely possible to eradicate foxes and feral cats from it. There is no information on the rates of emigration or immigration of foxes on Siniya Island. Once eradicated, further invasion of foxes and feral cats should be monitored and managed through the implementation of control measures.

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