The threat of terrestrial predators to mainland penguin colonies: searching for sustainable solutions

By

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Abstract

Anthropogenic activities including overexploitation of natural resources and the transformation of natural habitat have disturbed ecological systems and are increasingly challenging the natural persistence, movement, and interactions of wildlife populations. On the Cape Peninsula in South Africa, all large predators were extirpated to reduce threats to lives and livelihoods with the medium-sized caracal (*Caracal caracal*) emerging as the *de facto* apex predator. Overexploitation of Africa penguins (*Spheniscus demersus*), their prey and their island breeding sites in the south-western Cape resulted in a rapid decline in the African penguin population and a shift in their distribution. This shift coincided with the establishment of at least four mainland colonies, one of which is on the Cape Peninsula. In this manner a Least Concern, abundant predator encountered an Endangered bird species poorly adapted to terrestrial predators, setting the scene for a conservation conflict in the Anthropocene. My goal in attempting to mitigate this conflict was to first collate all available data on mainland penguin colony demographics and to understand the relative threat posed by terrestrial predators such as caracal on their mortality. Secondly, I reviewed historical and current management interventions by conservation authorities to protect mainland colonies from terrestrial predators and assessed both their success in protecting penguins and their impacts on the predators. Having identified discrepancies amongst stakeholders in how best to manage the interface between penguins and predators I reviewed the potential non-lethal and lethal methods and used a standardised evaluation scoring system to identify those strategies with the most support. I then developed a management plan that integrates these strategies and provides the most sustainable solution for reducing supernumerary predation events while also offering conservation benefits to caracal. I made use of a qualitative triangulation approach for the evaluation of management techniques as this explores anecdotal data from case-studies alongside the individual experiences of environmental managers and experts in the field. Annual counts at mainland penguin colonies revealed that only two of the four colonies had persisted, and both had exhibited strong early growth and were now recognised as important breeding sites with high conservation status. Surprisingly both surviving mainland colonies were established in peri-urban areas with high levels of anthropogenic disturbance including vehicular collisions, and disturbance by domestic animals and people. Leopard (*Panthera pardus pardus*) and caracal were both identified as posing a significant threat to the viability of the Stony Point and Simon's Town penguin populations respectively. Both predators had engaged in supernumerary predation events, which have cumulatively resulted in the recorded deaths of at least 346 penguins over the last decade. In response to predations local statutory authorities have attempted numerous intervention strategies at both colonies. Remote camera traps proved effective at early detection and identifying species responsible, while physical barriers were effective at reducing access to colonies. Capture and collaring of caracal on the Peninsula with follow-up monitoring of movement adjacent to the colony proved ineffective as the caracal readily evaded staff deployed to deter them. Relocation of caracal within the Peninsula has had limited success as only one individual established a stable territory far from the colony, while the remaining cats either returned to the colony or died in vehicular collisions. The average time between supernumerary predation events following relocations or the euthanasia of caracal was approximately six months. A total of 17 primary mitigation management interventions were evaluated by key stakeholders with three having high levels of support *vis-à-vis*: cameras for early detection of potential predators, physical barriers to deter entrance to the colony or funnel predators into capture cages for translocation to other protected areas within the City of Cape Town (CoCT). Together with local conservation authorities and managers these three interventions were then integrated into a management plan with standard operating procedures and a decision flow chart so as to 1) greatly reduce predation on penguins by terrestrial predators, 2) prioritise non-lethal interventions including the development of a translocation plan to CoCT nature reserves, 3) ensure the plan aligns with current local and international (IUCN) policy, 4) be cost effective and practically achievable with the resources available, and 5) have broad public, stakeholder, and statutory acceptability. Together these interventions provide a solution to a classic conservation conflict in the Anthropocene and can serve as a suitable template for the management of Least Concern predators impacted by urban development both in South Africa and elsewhere in the world.

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Introduction

Anthropogenic impacts on biodiversity

Human activities have adversely affected most terrestrial and marine ecosystems on earth, the consequences of which include loss of natural habitat and connectivity, reduced resource availability and shifts in ecosystem processes (Haddad *et al.,* 2015; IPBES, 2019). Where natural ecological systems have been disturbed, anthropogenic activities increasingly challenge the persistence, movement, and interactions of wildlife populations (Lewis *et al.,* 2012). Protected areas (PAs) are thus an essential buffer for the growing threats to biodiversity (Venter *et al.,* 2014), but their limited size, isolation and vulnerability to large-scale natural and anthropogenic impacts demands that they are largely managed within an adaptive framework (Lee, 2001).

Biodiversity conservation benefits from an ecosystem approach which requires that managers expand their perspective beyond, but not to the exclusion of, individual welfare and focus on landscape-level management, which prioritizes the maintenance of biodiversity and ecosystem functionality (Hann, 1990). However, it is often difficult to reach consensus on what measures or strategies are needed to achieve such broad goals (Fulton *et al.,* 2014). Many management approaches are incapable of providing ecological objectives that maintain biodiversity as well as the preservation of habitat for many species (Fuhlendorf & Engle, 2001). For example, the natural recolonization of large predators to restore key ecological processes is seldom an option when significant habitat disruption poses a barrier to their natural dispersal (Miller *et al.,* 1999). However, if it is not possible to preserve large core ecosystems, then the linking of smaller wild lands or natural areas can create important corridors, especially in urban areas (Way & Etough, 2006). In North America, for instance, coyotes (*Canis latrans*) and cougars (*Puma concolor*) travel substantial distances on linear paths such as powerlines, railway lines or golf courses, and for cougars, capable of using corridors as small as 100 m wide, any connection between two spaces is better than none (Beier, 1995; Way *et al.,* 2004). Grey wolves (*Canis lupus*) are another species capable of living on the edge of human dominated areas if they are not persecuted and for this reason even marginal habitats are crucial in facilitating animal movement (Way & Eatough, 2006; Haddad *et al.,* 2015). The use of corridors is an important conservation tool in linking fragmented landscapes and habitats that no longer provide most predators with sufficient land for their relatively large territorial demands (Way & Eatough, 2006; Vogt *et al.,* 2007; McManus *et al.,* 2021).

Aside from ongoing long-term efforts to preserve large tracts of relatively undisturbed land that will allow for natural ecological processes, the global biodiversity crisis often requires near-immediate solutions to acute threats posed to species facing extinction (IPBES, 2019). Such solutions must often be realised with few resources, limited foundational knowledge and even less time in which to explore and test solutions (Cusack *et al.,* 2021). Heavily impacted ecosystems are thus being actively managed to mimic complex processes that have evolved over millennia. Such management is an iterative process that embraces errors and borrows from the successes of nearby or related systems (Lee, 2001). The uncertainty inherent in such adaptive management makes it extremely vulnerable to the court of public opinion (Warburton & Norton, 2009), as it often relies on expert opinion and calculated 'best guesses' (McCarthy & Possingham, 2007). Adaptive management of wildlife in the Anthropocene, therefore, demands that, where possible, intervention frameworks should be built on strong foundations of sound ecological and conservation principles (Keith *et al.,* 2011).

Large predators are particularly vulnerable to anthropogenic impacts and being physically larger than their resource competitors these species invariably have large home ranges and relatively low densities (Ordiz *et al.,* 2013), factors which together equate to a greater secondary extinction risk (Courchamp *et al.,* 1999). Predators play an important role in structuring communities by exerting influence that filters through trophic levels (Glen *et al.,* 2007). In so doing, they limit the populations of prey and competing predators (Ordiz *et al*., 2013) and thus impact the diversity and even the effective functionality of entire ecosystems (Glen *et al.,* 2007). For instance, apex predators will often suppress surrounding mesopredator populations either directly through depredation or indirectly through competition and by instilling fear which drives behavioural changes in habitat use and therefore relative abundance (Ritchie & Johnson, 2009). These effects are amplified when different apex predator pressures combine to suppress mesopredator distribution and relative abundance, especially due to their dietary niche overlap (Courchamp *et al.,* 1999). The suppression or removal of apex predators may also lead to a proliferation of alien or invasive species, potentially driving secondary pest problems for agriculture or fisheries, which may, in turn, threaten vulnerable prey species (Letnic *et al.,* 2009; Wallach *et al.,* 2010). These cascading effects alongside the release of native mesopredators can lead to the extirpation of certain prey species, such as those with low growth rates inhabiting particularly exposed habitats that are predisposed to local extinction from stochastic events (Courchamp *et al.,* 1999).

Managing predators in transformed landscapes

Lethal control of predators in human dominated landscapes has been a widely used method providing both livestock and game producers with relief from the considerable costs of predation (Anthony *et al.,* 2010; Bergstrom *et al.,* 2014; Kerley *et al*., 2018). Increasingly however, such lethal management is not considered to be an effective long-term strategy because of the magnitude of knock-on ecological impacts, including biodiversity loss (Anthony *et al.,* 2010; Ripple *et al.,* 2016), destabilization of trophic levels (Ordiz *et al.,* 2013), loss of ecosystem services (Ripple *et al.,* 2016; McManus *et al.,* 2021) and the opportunity for biotic invasions (Bergstrom *et al.,* 2014). In the United States for instance, the successful extirpation of grizzly bears (*Ursus arctos horribilis*) and grey wolves from large parts of their historical distribution was associated with substantial disruption of natural trophic cascades (Bergstrom *et al.,* 2014; Ripple *et al.,* 2016). Where lethal methods are highly localized, immigrants will move into vacant territories resulting in a long-term lethal population 'sink' without the guarantee of relief from predation (Robinson *et al.,* 2008; Bergstrom *et al.,* 2014).

For example, the reduction of grey wolf populations contributed to an increase in coyote populations through mesopredator release, with unintended consequences on native ungulate populations (Bergstrom *et al.,* 2014). Indiscriminate lethal methods such as poisoning and trapping may also impact non-target species, for example, the poisoning of prairie dogs (*Cynomys ludovicianus*) almost led to the extinction of the black-footed ferret (*Mustela nigripes*). Consequently, integrated wildlife management including non-lethal methods such as barriers (Kerley *et al.,* 2018), aversive deterrents (Andelt *et al.,* 1999) and conditioned aversion (Andelt *et al.,* 1999; Snijders *et al*., 2021) are all considered to be better long-term options that will allow people and wildlife to achieve a more stable equilibrium in shared landscapes (Bergstrom*, et al.,* 2014; Kerley *et al*., 2018).

Many non-lethal alternatives to lethal predator management are available (Kerley *et al*., 2018). Electronic training collars provide an example of aversive conditioning and have been used on both captive and free ranging predators to condition them not to attack livestock (Andelt *et al.,* 1999; Shivik *et al.,* 2002). Plastic and metal collars that protect the necks of livestock from predator kill-bites have also been developed and although initially successful for both coyote and black backed jackal (*Canis mesomelas*), reports soon emerged of both predators attacking livestock on the hindquarters instead (Blackwell *et al.,* 2016; Nattrass & Conradie, 2018). Some evidence suggests that wolves have been effectively deterred using flagging or fladry (i.e., strips of flagging hanging from a rope to act as disruptive stimuli; Musiani & Visalberghi, 2001), the success of which was improved when the wires supporting the fladry were electrified (Beck *et al*., 2009; David-Nelson & Gehring, 2010; Miller *et al*., 2016). Another option that has shown some promise is the use of Radio-Activated Guards (RAG) or Movement Activated Guards (MAG), which include devices that are activated remotely or when a radio collared animal is in the vicinity of a designated area. Activation is associated with lights and sounds designed to limit habituation by the predators to the disturbance (Darrow & Shivik, 2009; Khorozyan & Waltert, 2019). The territorial defense behaviour of scent marking carnivores has also been exploited and has been successful in keeping African wild dogs (*Lycoan pictus*) in PAs (Jackson *et al*., 2012), but it has limited success with wolves and coyotes (Jackson *et al.,* 2012). While further disruptive aversive techniques such as human herder and animal guard dogs have been proposed (Kerley *et al*., 2018), it is likely that the combination and rotation of several adaptive management tools are needed for non-lethal techniques to be successful in protecting livestock (Kerley *et al*., 2018).

Translocations are widely used for the establishment, re-establishment, and augmentation of populations in managed species (Fernando *et al.*, 2012) and are defined by the International Union for the Conservation of Nature (IUCN) as “the deliberate and mediated movement of organisms from one site to another with the intended goal of yielding a measurable conservation benefit at the levels of a population, species, or ecosystem, and not only provide benefit to translocated individuals” (IUCN/SSC, 2013). However, translocations have also been increasingly employed in the context of managing ‘problem’ or Damage Causing Animals (DCAs); i.e., animals that damage livestock, crops, persons, or property (Anthony *et al.*, 2010), due largely to the growing ethical and welfare concerns linked to lethal control measures (Fernando *et al.*, 2012). Generally, population restoration is achieved by increasing population size and genetic diversity, as well as by increasing the representation of specific demographic groups or life stages (IUCN/SSC, 2002), while reintroduction is the intentional movement and release of an organism inside its native range from which it has disappeared (Rouget *et al.,* 2003). The IUCN guidelines for the placement of confiscated animals, however, confirms that the prevailing legislation, cultural practices, and economic conditions of the case will influence decisions on appropriate disposition of these animals within a conservation context (IUCN/SSC, 2002). The available IUCN policy options for DCAs are therefore to 1) maintain these animals in captivity for the remainder of their natural lives, 2) return the animals to the wild, or 3) to euthanize the DCA (i.e., imminently destroy them following appropriate statutory and welfare legislation). The IUCN guidelines further state that if a decision is made to return DCAs to the wild, it should be consistent with IUCN conservation principles and practices (IUCN/SSC, 2013). Regardless, any release into the wild must follow the necessary screening and monitoring protocols to address potential negative impacts to the translocated individual, the receiving population or other wildlife and domestic animal populations. Unfortunately, many conservation managers lack the available data, resources, and experience to develop pro-active conflict mitigation policies to meet these international standards before its structured implementation and feedback assessment (Messmer, 2000; Addison *et al.,* 2016). Instead, the reality is that statutory authorities, local conservationists, and impacted stakeholders are often required to make more immediate reactive decisions concerning predator management based on experience, anecdotal data, and comparative systems.

Mitigating conservation conflict with limited data

The paucity of fine-scale data severely limits the application of quantitative methods to real-world conservation challenges and therefore important decision-making processes (both pro- and re-active) are seldom supported by an evidence-based, peer-reviewed process such as evaluating the necessity for standard procedures and determining the relative success of intervention strategies (Grimble *et al.,* 1997; Addison *et al.,* 2016). Even if the species is intensively studied, management decisions often depend on exploratory and qualitative methods that are specific to the complexities of the landscape (Sutherland *et al.,* 2018). The aim of such qualitative research is to gain a better understanding of the situation under investigation by triangulating a multi-faceted array of alternative qualitative techniques, including literature reviews, historical data assimilation, and in-depth consultation with experts in the field (Klopper, 2008). Such qualitative research is used to investigate and clarify rather than to prove a cause-and-effect relationship (Farrelly, 2013) and typically commences with a search for historical records which are an important source of original data for investigating patterns and trends relevant to a particular conservation issue (Bucheli & Wadhwani, 2013). Qualitative triangulation is thus a fitting approach for the evaluation of management techniques as this explores anecdotal data from case-studies alongside the individual experiences of environmental managers rather than needing to rigorously quantify measures of success directly and statistically (Sutherland *et al.,* 2018). The advantage of such qualitative research is that it allows for adaptability within the researcher-expert relationship, while being cognisant of and discussing limiting personal biases (Masadeh, 2012; Farrelly, 2013).

Reserve managers and scientists working for conservation bodies would thus typically give input into potential non-lethal and lethal management techniques given access to historical information and first-hand experience in what has been trialled and applied elsewhere (Robinson, 2014). This approach, called purposive sampling, refers to participants being grouped according to preselected criteria relevant to a particular research question (Trotter, 2012). Purposive sampling can also reveal case studies which focus on in-depth analyses and explanations of a single unit or system that is restricted by space and time (Hancock *et al.*, 2021), but can nevertheless provide reliable indications for the directions in which future research can go (Boddy, 2016). The benefits of mixed-method approaches when data are limited, as is the case for most urgent interventions concerning conservation challenges, is that these enhance the relative integrity and context of existing findings, but also reveal previously undetected connections and begin to formalise a holistic summary of the *status quo* (Schoonenboom & Johnson, 2017). Mixed-methods research requires that the research team combine elements of quantitative and qualitative research approaches (e.g., literature reviews, sourcing multiple viewpoints, data collection and collation, spatio-temporal analyses, and several inference techniques) to improve understanding and corroboration (Sutherland *et al.,* 2018).

Predators in the Cape Peninsula of South Africa

South Africa has a long history of human wildlife conflict (HWC) and exemplifies the complexities in managing these problems (e.g., global biodiversity hotspots, rapid urbanization, trophy hunting and bushmeat economies, illegal wildlife trade and cultural wildlife use) in unique socio-ecological systems (Seoraj-Pillai & Pillay, 2017). The earliest written records of negative interactions between people and large predators in South Africa are dated around the establishment of the first European settlement in the Cape Colony in the mid-1600s. Here, early settlers clashed with many large predators, such as lion (*Panthera leo*), brown hyaena (*Hyaena brunnea*), spotted hyaena (*Crocuta crocuta*) and leopard (*Panthera pardus*; Du Plessis, 2013). Negative interactions with many smaller predators were also recorded, including African wild dog (*Lycaon pictus*), black-backed jackal (*Canis mesomelas*) and caracal (*Caracal caracal*; Glen *et al.,* 2007). Bounties were paid by governing administrators for every 'undesirable' predator killed (i.e., most carnivores were considered and formally classified as 'vermin' at the time) through a largely unregulated array of methods which included shooting, trapping, poisoning, and hound hunting (Linnell *et al.,* 1999). Together these lethal interventions drastically and permanently reduced large predator densities and distributions throughout the Cape and ultimately South Africa (Glen *et al.,* 2007). While most large predators, such as lion and spotted hyaena, are today solely confined to PAs or game ranches, the intermediate body size of mesopredators often permits them to fill a mid-trophic position in the food web in mixed use landscapes including small livestock farming (Prugh *et al.,* 2009). The small home range demands of these mesopredators, often result in higher relative abundance and density, which could be further amplified in the absence of apex predators through mesopredator release (Hayward & Kerley, 2008; Prugh *et al.,* 2009; Richie & Johnson, 2009). This general absence of apex predators in South Africa has resulted in widescale mesopredator release with smaller species such as black-backed jackal and caracal having increased in abundance, acting as trophic apex predators in many transformed landscapes throughout the country (Glen *et al.,* 2007; Ramesh *et al.,* 2017; Drouilly *et al.,* 2018).

Problem statement, study aims and objectives

The Cape Peninsula (CP), in the Western Cape province of South Africa, is an anthropogenically impacted landscape in which the loss and fragmentation of natural habitat has resulted in substantial declines in faunal biodiversity and abundance (Skead, 1980; Schnetler *et al.*, 2021). Remaining wildlife are largely restricted to the Table Mountain National Park (TMNP) which extends the length and breadth of the Peninsula and borders both urban and agricultural land uses (Schnetler *et al.*, 2021). As is typical for such disturbed landscapes, a mesopredator, the caracal has become the *de facto* apex predator following the eradication of all larger predators (Nattrass *et al.,* 2020). Caracal are classified by the IUCN red list of threatened species as 'Least Concern' (Avgan *et al.*, 2016) and have persisted in these transformed landscapes because they are highly adaptable, discrete, and opportunistic predators (Lewis *et al.*, 2012; Leighton *et al.*, 2020). Except for the occasional predation on domestic cats (Lewis *et al.,* 2012; Nattrass & O'Riain, 2020) caracal are rarely linked to negative impacts on the CP. Caracal do, however, present a challenge to conservationists when Endangered African penguins (*Spheniscus demersus*; BirdLife International, 2020) are included in their diet (Figure 1; Vanstreels *et al.*, 2019). Due to a high associated risk of terrestrial predation on penguins, this species seldom establishes land-based colonies (Crawford *et al.*, 1995). Sherley *et al.,* (2020) stated that the protection of African penguin mainland colonies is a priority, largely due to the competition with commercial fisheries (Sydeman *et al.,* 2021) and the failure of island populations to thrive." Consequently, considerable efforts have been invested in protecting these mainland penguin colonies from a multitude of natural and anthropogenic threats both at sea and on land (Crawford *et al.,* 1995). Caracal have been recorded engaging in repeated supernumerary predation events in both the Simon's Town and Betty's Bay (mainland) penguin colonies while leopard have similarly attacked penguins in Betty's Bay and the nascent colony in the De Hoop Nature Reserve (Vanstreels, 2019). Such events are presumably triggered by a poor anti-predator response in the penguins with supernumerary killings having been recorded for both predator species when confronted by small livestock confined to small spaces (e.g., within a kraal or pen; Nattrass & O'Riain, 2020). As both predators are opportunistic generalists, it is expected that this threat to penguins will persist and even increase without direct human intervention (Nattrass & O'Riain, 2020). Consequently, conservation authorities have actively sought to manage such predators threatening mainland penguin colonies using both non-lethal (e.g., physical barriers, aversive conditioning, and translocation) and lethal methods (i.e., either by shooting or capture and lethal injection).

Attempts to understand both the threats to mainland penguin colonies and the potential solutions to mitigate those threats have largely been conducted on an *ad hoc* basis and often as part of crisis management when predation levels surge at a mainland colony. While there have been numerous workshops and meetings to ensure stakeholder engagement on possible shared solutions, to date, there has not been a formal review of the relevant literature and only minimal use of appropriate methods for understanding this conservation conflict. Furthermore, there have been limited efforts to engage in qualitative triangulation, purposive sampling, and the retrospective assessment of case studies. The primary aim of this study is thus to understand the population dynamics of mainland penguin colonies and explore management interventions that can reduce terrestrial predation of Endangered African penguins living in mainland colonies on the South African coastline. Key objectives include: 1) collating and quantitively analysing historical and unpublished data on penguin population growth and mortality in mainland colonies; 2) collating and analysing data on causes of mortality for penguins inhabiting mainland colonies; 3) collating data and performing a qualitative analysis on the success of *ad hoc* interventions (i.e., case studies) attempted to date, including attempts to identify predators, deterring them from the colony, translocating them away from the colony and killing predators that pose a persistent threat to colonies; 4) reviewing the literature on all potential non-lethal management interventions to reduce terrestrial predation of penguins and using standardised evaluation scores to prioritise interventions for preventing predation by caracal (i.e., the primary terrestrial predator) in the Simon's Town penguin colony; 5) evaluating the welfare, disease and conservation 'cost versus benefit' implications of the highest scoring intervention methods (i.e., physical barriers, deterrent strategies, and translocation) for caracal, 6) developing a comprehensive decision matrix for the City of Cape Town (CoCT) managers so that they can objectively decide on when to translocate caracal, where to take them to, how to monitor individuals post-release success and the potential criteria for defining a successful translocation.

Methods

Study system – mainland penguin breeding colonies

One of the most severe effects of human activity worldwide, has been the decline in abundance of major living resources, primarily due to overfishing (Bourque, 2001; Shantz *et al*., 2020). In the northern cold Benguela upwelling system off the southwestern coast of southern Africa, overfishing has been particularly severe and historically abundant small pelagic fish populations have been virtually eradicated from the ecosystem (Heymans *et al.,* 2004; Roux *et al.,* 2013). This drastic loss of small pelagic fish also threatens global sea bird populations, which rely heavily on this prey source and have subsequently declined by more than 70% since 1950 (Crawford *et al.,* 2001; Heymans *et al.,* 2004; Roux *et al.,* 2013; Clay *et al.,* 2019). Among those species particularly affected, are African penguins whose global population has declined by 65% since 1989, with an estimated 17,700 wild breeding pairs remaining in 2019 (Sherley *et al.,* 2020). The African penguin is thus currently classified as 'Endangered' on the IUCN red list of threatened species (BirdLife International, 2020). It is estimated that at the turn of the 20th century there were once as many as 1,5–3 million African penguins breeding across approximately 32 islands and selected mainland colonies before significant anthropogenic impacts such as egg collection and guano scraping, pollution, habitat loss and modification, predation on land, and climate change led to their rapid decline (Sherley *et al.,* 2020).

Historically, African penguins were exclusively located on islands, with the exception of two colonies at coastal caves in Namibia (Crawford *et al.,* 2001; Vanstreels, 2019). Since the early 1980s penguins have attempted to establish new mainland breeding colonies throughout their range, with failed attempts in South Africa including Cape Recife in 1981, Lamberts Bay harbour in 1982 and in De Hoop Nature Reserve in 2003 (Crawford *et al.,* 2001; Vanstreels, 2019). The successful establishment of penguin breeding colonies at Stony Point (i.e., within Betty's Bay along the Overstrand) in 1982 and at Boulders Beach (i.e., within Simon's Town along the CP) in 1985 means that mainland colonies now represent 32% of the total penguin population in the Western Cape province and 18% of the total population in South Africa (Crawford *et al.,* 2001; Vanstreels, 2019). The positive demographic trajectory for these colonies is partially attributed to their distribution in relation to that of common prey species and limited commercial fishing activities surrounding the colonies (Underhill *et al.,* 2006; Vanstreels, 2019). Additionally, there is less competition with Cape fur seals (*Arctocephalus pusillu*s) for breeding space on the mainland (Crawford *et al.,* 1989; Nel *et al.,* 2003). African penguins show strong pilopatric behaviour, but the fish availability can potentially influence the decision of adults to breed, as well as their survival (Ludynia *et al.,* 2014). Historical accounts suggest that these relatively 'newly established' mainland breeding colonies experienced considerable pressure from terrestrial predators with an estimated 130 penguins killed at the De Hoop colony by caracal in the early 1990s (Vanstreels, 2019).

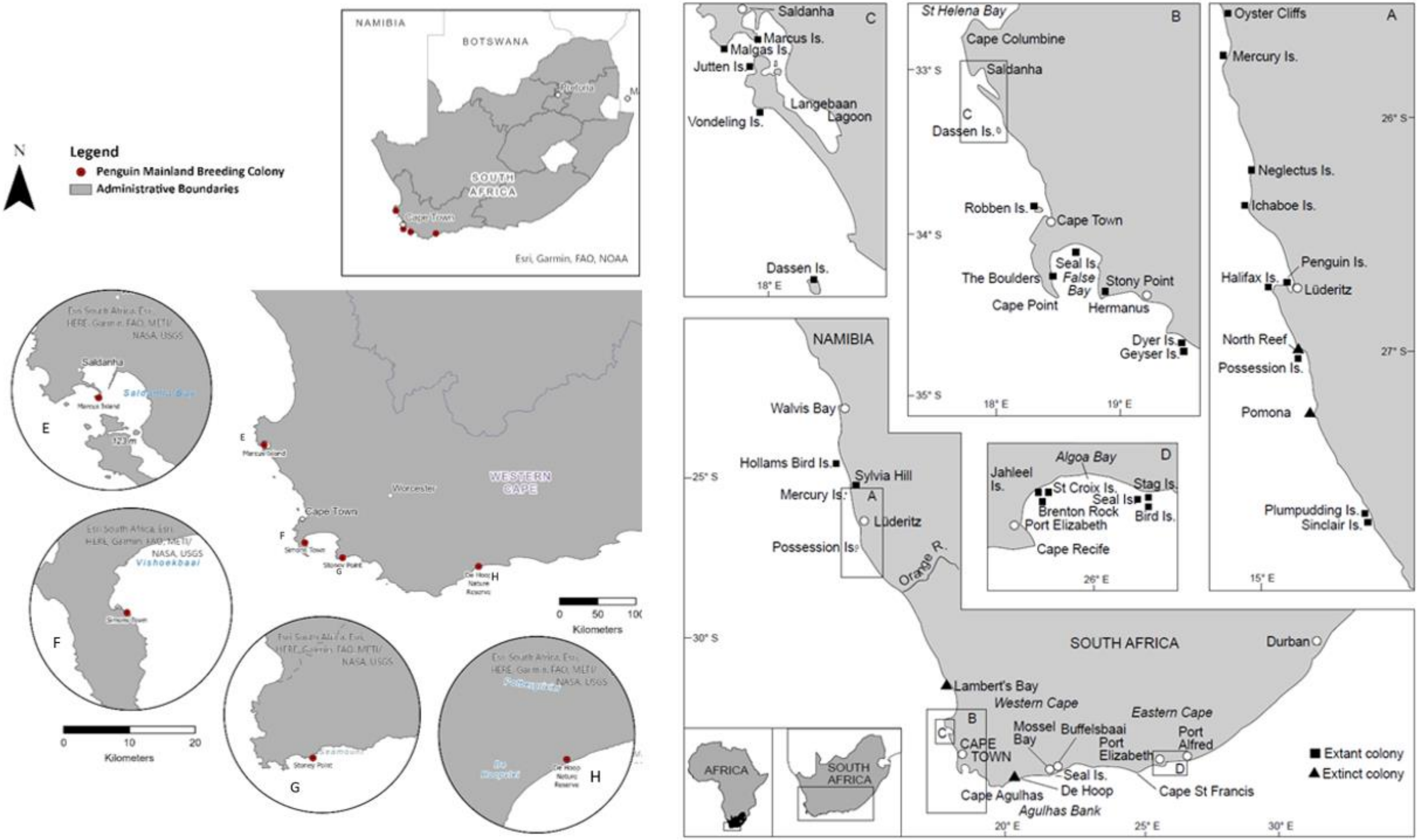

Figure 1. Maps showing the geographic distribution of the breeding localities of African penguins (*Spheniscus demersus*, 1990-2010) on both islands and on the mainland throughout their known distribution in southern Africa. The three primary breeding regions are depicted by plates 'A' (Namibia), 'B' (Western Cape), 'C' (Western Cape) and 'D' (Eastern Cape) respectively (Parsons & Underhill, 2005). The four mainland breeding colonies in the Western Cape province of South Africa are depicted by inserts 'E' (Marcus Island), 'F' (Simon's Town), 'G' (Stony Point) and 'H' (De Hoop Nature Reserve; Crawford *et al.,* 2008).

Currently, African penguins breed at 25 island colonies along the coast of Namibia, as well as in the Northern, Western and Eastern Cape provinces of South Africa (Figure 1; Parsons & Underhill, 2005; Crawford *et al.,* 2008), while the two mainland colonies (i.e., Stony Point and Simon's Town) are both within the Western Cape (Geldenhuys, 2018; Klusener *et al.,* 2018). These two mainland colonies provide a unique opportunity for the public to observe penguins and have become popular tourist destinations, drawing substantial public interest and revenue (DEA, 2013). Penguin colonies situated in the Western Cape have a predominantly Mediterranean climate characterised by cold, wet winters and warm, windy dry summers (Mucina & Rutherford, 2006).

Marcus Island (Figure 1E; 33°02'590'' S, 17°58'260'' E) is the most northly mainland colony in South Africa and is situated within Saldanha Bay, on the western coastline (Daturi, 1986). The island is connected to the mainland via a manmade causeway effectively making it a 'mainland colony' and providing terrestrial predator access. Marcus Island is the oldest land-based colony (i.e., in the Western Cape) with the first recorded penguins settling in 1956, around 25 years before the Simon's Town and Stony Point colonies. The island is flat with scattered boulders, and the penguins often nest under these boulders (La Cock *et al.,* 1987).

Simon's Town is one of the oldest settlements in South Africa, situated 35 km south of the CoCT (Figure 1F; 34°11'36"S 18°26'00"E). The CoCT is situated in the Cape Floristic Region (CFR), a globally renowned biodiversity hotspot, with high rates of endemism (Rebelo et *al.,* 2011). The CoCT is also however one of the fastest-growing cities in Africa, where both agricultural and housing demands are increasing pressure on remaining patches of natural land (Rouget *et al*., 2003). Currently, most of this land is conserved within 17 nature reserves that together comprise roughly 9% of the total surface area of the CoCT municipal area (Schnetler *et al.,* 2021). This site was established as a breeding colony in 1985 and is currently the largest inland breeding colony in South Africa. The penguins here are remarkably habituated to people and urban infrastructure and have begun to breed on the mountain side of the main road and even in private residential gardens (Vanstreels, 2019).

The Stony Point Nature Reserve, located within the coastal town of Betty's Bay in the Overberg region, is home to the second largest mainland African penguin colony (Figure 1G; 34.3741◦ S, 18.8917◦ E) in South Africa. This coastal town boasts both penguin and cormorant colonies and is a popular ecotourism attraction, welcoming over 75,000 visitors annually (Scheun *et al.,* 2021). Some sections of the reserve are not accessible to the public, but a boardwalk through the colony allows visitors to observe the penguins in their natural habitat without disturbance.

De Hoop Nature Reserve (Figure 1H; 34.4222° S, 20.5455° E) is a coastal PA in the Overberg region which includes an adjacent Marine Protected Area (MPA; Mudavanhu *et al.,* 2016). The reserve is open to tourists and a small group of permanent staff who live far from the colony. As such this is the least anthropogenically impacted of the four mainland colonies in the region.

Study species – caracal predating on penguins

Caracal are widely distributed (Figure 2), occurring throughout Africa, the Arabian Peninsula, the Middle East, and India, as well as throughout central and southwest Asia (Avgan *et al.,* 2016). Optimal habitat for caracal includes arid woodlands, savanna, scrublands, hill steppes, and arid mountainous regions. While they are considered abundant throughout southern Africa, there is evidence of significant range reduction in the north and west African distribution, while habitat fragmentation and range reduction are of concern throughout most of Asia (Avgan *et al.,* 2016; Veals *et al.,* 2020). As the largest of the small Felidae in Africa (Jansen *et al.,* 2019), caracal are medium-sized cats with long legs and a reddish-cream coat (Nattrass & O'Riain, 2020). They have a short tail, hind legs that are longer than the front, characteristic tufts on the ear tips, black marks behind the ear, and slight spotting on the inner legs and belly (Stuart, 1982). Adult males weigh between 8–20 kg and females between 5,8–22 kg (Veals *et al.,* 2020).

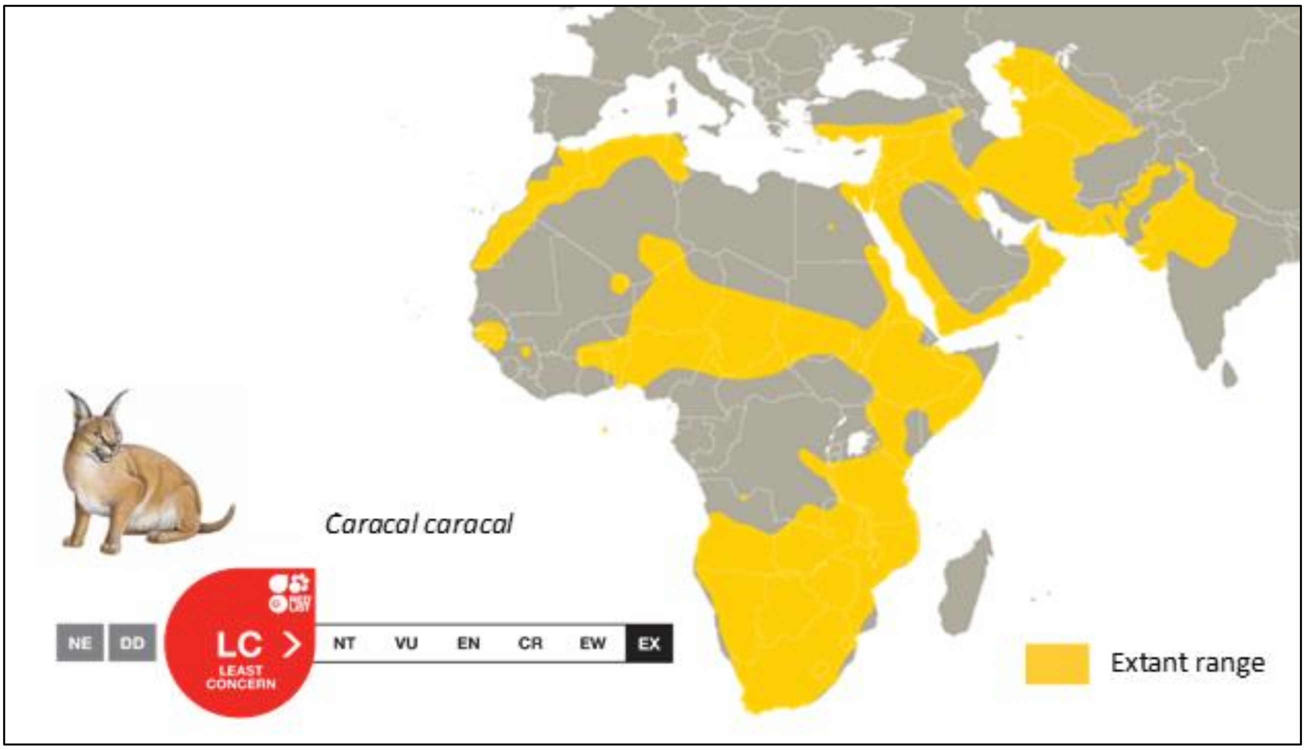

Figure 2. International Union of Nature (IUCN) Red List of Threatened Species distribution for caracal (*Caracal caracal*) and caracal illustration (credit: Kim Thompson).

Caracal are largely solitary and territorial, limiting or excluding members of the same sex from their territories, however, tolerance does increase with resource availability (Du Plessis, 2013). Female-female territorial overlap has been recorded at ≤ 19% of overall territory size, while male territories overlap with ≥ 80% of female territories and male-male territorial overlap is rare (Avenant & Nel, 1998). In areas where same-sex territories do intersect, there is little temporal overlap (Stuart, 1982; Avenant & Nel, 1998). Sexual maturity in caracal occurs at 7–10 months post-partum and reproduction is largely opportunistic and polygamous thereafter (Bernard & Stuart, 1987; Du Plessis, 2013). After a gestation period of *ca.* 79 days (Stuart, 1982), litters of two to three kittens are born per female (Pringle & Pringle, 1979; Bernard & Stuart, 1987; Avenant & Nel, 1998), with birthing rates peaking between October and February in southern Africa (Stuart, 1982). Reproduction is thought to occur during the summer months (i.e., December to March) so that the energy requirements of suckling coincide with an increase in rodent numbers, but also when predation on juveniles on stock farms increases (Avenant & Nel, 1998). Wild caracal have been recorded living up to 10 years of age, while records for captivity are around 19 years (Veals *et al.,* 2020). Caracal diet is highly varied, including insects, birds, rodents, small and medium sized mammals, snakes, spiders, lizards, and tortoises largely consumed in accordance with their relative availability (Stuart, 1982; Palmer & Fairall, 1988; Avenant & Nel, 1998; Kok & Nel, 2004). In addition to these natural sources, caracal are considered among the primary mesocarnivores responsible for livestock predation in South Africa (Avenant & Du Plessis, 2008; van Niekerk, 2010). Though caracal have a wide prey species range, they are thought to concentrate on those prey that are most abundant locally and are thus considered generalist, opportunist feeders (Avenant & Nel, 2002). The social and reproductive status of caracal are also expected to influence individual diet (Avenant & Nel, 2002), for instance, lactating females select larger prey (Du Plessis, 2013) and females with kittens are often involved in excessive livestock killings (Stuart, 1982).

Caracal movement is highly variable. They are primarily nocturnal, although daytime activity has often been documented and is believed to be influenced by the peak activity of their most abundant prey (Avenant & Nel, 1998). Caracal either hunt by moving to core areas within their home range where food is plentiful, or by moving randomly across their home range and consuming food as encountered (Stuart, 1982; Avenant & Nel, 1998; Du Plessis, 2013). Males are more nocturnal and have larger home ranges than females (Ramesh *et al.,* 2017). Low lying land (i.e., < 1200 m) is preferred over high altitudes bringing caracal into contact with agricultural landscapes that are more prevalent at lower altitudes. Caracal are also drawn to the abundant prey in agricultural landscapes, particularly livestock and rodents in regularly irrigated farmlands (Ramesh *et al.,* 2017). Beyond prey availability, habitat is also selected for shelter and the avoidance of medium to large predators (Avenant & Nel, 1998). Ultimately, caracal feeding behaviour, movement, home range dynamics and habitat selection are highly adaptable and therefore tend to be site-specific.

Caracal and black-backed jackal are the two most common medium-sized predators in South Africa, sharing much of their distribution across predominantly transformed landscapes (Daly, 2006), where they are thought to be responsible for most livestock farming damage (Du Plessis, 2013). Caracals are still often considered a DCA by landowners and have been linked to predation on many small livestock farms (De Waal, 2009). However, poor land management (e.g., overstocking) and animal husbandry practices (e.g., limited non-lethal deterrents) likely entice these predators onto commercial land and the associated ecology remains poorly understood (Avenant & Du Plessis, 2008). Nevertheless, as one of the primary predators in many parts of South

Africa, caracal play an important role in ecosystem functioning (Du Plessis, 2013). Caracal occur throughout South Africa, with the highest densities of *ca.* 38.5 individuals per 100 km^2 in the South and West (Stuart, 1982). The population continues to grow and spread into agricultural areas in South Africa and Namibia, where they are often regarded as vermin and therefore unprotected by provincial law (Veals, *et al*., 2020). CapeNature (CN) regularly issues hunting permits to livestock farmers to lethally control caracal (Nattrass & O'Riain, 2020), which are perceived to be expanding their distribution in South Africa and Namibia due to the local extirpation of the black-backed jackal (Nattrass *et al.,* 2020). For instance, on farmland in the central Karoo, the dietary niche overlap between black-backed jackal and caracal was more than 64% compared to the dietary overlap between caracal and leopard, with only 53% in a protected area in the Western Cape province of South Africa (Du Plessis, 2013; Drouilly *et al.,* 2018).

Caracal are being noticed frequently on the Cape Peninsula (Figure 3), mostly on the urban fringe and popular walking routes in mountainous areas (see the Urban Caracal Project; UCP). The CP is a mosaic of natural, agricultural, and urban land uses with high lying mountainous sections falling mostly within TMNP. Recent studies in the Greater Cape Town (GCT) region confirm the presence of caracal in both small and large PAs neighbouring urban land uses (Schnetler *et al*., 2021; Serieys *et al.,* 2021). These caracal primarily make use of undeveloped habitat patches and shrubland vegetation, as well as vineyards, pine plantations and exotic tree stands (i.e., mostly *Eucalyptus* species; Serieys *et al.,* 2021). Caracal on the CP have shown different preferences for habitats based on their age class, with adults avoiding the urban interface more strongly than subadults and juveniles (Serieys *et al.,* 2021). Human activities increasingly isolate and disrupt wildlife populations through a range of disturbances, and successful dispersal appears near impossible for the young males that attempt to leave the Peninsula. Living on the urban edge is associated with high health and mortality risks and consequently urban areas are a population sink for young male caracal in particular (Serieys *et al.,* 2019; Leighton *et al.,* 2022).

Mainland penguin colony status, mortality, and predation

The most recent colony demographic count data were collated from CN, the CoCT, the Department of Forestry and Fisheries (DEFF) and South African National Parks (SANParks), all of whom have a statutory mandate to actively conserve and manage African penguins in the four land-based colonies. The counts were undertaken annually (between February and September) between 1985 and 2021 at each extant colony, by teams of staff walking through each penguin colony and systematically counting the occupied nests sites (Sherley *et al*., 2020). An occupied site was considered active if it contained fresh eggs or chicks or had a penguin pair defending it, and the presence of fresh guano and nesting material. Where more than one count was made in a year, the highest count was taken as the annual number for that colony as it assumes that more members of breeding pairs were present at the time of the count (Sherley *et al*., 2020). Penguin carcasses were also recorded at each colony by either CN, the CoCT, the DEFF and SANParks on an *ad hoc* basis and all carcasses were submitted to the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) for post-mortem examination. Post-mortem examinations followed standard necropsy protocols by experienced veterinarians and any macroscopic lesions were noted (Vanstreels *et al.,* 2019). Mortality data were supplemented with field evidence including both direct observations (i.e., including those from CCTV cameras and camera traps) and indirect signs of predators (e.g., spoor and scat; Vanstreels *et al.,* 2019), the field evidence for depredation was collected during daily patrols, between 08h00 and 11h00 by trained penguin monitors. Predation events were defined as the killing of penguins over consecutive days (i.e., if a day was skipped then a new event was logged), while natural mortality included events such as physical injuries, malnourished chicks, starvation, and moulting. Environmental factors were ascribed to birds who died from dehydration, heat stress, hyperthermia, and the spring tide effect. Caracal data were collated with input from CN, the CoCT, SANParks and the UCP at the University of Cape Town (UCT). Data included the sex, age class and condition of all caracal captured in Simon's Town, whether within or in close proximity to the penguin colony. Data from the Peninsula colony also included GPS positions from collars affixed to caracal (n=4) that were captured and relocated in or close to the colony and translocated elsewhere. Lastly, all available data on the outcome of management interventions to date, including the use of barriers, aversive foot patrols around the colony and relocations were obtained. It is important to note that local conservation authorities responsible for caracal-penguin interactions on the CP (i.e., CN, the CoCT and SANParks) consider the artificial movement of a DCA caracal within contiguous range of the penguin colony a 'relocation' (e.g., within TMNP), whereas a 'translocation' is defined as the artificial movement of a DCA animal to a site with barriers that would otherwise restrict movement back to the colony. As such, there have been management relocations on the CP to mitigate caracal predation on penguins, but no translocations to date.

Proactive management of caracal-penguin conflict at mainland penguin colonies

African penguins and caracal occur at the urban-national park interface and hence their co-management necessitates participation by staff from the CoCT and SANParks (i.e., TMNP) with CN being the provincial authority for wildlife outside of the national park. Staff from all three organisations are thus mandated to address conservation challenges associated with both species on the CP. Additionally, researchers from the Institute for Communities and Wildlife in Africa (iCWild) at UCT are typically invited to meetings relevant to the management of these species, providing expertise on understanding the drivers of conservation conflicts and sharing available data on caracal behavioural ecology. In this study, I used a systematic approach for assessing local conservation authority expertise and experiences to derive a composite score for each of the non-lethal and lethal management options that were considered for reducing predation by caracal on penguins in Simon's Town. I attended four meetings between March 2021 and February 2022 each lasting between 60 and 120 minutes. These meetings were attended by approximately 30 invited representatives from the local conservation authorities, who are familiar with the study system, its species, and the nature of management around the ongoing conflict Relevant information included methods that had been attempted by the various authorities, researchers and NGOs to limit predation of penguins by terrestrial predators. I then selected the combination of methods that was most likely to meet with international best practice standards and that would be acceptable to local residents and the authorities. The process culminated in an intervention strategy guiding document, where potential strategies were ranked (out of 10) by the 10-member panel as a function of their cost versus benefit given past management experience or site-specific knowledge on resource feasibility and ecological viability. The overall ethical justification, security around ecological integrity, evidence and research-based support were considered as well as stakeholder support, effort and logistics such as initial cost, annual running costs and overall turn-around time. These collaborative Management Strategy Workshops (MSWs) including a close group of key conservation partners have been formalised and now occur quarterly, unless a caracal is detected near the colony in which case an emergency meeting is called. The management team have since collaborated on designing a decision framework for caracal translocations which includes a site selection tool, a Standard Operating Procedure (SOP) and an assessment of the risks (e.g., disease) to the potential receiving population and the translocated individual presented by the biophysical properties of all candidate nature reserves. This study sought to collate the available data, standardise its collection, formalise its dissemination among management partners and optimise its value in the decision-making process, to ensure pro-active intervention towards the non-lethal management of caracal-penguin conservation conflict on the CP.

Figure 3. Camera trap photograph of a mature male caracal (*Caracal caracal*) killing an adult African penguin (*Spheniscus demersus*). Photo credit: CoCT (2016).

Results

Demographic records of mainland penguin colonies

The Marcus Island penguin population (Figure 4A) declined sharply from 1985 to 1987, from an initial 1,200 breeding pairs to only 200, two years later in 1987. Numbers remained constant thereafter from 1987 to 1995, before gradually decreasing to complete extirpation by 2018. The Boulders breeding colony in Simon's Town was colonised by African penguins in 1982 with the first breeding pairs appearing in 1985 (Figure 4B), a steady population increase followed, with a peak around 1,227 pairs in 2005.

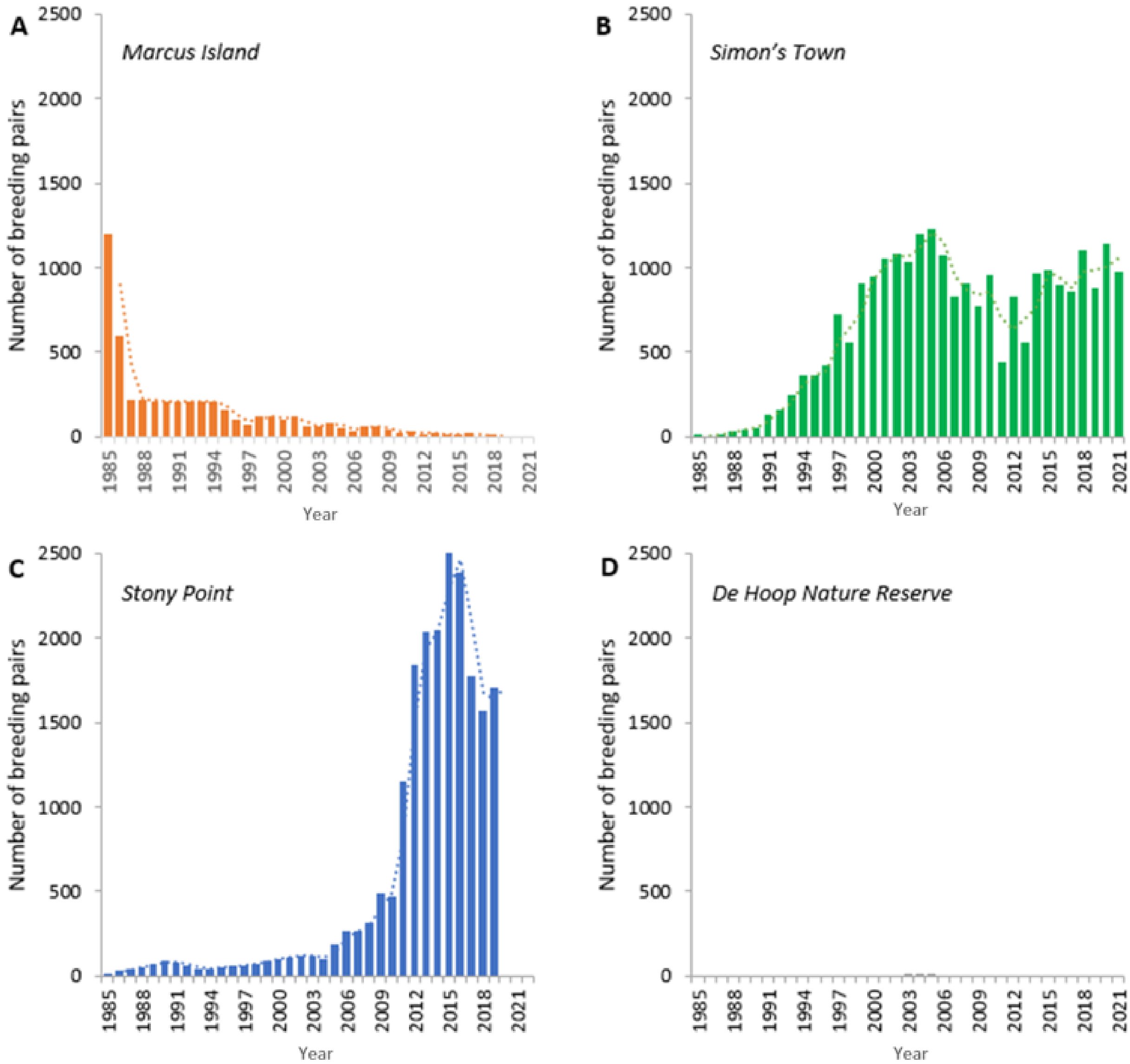

Figure 4. Historical to contemporary demographic trends in the number of African penguin breeding pairs at the four land-based breeding colonies in the Western Cape province of South Africa, namely Marcus Island (A, orange), Simon's Town (B, green), Stony Point (C, blue) and De Hoop Nature Reserve (D, grey).

Thereafter an average decline of 54 breeding pairs has been observed from 2006 to date. The population fluctuated during this period however, dropping to just over 444 breeding pairs in 2011, and increasing to 1,137 pairs in 2020. Stony Point in Betty's Bay was colonised by African penguins in 1985 (Figure 4C). Less than 100 breeding pairs were observed annually thereafter, until in 1998, when these numbers began to increase, reaching 487 breeding pairs in 2010 and peaking in 2015 at more than 2,500 active breeding pairs. These numbers then declined before stabilising at approximately 1,700 breeding pairs from 2017 to the last count in 2019. Penguins were first detected at De Hoop Nature Reserve in 2003 with a single breeding pair (Figure 4D). This increased to 15 pairs in 2005 before the colony was extirpated with no subsequent recolonisation.

Causes of mortality at mainland penguin colonies

Collated mortality data provided by SANParks indicate that 2,689 penguin mortalities were recorded at the Simon's Town breeding colony between January 1999 and September 2021 (Table 1). Primary causes of mortality (i.e., those which account for 90% of mortalities during this time) include dehydration (19%), motor vehicle collisions (14%), predation by caracal (11%), seals (9%) and domestic dogs (3%), bee stings (2%), oil spills (2%), drowning (2%), abandoned chicks (2%) and many unknown causes of mortality (26%). Penguin mortalities spiked (i.e., > 100 mortalities per annum) from 2004 to 2008, in 2011, between 2015 and 2017, in 2019 and again in 2021 (Table 1). Overall, around 30% of mortalities were due to predation (i.e., caracal [11%], seals [9%], domestic dogs [3%], unknown predators [3%], drowning [2%], decapitation [1%], mongoose [1%], other domestic predators [< 1%] and kelp gulls [< 1%]), around 23% were due to environmental effects (i.e., dehydration [19%], hypothermia [1%], heat stress [1%], starvation [1%], malnourishment [< 1%], spring tide [< 1%], and physically trapped [< 1%]), around 15% were attributed to anthropogenic effects (i.e., motor vehicle collisions [14%], oil spills [2%], euthanasia [< 1%], and fishing gear [< 1%]), and around 6% were due to natural causes (i.e., bee stings [2%], chick abandonment [2%], avian flu [1%], interspecies conflict [1%], arrested moult [< 1%], injuries [< 1%], and other natural causes [< 1%]), while 26% are due to unknown causes (Table 1). Predation was thus the greatest contributor to penguin mortality (30%), with an average of 66 predated birds per year between 2016 and 2021, but an overall average of 33 birds per year from 1999 to 2021.

The total number of penguins killed by caracal over the 10 years from 2011 to 2020 in Simon's Town is 291 (Figure 5). Caracal predation was rare between 2011 and 2015 but peaked dramatically in 2016 and 2017 with a total of 261 penguins killed. Since 2017 however, caracal predation has been less than 20 penguins per annum. Temporal trends in the five main causes of mortality reveal a clear peak in environmental causes in around 2006 which was the single largest peak over the study period followed by more intense predation in 2016 and 2017 and before that the third highest peak in 2004–2006 (Figure 5).

Table 1. The total number and relative proportion of all causes of African penguin (*Spheniscus demersus*) mortality recorded at the Simon's Town breeding colony between January 1999 and September 2021.

Cause of mortality	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total	%
Unknown	5	1			10	65	61	35	61	11	15	19	31	17	24	30	43	43	42	34	76	39	53	**715**	26
Dehydration						11	26	219	148	71	12	3	3	7			1							**501**	19
Motor vehicle collision	18	3			32	30	26	27	12	31	17	9	44	22	11	12	8	26	25	9	5	5	9	**381**	14
Predation - caracal													1				1	131	122	8	15	6	7	**291**	11
Predation - seal	5				27	60	63	21	9	11	10	3	5	1	1	6	2	1			9	2		**236**	9
Predation - domestic dog	15					6	5	1	2	5	1		2		2	2	44		1			1	1	**88**	3
Predation - unknown	4				3	19	6			4	1		4				4	1		6	4	8	9	**73**	3
Bee stings																							63	**63**	2
Oil spill						49	11				1						1							**62**	2
Drowning						2	20	33		3	2				1									**61**	2
Abandonment													2			1	2	37	3		2	1		**48**	2
Decapitation	1						1	1	1				13		19	2								**38**	1
Hypothermia							1			6	1						11	4		2				**25**	1
Avian flu																				17		1		**18**	1
Predation – mongoose										2		1					10	2						**15**	1
Heat stress																				2	9	3		**14**	1
Starvation																			4	5	2	2	1	**14**	1
Malnourishment																		9	1					**10**	<1
Arrested moult						1	1						1	1			1					1		**6**	<1
Spring tide											4													**4**	<1
Predation – domestic dog						2	1																	**3**	<1
Euthanasia							1						2											**3**	<1
Predation - kelp gull											1						2							**3**	<1
Physically trapped										1							1						1	**3**	<1
Fishing gear											1									1				**2**	<1
Injured																						1	1	**2**	<1
Natural causes																				2				**2**	<1
Other (<1)												1		1			1	1	2		1		1	**8**	<1
Total	**48**	**4**	**0**	**0**	**72**	**245**	**223**	**337**	**233**	**145**	**66**	**36**	**108**	**49**	**58**	**53**	**132**	**255**	**200**	**86**	**123**	**70**	**146**	**2,689**	
Proportion (%)	2	<1	<1	<1	3	9	8	13	9	5	2	1	4	2	2	2	5	9	7	3	5	3	5		

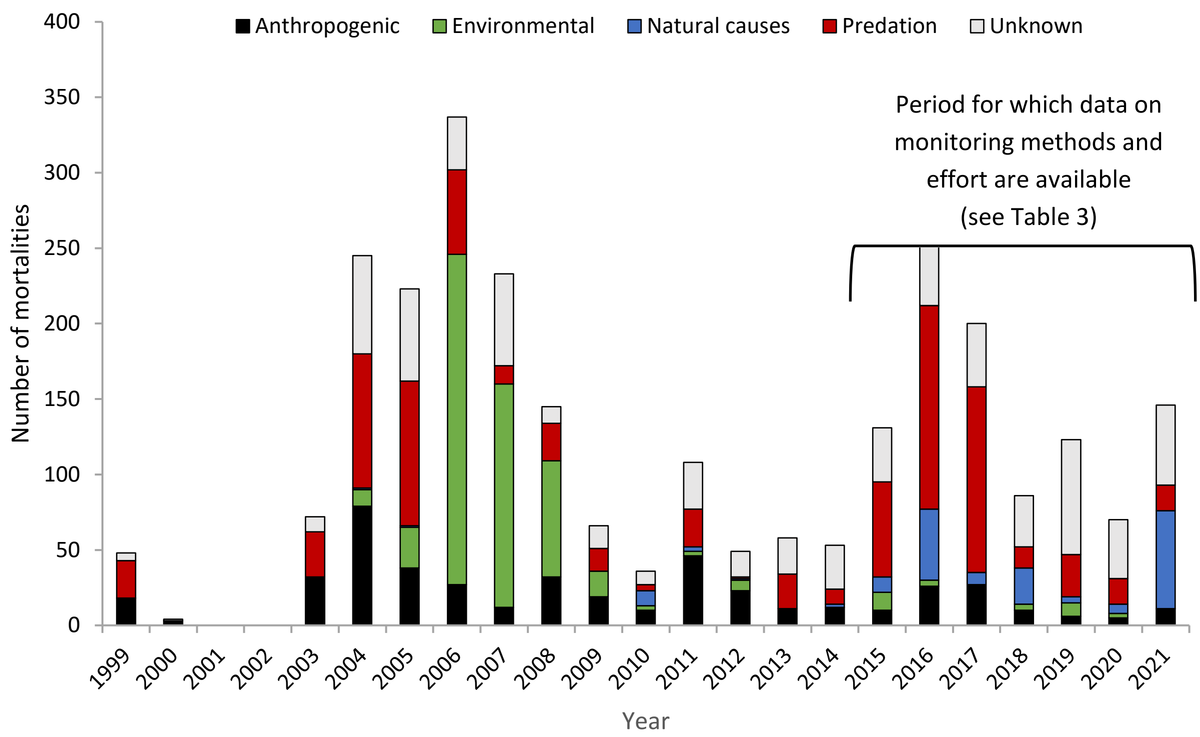

Figure 5. The number of mortalities attributed to five different categories of mortality for African penguins in Simon's Town between 1999 and 2021.

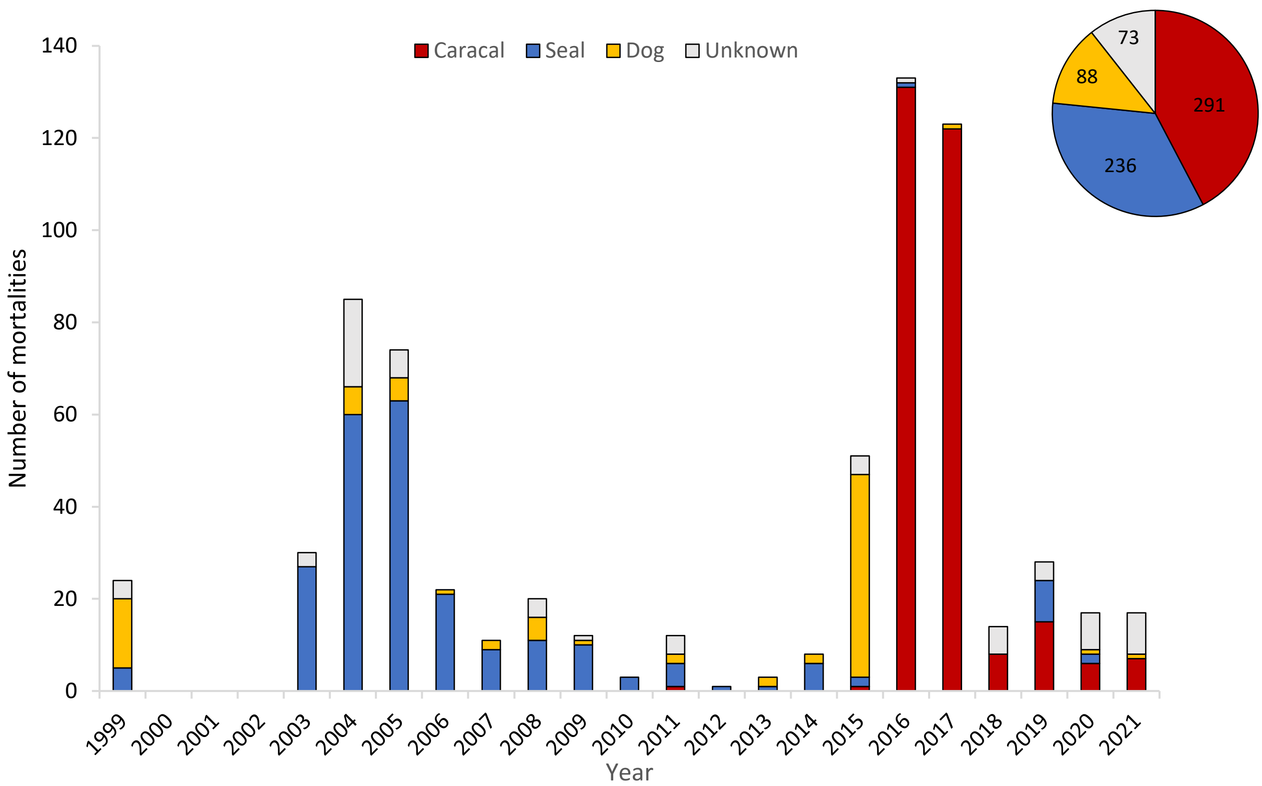

Figure 6. The annual total number of penguins killed by predators in Simon's Town from 1999 to 2021 following intensive, standardised monitoring by the City of Cape Town. Inset is the overall summary of predation by predator type for this period.

Table 2. An overview of information on methodology and effort of monitoring for periods where such information exists, showing recent predation events at the Simon's Town penguin colony for the period 2015 – September 2021. Data include the type of predator, the number of independent predation events, the total number of penguins killed, and the methods used to identify predators after a killing event**.**

Predator	Penguins killed	Independent events	Predator identification
Caracal (*Caracal caracal*)	290	7	1 - Footprint and scat from caracal found in the colony. 2 - Camera traps confirmed the presence of a caracal in the colony, including some photographs of caracal killing penguins. 3- Traps were set and caracal captured, following predation events. Following removal of the caracal predation events ended abruptly.
Domestic dog (*Canis lupus familiaris*)	47	9	1 - Direct observation. 2 - Spoor around penguin carcasses.
Cape fur seal (*Arctocephalus pusillus*)	14	4	1 - Direct observations of seal predation. 2 - The presence of penguin "skins" - indicative of seal predation in which violent shaking results in the 'degloving' of the skin and feathers from the body.
Cape grey mongoose (*Herpestes pulverulentus*)	12	7	1 - Cape grey mongoose was seen attacking a medium-sized downy chick and dragging it away into the bushes, where it was killed out of sight (one occasion). 2 - Cape grey mongoose seen entering the colony in periods when carcasses were found. 3 - Cape grey mongoose faeces were found in the area and contained penguin feathers. Cannot prove killing versus scavenging. 4 - Bite marks on penguin carcasses consistent with mongoose. Cannot prove killing versus scavenging.
Kelp gulls (*Larus dominicanus*)	2	2	1 - Kelp gulls observed with eggs, dead chicks. 2 - Direct observations of predation by CoCT / SANParks staff.

Anthropogenic causes of mortality peaked in 2004 with a smaller peak in 2011. Natural causes of mortality were the lowest of the five causes over the study period and defined by two small peaks in 2016 and 2021. Of these 365 predations between 2015 and 2021 (Table 2), the majority were due to caracal (79%), followed by domestic dogs (13%).

Mortality data provided by CapeNature for Stony Point indicates that 3,074 penguin mortalities were recorded between 2013 and 2018 (Table 2). The primary cause of mortality was abandonment (86% with an annual average of 438 birds), followed by predation (10%) which was attributed to grey mongoose (5%), Cape fur seal (3%), caracal (2%) and unknown causes (1%). Penguin mortalities were 10% in 2013 due to abandonment and 19% in 2014 (abandonment and predation by grey mongoose), but spike (i.e., ≥ 1000 mortalities per annum) in 2015 and 2016, and then dropped to 2% in 2017 and 2018 respectively. Records dating back to 1986 identified both leopard and caracal as posing a significant threat to the viability of the Stony Point and Simon's Town populations respectively, with leopard killing 65 penguins in two nights in 1986 and another 50 in 1990 at Stony Point and caracal killing 57 penguins between 2013 and 2018 at Stony Point, and 289 in Simon's Town between 2016 and 2021. No data on predation were available for the Marcus breeding colony while the De Hoop colony grew to 18 breeding pairs before being abandoned when predation by caracal occurred in 2008 (Hagen pers. comm).

Table 3. Causes of African penguin (*Spheniscus demersus*) mortality at the Stony Point breeding colony between January 2013 and 2018.

Causes of mortality	2013	2014	2015	2016	2017	2018	Total	%
Abandonment	279	393	939	1017	0	4	**2632**	**86**
Grey mongoose	1	127	28	2	0	8	**166**	**5**
Cape fur seal	0	0	2	5	55	15	**77**	**3**
Unknown cause	23	29	4	13	5	9	**83**	3
Caracal	7	15	13	22	2	0	**59**	2
Predation - unknown	5	0	8	0	6	0	**19**	1
Dog	0	0	0	0	0	5	**5**	<1
Entangled	0	3	0	0	0	0	**3**	<1
Flooding	0	0	0	0	2	1	**3**	<1
Human	0	0	0	0	0	2	**2**	<1
Kelp Gull	0	0	0	0	0	2	**2**	<1
Large grey mongoose	0	0	0	0	0	11	**11**	<1
Poor condition penguins	0	6	0	2	1	3	**12**	<1
Total	**315**	**573**	**994**	**1061**	**71**	**60**	**3074**	
Proportion (%)	10	19	32	35	2	2		

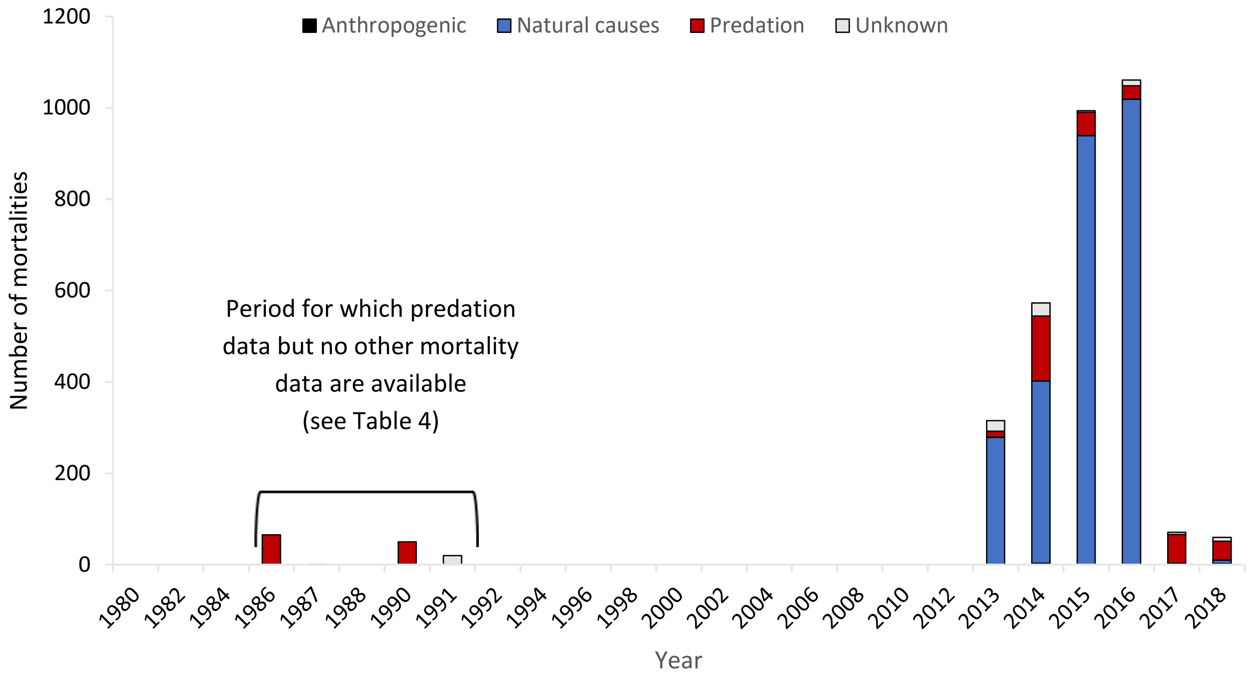

Figure 7. Causes of African penguin (*Spheniscus demersus*) mortality at the Stony Point breeding colony from 1980 to 2018.

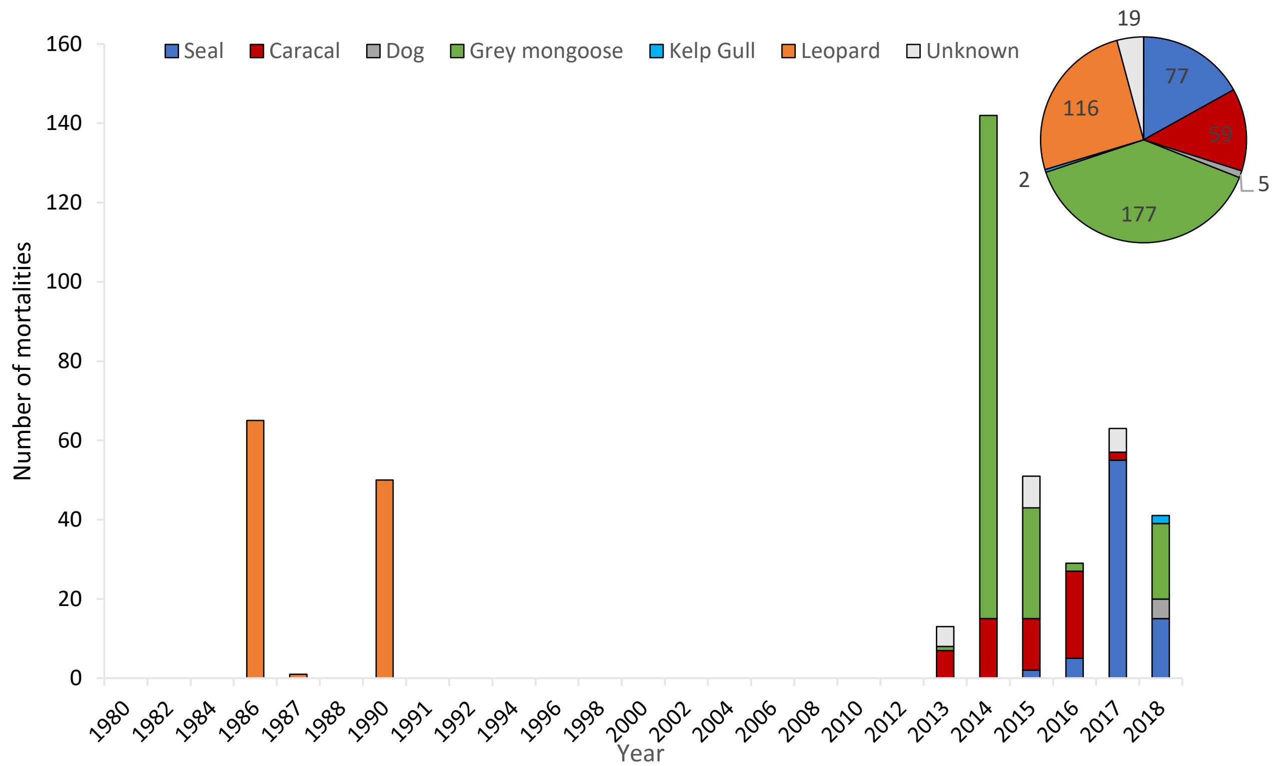

Figure 8. The annual total number of penguins killed by predators at Stony Point from 1999 to 2021 following intensive, standardised monitoring. Inset is the overall summary of predation by class for this period.

The total number of penguins killed between 2013 and 2018 at Stony Point was 3,074, with only five recorded as anthropogenic and 83 of unknown causes. The primary cause of mortality was natural nest abandonment accounting for 2,628 deaths between 2013 and 2016, while predation accounted for 359 over the period with 151 in 2014. Different types of predation events occurred at Stony Point between 2013 and 2018 (Figure 8), with grey mongoose accounting for 166 (52%) of all predations in this period, with 127 in 2014 alone. Cape fur seals accounted for 77 predation events, with 55 in 2017 and caracal were responsible for 59 predations (18%).

Table 4. An overview of the methodology and effort of monitoring for periods where such information exists, showing recorded predation at Stony Point between 1986 and 1990 (Whittington et al., 1996).

Predator	Penguins killed	Period	Predator identification
Leopard (*Panthera pardus*)	65	Two days in December 1986	1 - spoor around penguin carcasses 2 - predator trapped in colony
	1	February 1987	1 - spoor around penguin carcasses
	50	Between August and September 1990	1 - spoor around penguin carcasses
Unknown predator	15 – 20	1991 – Unknown period	1 - Direct observations of seal predation. 2 - The presence of penguin "skins" indicative of seal predation in which violent shaking results in the "degloving" of the skin and feathers from the body.
The following predators were found in the colony and relocated or translocated.		Caracal (*Caracal caracal*) Large-spotted genet (*Genetta tigrina*) Small grey mongoose (*Galerella pulverulenta*) Water mongoose (*Atilax paludinosus*) Cape clawless otter (*Aonyx capensis*)	

Of these > 131 predations at Stony Point between 1986 and 1990, the majority (n = 116; 89%) were confirmed leopard predation, with 65 being killed in one event over two days in 1986, and another 50 killed in 1990. During 1990, between 15-20 penguins were killed by an unknown predator. Other predatory species like caracal, large spotted genet (*Genetta tigrina*), mongoose, and otters were caught in the colony and translocated, but further details (e.g., receiving population and post release monitoring) were not recorded.

Strategies for reducing predation by terrestrial predators on mainland penguin colonies

The assessment of potential management strategies and both the requirements for realising a given strategy and the estimated cost are provided below (Tables 5–11). While these tables are thorough, they are by no means exhaustive, nor is it suggested that any of these approaches should be used in isolation, rather, their contents were developed by and used in a workshop with relevant stakeholders, statutory authorities, and experts in the field to enable an overall evaluation or 'scoring' to systematically justify and prioritise multiple methods for mitigating the impacts of caracal on penguins in Simon's Town while doing the least harm to caracal.

Table 5. A list of potential management strategies for preventing terrestrial predators from killing penguins in the mainland colony of Simon's Town including the requirements for achieving the strategy and estimated costs.

Management strategies	Activity	Requirements	Estimated Costs
Collaborative and integrated networks amongst the different conservation authorities.	Wildlife does not conform to jurisdictional boundaries and hence effective wildlife management requires collaboration between management agencies.	Regular meeting space. Incentivise 'soft' engagement and network development.	Free (alternate availability in existing facilities). Bi-annual meeting catering – R 2,000 p/m or free if sponsored. Annual Fee – R 4,000.
Create and manage public engagement forums.	Facilitate community meetings with all relevant stakeholders, experts and interested and affected parties.	Regular meeting space. Incentivise 'soft' engagement and network development (i.e., during meals and refreshments). Employ a public relations specialist to facilitate.	Free (alternate availability in existing facilities). Bi-annual meeting catering – R 2,000 p/m or free if sponsored. Bi-annual meeting (4 hrs @ R 500/h) or free if sourced internally and sponsored. Annual Fee – R 8,000.
Publicise the adaptive management processes.	Directly inform key stakeholders of predations and attempted predation events on penguins by caracal.	Publish and regularly advertise on an information platform. Incentivise 'soft' engagement and network development (i.e., during meals and refreshments). Employ a public relations specialist to facilitate.	Free (alternate availability in existing facilities). Bi-annual meeting catering – R 2,000 p/m or free if sponsored. Bi-annual meeting (4 hrs @ R 500/h) or free if sourced internally and sponsored. Pamphlet design and print – R 1,500 p/a Newspaper/magazine article – R 1,000 p/a. Host a blog or public webpage – free if sourced internally and sponsored. Fee – R 10,500.

Table 6. Mitigation strategies to reduce predation events at mainland penguin colonies of Simon's Town and Stony Point and an estimated cost.

Mitigation strategies	Activity	Requirement	Estimated Cost
Resident-driven predator proofing.	Publicly request that all residents caracal-proof their properties and the area immediately surrounding Simon's Town.	Employ community engagement officer at ≥ minimum wage (2021; R21.69/hour) 60 for three working days (8 hours) a month with the option of using volunteers.	R 550 p/m or free. R 6,600 annually.
Deploy CCTV cameras for the early detection of caracals entering the penguin colony.	CCTV cameras are an increasingly important and sophisticated component of crime prevention in urban areas.	Installation of three strategically placed CCTV stations. Employ security officers at ≥ minimum wage (2021; R21.69/hour) 60 for ~30 working days (24 hours) a month with the option of using volunteers.	R 13,000 (once-off not including maintenance). R 16,000 p/m x 12 months = R192,000 annually.
Deploy camera traps directly linked to a cellular manager alert system.	Establish site-specific monitoring of caracal movement before they enter the penguin colony using camera traps equipped with the ability to send photographs directly to a constantly monitored cell phone network.	Camera traps with cellular transmission (x20). Employ security officers at ≥ minimum wage (2021; R21.69/hour) 60 for ~30 working days (24 hours) a month with the option of using volunteers.	R 12,000 (per trap) x 20 = R 240,000 (once off). R 16,000 p/m x 12 months = R192,000. R 240,000 + R192,000 = R432,000 per year one. Year two only R200,000 staff salary Camera's to be replaced around 5 years.

Table 7. Barriers to prevent caracal from accessing the mainland penguin colonies of Simon's Town and Stony Point and an estimated cost.

Barriers	Activity	Requirement	Estimated Cost
Erect a fence to exclude caracal.	Install caracal-proof metal fencing specially designed to physically prevent caracals from accessing the penguin colony.	500m of 1.8m steel welded mesh with overhang.	R 500,000 (once-off not including maintenance).
Erect an electrified fence to exclude caracal.	Install caracal-proof metal fencing specially designed to physically prevent caracals from accessing the penguin colony. This includes an electrified component as part of the overhang, preventing caracal from jumping over or balancing on the fence and jumping over.	500m (strategic sections only) of 1.8m steel welded mesh with an electrified (solar-powered) overhang.	R 700,000 (once-off not including maintenance).
Erect a mesh netting fence to exclude caracal in strategic sections only.	Install caracal-proof flexible netting (similar to a volleyball net) designed to physically prevent caracals from accessing the penguin colony. This includes flexible netting that is difficult to climb as it is not firm, preventing caracal from jumping over or balancing on the fence and jumping over.	500m (strategic sections only) of 1.8m steel mesh netting with an overhang.	R 250,000 (once-off not including maintenance).
Erect a combination fence to exclude caracal in strategic sections only.	Install a fence made of various materials such as the one designed by BirdLife South Africa for future implementation at the De Hoop Nature Reserve penguin colony (see Appendix A). Using wooden posts, trawl netting, an angled overhang, electric strands (solar powered), a gabion roll and anchovy netting on the ground. Remove the bottom electrified strand to avoid harming animals that become entangled in trawl mesh.	500m (strategic sections only) of 1.8m combination mesh fencing with an electrified (solar-powered) overhang and base roll.	R 350,000 (includes labour and materials).
Establish a virtual fence to exclude and secure the penguin colony area against caracal incursions.	Use noise aversion to establish a virtual barrier to caracal incursion. GPS collars on caracals send an alert to a cell phone in real-time when the collared animal passes through a 'geofence' (a virtual line of GPS points) allowing guards to respond and place noise aversion devices in the path of the approaching caracal to deter it.	Modified GPS collars and virtual fencing software and hardware.	R 50,000 – R 70,000 per caracal. It is estimated that two caracal per year might "find" the colony, so cost is an estimate of R140,000 per year.

Table 8. Guards to patrol the Simon's Town breeding colony, to detect mortalities and potential predators.

Guards	Activity	Requirement	Estimated Cost
Employ rangers to monitor the colony, detect mortalities, signs of predators and to actively deter caracal from entering the penguin colony.	A guard or monitor is employed to patrol Burghers' Walk and Boulders boardwalk creating a noise (e.g., clapping or playing a recording) throughout the night, creating a noise deterrent for any nearby caracal and establishing a permanent human presence in the area surrounding the penguin colony.	Employ monitor at ≥ minimum wage (2021; R21.69/hour), uniform, transport, overtime. (12 hours) a month with the option of using volunteers.	R500,000 per year.
Deploy guard dogs to detect the scent and deter caracal from entering the penguin colony.	Domestic dogs pose a predation threat to caracal and can thus be used as a patrolling deterrent to caracal in the area surrounding the penguin colony. Guard dogs (generally neutered males) must be socialised with humans to keep them tame, following the 'Warrnambool Method' to avoid dangerous and feral behaviour	Maremma sheepdog. Employ handler at ≥ minimum wage (2021; R21.69/hour), uniform, transport, overtime. (12 hours) a month with the option of using volunteers.	R500,000 per year for Handler. R8,000 once off for dog (excluding food, veterinary care and training costs).

Table 9. Aversive techniques like light and noise disturbance, and the use of a bio fence at the Simon's Town breeding colony to disturb predators to reduce potential penguin mortalities.

Aversive measures	Activity	Requirement	Estimated Cost
Deploy light and sound aversion devices to deter caracal from entering the penguin colony.	Devices that use sound or light to discourage the presence of nuisance animals (caracal). These devices are either placed in a stationary location and activated by a sensor, or are hand-held and activated manually (e.g., bear bangers have been used successfully to deter baboons from urban areas on the Cape Peninsula).	Action Stations (x 20 units).	R 10,000 per station. R 200,000.
Employ conditioned taste aversion (CTA) to deter caracal from eating penguins.	This entails treating baits (e.g., carcasses of recently killed penguins) with chemicals so that when a caracal eats the bait, they become nauseous and are behaviourally deterred from killing penguins.	Capture, tranquillisation, and transport.	R 30,000 per caracal. R 30,000 – R 60,000.
Employ a bio-fence boundary to deter caracal from entering the penguin colony.	Place artificial caracal scent around the penguin colony to deter immigrant caracal males from entering the colony.	Artificial chemical analysis and development.	R 1,000 to buy and regularly treat with the predator urine and faeces.

Table 10. Non-lethal control methods at the Simon's Town and Stony Point penguin breeding colonies and potential associated costs.

Non-Lethal control	Activity	Requirement	Estimated Cost
Trap and translocate caracal in the vicinity of the penguin colony, before any predation events.	Monitor the area surrounding the colony with camera traps and if a predator is detected in the vicinity of the colony, capture and remove it.	Capture, tranquillisation, transport, and collaring.	R 45,000 per caracal.
Use contraceptives or surgical sterilisation to reduce reproduction of territorial resident caracal living adjacent to the penguin colony.	Use surgery or chemical contraceptive (baited oral or skin implant) to lower caracal recruitment in the vicinity of the penguin colony and so maintain presence of territorial caracal.	Capture, transport, intervention, and monitoring. Deslorelin (6mg dose), surgery or implant.	R45,000 per caracal.

Table 11. Lethal control of caracal at the Simon's Town and Stony Point penguin breeding colonies and potential associated costs.

Lethal control	Activity	Requirement	Estimated Cost
Trap and euthanise caracal that are actively predating on the penguin colony.	Caracal presence is detected by penguin predation events, a cage trap is set up, using the recent prey carcass as bait. The trapped caracal is then removed and destroyed humanely by a veterinarian.	Trap maintenance, capture, and procedure.	R 5,000 per individual.
Without trapping, shoot 'potentially' damage-causing caracal before they enter the penguin colony.	When a caracal has killed in the vicinity of the colony, it is shot by a CoCT-approved professional hunter (PH) the following evening without capture. The kill of the previous evening is used as bait.	PH call-out fee and processing.	R 5,000 per individual.

The mitigation strategies to reduce predation events by terrestrial predators at the mainland colony of Simon's Town are evaluated and an estimated cost determined (Tables 6–11) to rank the relative value of each and ultimately combinations thereof. In these meetings, the pros and cons were discussed for each strategy (see Appendix F1b for detailed pros, cons and costs), whereafter an overall positive or negative score was agreed upon by all participants (Table 12).

Table 12. A summary of overall standardized evaluation scores for the 17 primary mitigation strategies proposed for the management and resolution of caracal-penguin conflict near the Simon's Town penguin breeding colony.

Category		Strategy	Overall score (Not Recommended / Recommended)
Non-contact	1. Early detection	a. Resident security	0
		b. CCTV cameras	22
		c. Camera traps	12
	2. Barriers	a. Metal fence	6
		b. Electrified fence	4
		c. Mesh fence	2
		d. Combination fence	18
		e. Virtual fence	8
	3. Guards	a. Night/hazing rangers	10
		b. Guard dogs	8
	4. Aversive measures	a. Light and sound	8
		b. Conditional taste	-12
		c. Bio-fencing	-12
Contact	5. Non-lethal control	a. Translocation	18
		b. Fertility regulation	-12
	6. Lethal control	a. Injection	0
		b. Shoot	-2

The three highest scoring strategies that were considered were CCTV cameras, combination fence, and translocation. The first recommended strategy is CCTV cameras for the early detection of caracals entering the penguin colony (Table 6). CCTV cameras are an increasingly important and sophisticated component of crime prevention in urban areas and inadvertently detect wild animals moving along fence lines and through the same green corridors that criminals use. Strategically placed CCTV coverage could be used to monitor human and caracal presence and movement in the area, providing an early warning detection system before a caracal enters the colony. This only locates the caracal and would need to be linked to another intervention such as actively deterring the detected caracal or translocation. Detailed pros, cons and costs were discussed (Appendix F1b). While there is evidence to substantiate its efficacy, the additional benefits of improved security will likely engender support from residents. The overall support score for this intervention was +22 (Table 12), as the pros (especially evidence of efficacy and stakeholder benefits and support) strongly outweighed the cons (costs).

The second recommended strategy considered was a combination fence (Table 7) made of various materials such as wooden posts, trawl netting, an angled overhang, electric strands (solar-powered), a gabion roll and anchovy netting on the ground. The bottom electrified strand can be removed to avoid harming animals that become entangled in trawl mesh. Detailed pros, cons and costs were discussed (Appendix F2d). This strategy excludes and potentially endangers non-target species which poses ethical and ecological risks. While there is evidence of its efficacy and benefits to residents (mostly security), the unsightly nature and limitation on access may not engender support from residents. There would be a short delay in turnaround time and an annual cost (including monitoring of tangled non-target species) - with minimal initial implementation effort and costs. However, it requires relatively little resident effort. The overall relative support score for this intervention was +18 (Table 12), as pros (fit-for-purpose design, efficacy, and resident security benefits) mostly outweigh cons (cost of installation and ethical or ecological concerns).

The third recommended strategy was the first form of non-lethal control considered, which was translocation of the predator from the area in which penguin losses occur (Table 10). Caracal have been observed returning to the kills made the preceding evening. The use of penguin carcasses from the previous night's hunt as bait placed inside walk-in traps has seen a 100% capture rate. Detailed pros, cons and costs were discussed (Appendix F5a). This strategy is highly specific to damage-causing individuals, posing few ethical and ecological risks. While there is evidence of its efficacy, there are few specific benefits to residents. It has a short turnaround time (assuming capture), with some initial implementation costs and effort, however, it requires relatively little resident effort, and the associated annual costs of implementation are relatively low. The overall relative support score for this intervention was +18 (Table 12), as pros (evidence of efficacy, as well as permanence and simplicity of implementation) significantly outweigh the cons (annual implementation cost and effort).

The three lowest scoring (not recommended) strategies were conditional taste, bio-fencing, and fertility regulation. The first non-recommended strategy considered were conditional taste, a form of aversive measures (Table 9). It entails treating baits with chemicals so that when a caracal eats the bait, they become nauseous and are behaviourally deterred from killing penguins. There is an option to treat killed penguins with bitter compounds that make caracal temporarily ill the day after it has been killed. Next time, the smell alone may be enough of a deterrent. Detailed pros, cons and costs were discussed (Appendix F4b). This strategy poses both ethical and ecological risks and while there is some evidence of its efficacy, there are few specific benefits to residents who may not be comfortable with captive aversive conditioning. The process carries a long turnaround time (assuming caracal can be safely released), with relatively high initial and annual implementation cost and efforts. However, it requires relatively little resident effort. The overall relative support score for this intervention was -12 (Table 12), as pros (mostly evidence of efficacy) are generally outweighed by the cons (long turnaround time, as well as substantial initial and annual implementation cost and efforts, in addition to ethical and ecological concerns).

The second non-recommended strategy considered was bio-fencing, a form of aversive measures (Table 9). This entails placing artificial caracal scent around the penguin colony to deter immigrant caracal males from entering the colony. Caracal are territorial and hence are predicted to respond to territorial cues in the environment. The scent should be artificially manufactured as obtaining real urine would require long-term captivity of a dominant caracal, which is ethically questionable. Detailed pros, cons and costs were discussed (Appendix F4c). This strategy poses few ethical and ecological risks and while there is good evidence of its efficacy, there are few specific benefits to residents. The process carries a long turnaround time (assuming a suitable artificial substitute can be synthesised), with extremely high initial implementation costs and effort. However, it requires relatively little resident effort and the associated annual costs of implementation are low. The overall relative support score for this intervention was -12 (Table 12), as pros (evidence of efficacy and simplicity of implementation after development) are generally outweighed by the cons (long turnaround time and substantial initial implementation costs and effort).

The third non recommended strategy considered was a form of non-lethal control (Table 10) termed fertility regulation. This entails using surgery or chemical contraceptives to temporarily prevent caracal in the region from having offspring, hardening territorial boundaries and predatory pressure by limiting population growth and dispersal. Detailed pros, cons and costs were discussed (Appendix F5b). This strategy, though highly specific to damage-causing individuals, is invasive and poses ethical and ecological risks. While there is some evidence of its efficacy, it has yet to be tested in caracal and there are few resident-specific benefits. The process carries a long turnaround time (assuming the majority of one sex on the Cape Peninsula can be captured), with substantial implementation costs and effort. However, it requires relatively little stakeholder effort. The overall relative support score for this intervention was -12 (Table 12), as pros (evidence of efficacy) do not outweigh the cons (lack of research and uncertainty, the long turnaround time, as well as implementation cost and efforts). See Appendix F and Appendix G for more details on the detailed pros, cons and costs discussed for each strategy in Table 12.

In addition to strategies for reducing predation by terrestrial predators on mainland penguin colonies, it was also suggested that the task team address other causes of penguin mortality by a) fixing existing barrier fences for penguins to better secure the colony, b) enforcing CoCT 'dogs-on-leash' laws to minimise conflict in public spaces, c) establishing and enforcing speed calming measures to reduce vehicular collisions, d) building a penguin passage under the existing boardwalk to reduce disturbance by people, e) Reducing harassment and disturbance of penguins by visitors, f) rehabilitating the natural vegetation in and around the existing penguin colonies, g) modifying and improving on artificial nest development to improve breeding success, and h) mandating a 20 km ‘no-fishing’ zone around the colony. These efforts are discussed extensively in the developed management plan and would serve to reduce non-caracal related mortalities in Simon’s Town.

Further strategies to support the growth of the colony and reduce predation were also considered, including the a) supplementary feeding of predators or restocking of their preferred prey species, b) introducing natural predators and competitors to offset caracal predation pressure, c) establishment of an artificial island for penguins to colonise and safely breed on locally, d) translocation of penguins to an existing island for safety and recolonisation, e) collaring and constant monitoring of all caracals along this section of the Cape Peninsula, f) building a caracal ‘scarecrow’ to deter caracal from entering the penguin colony, and g) determining and maintaining a sustainable level of caracal predation within the penguin colony. These considerations were put forward as part of the workshopping process towards exploring management interventions that can reduce terrestrial predation of critically Endangered African penguins living in mainland colonies on the South African coastline.

Relocation of caracal from mainland penguin colonies

Local conservation authorities have caught and released one caracal and translocated three within the TMNP or elsewhere to date (Figure 9).

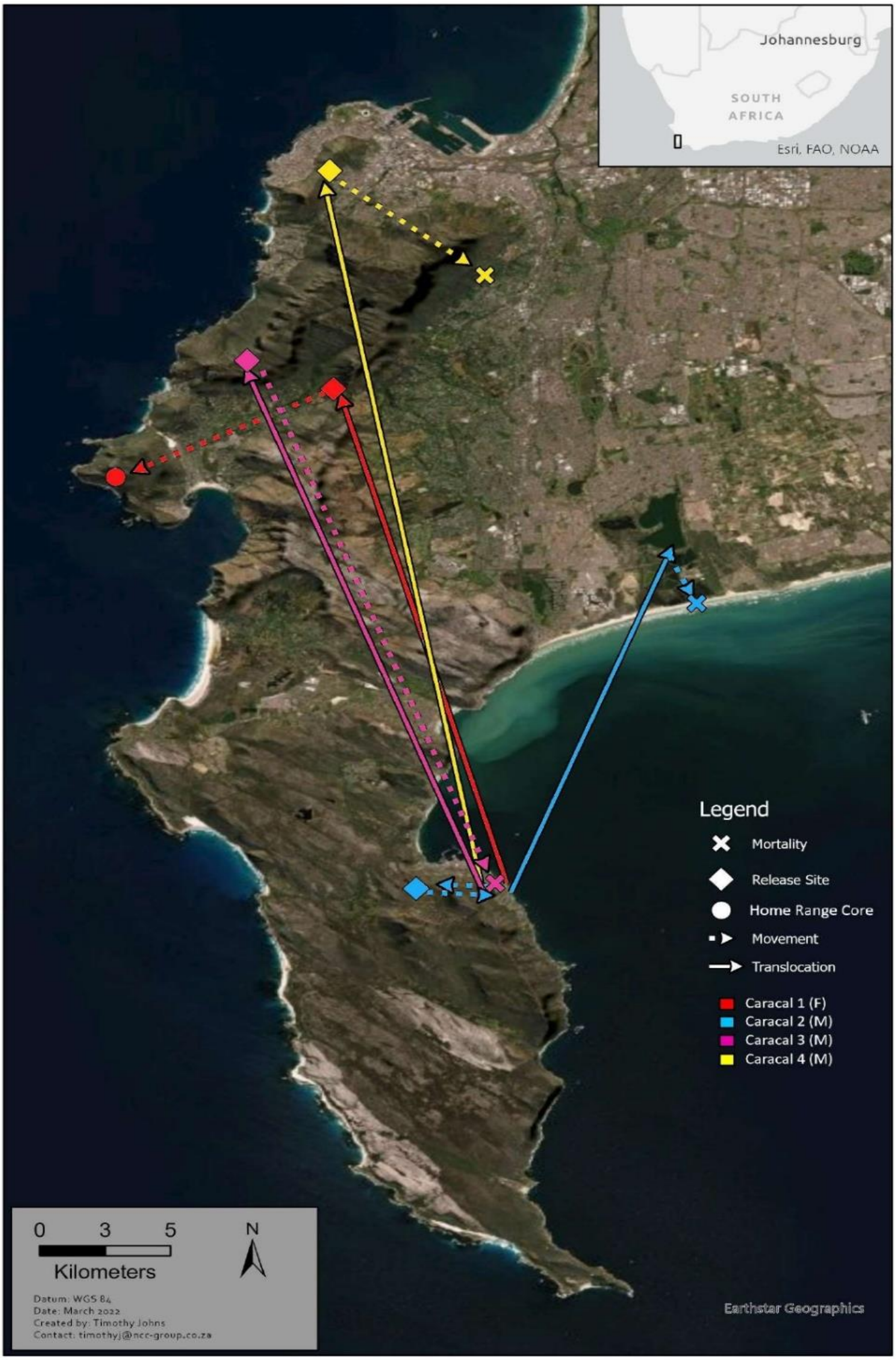

Figure 9. A map showing where captured caracal (*n* = 4), that had been predating on penguins in Simon's Town, were translocated to. The solid arrow with a diamond shows the release site, subsequent movement is denoted by the dashed arrow with the centre of the new home range shown as a filled circle or the mortality site as a cross.

In 2016, an adult female (Figure 10; red) was caught in the colony and relocated to Orange Kloof nature reserve (*ca.* 22 km from the colony) within TMNP. After being released, this caracal moved into the Karbonkelberg region of TMNP where it remained until its collar battery died. The female caracal (TMC27 – 'Disa') travelled a total of 273.1 km between 8 July 2016 and 18 November 2016 (134 days), at an average of two kilometres per day and was never recorded at the penguin colony again.

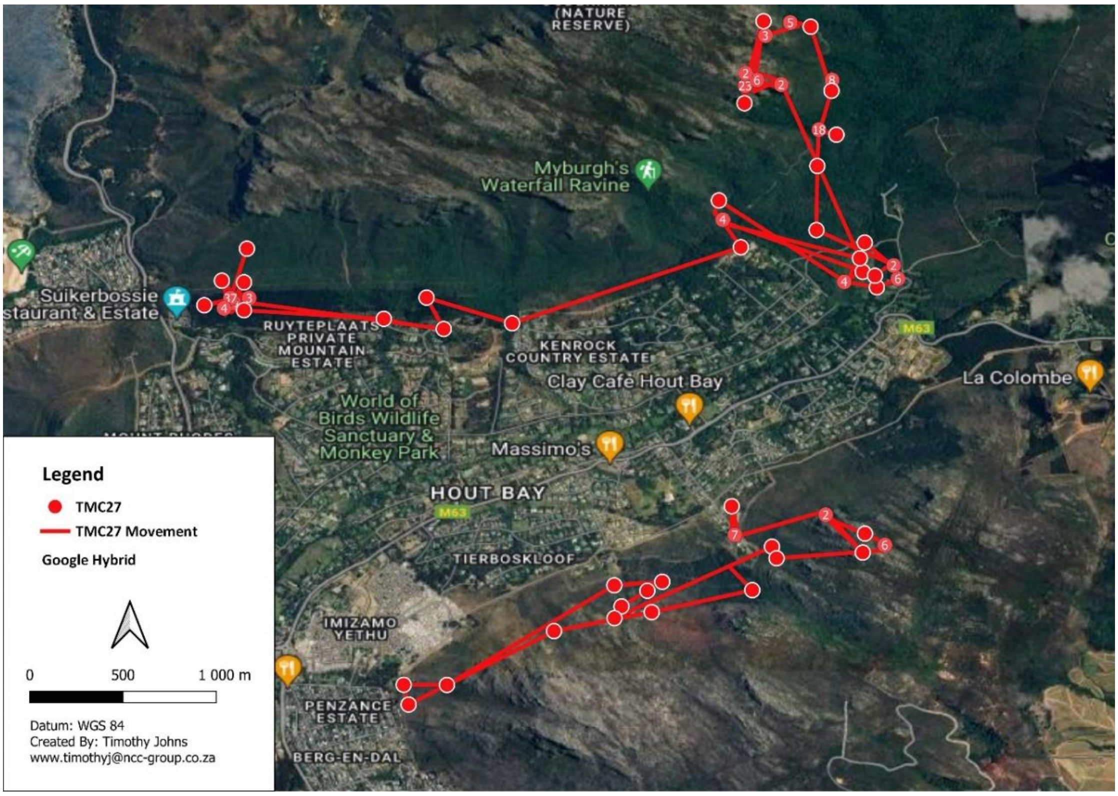

Figure 10. The movement patterns (red lines) of Caracal1F (classified as TMC27 by Urban Caracal Project) after it had been captured and released at Orange Kloof within Table Mountain National Park. The red circles have more than one point at each location.

In 2018, a young male (Figure 9; magenta) was captured whilst approaching the colony and released near Oudekraal-Llandudno ravine (*ca.* 25 km from the colony) within the TMNP. It took this individual approximately 12 days before it reached the colony again following which it was recaptured and euthanised. This individual was not collared as there was no collar available at the time of capture.

In 2017, a young male (Figure 9; gold) was caught approaching the colony in the TMNP area and relocated and released on Signal Hill (*ca.* 32 km from the colony) within the TMNP. This caracal died in a vehicle collision on a major highway 5-7 days later and approximately 8 km from its release site.

In 2017, a young male (Figure 11; blue) caught in the colony and released at Red Hill (*ca.* 3 km from the colony), returned to the penguin colony within 24 hours. Non-lethal deterrents (i.e., noise aversion and untrained guards) were used to try and deter the male, whose movements were monitored using the GPS collar from the colony, but these were unsuccessful. The male re-entered the colony and killed twelve penguins in one night and was subsequently recaptured and translocated to False Bay Nature Reserve (Figure 12) (*ca.* 21 km from the colony) where he persisted for 10 days, before being killed in a vehicular collision on a road along the southern border of the reserve. This caracal travelled 68.33 km between 28 September 2017 and 19 October 2017 (22 days; 3km/day) before being killed in the vehicle collision.

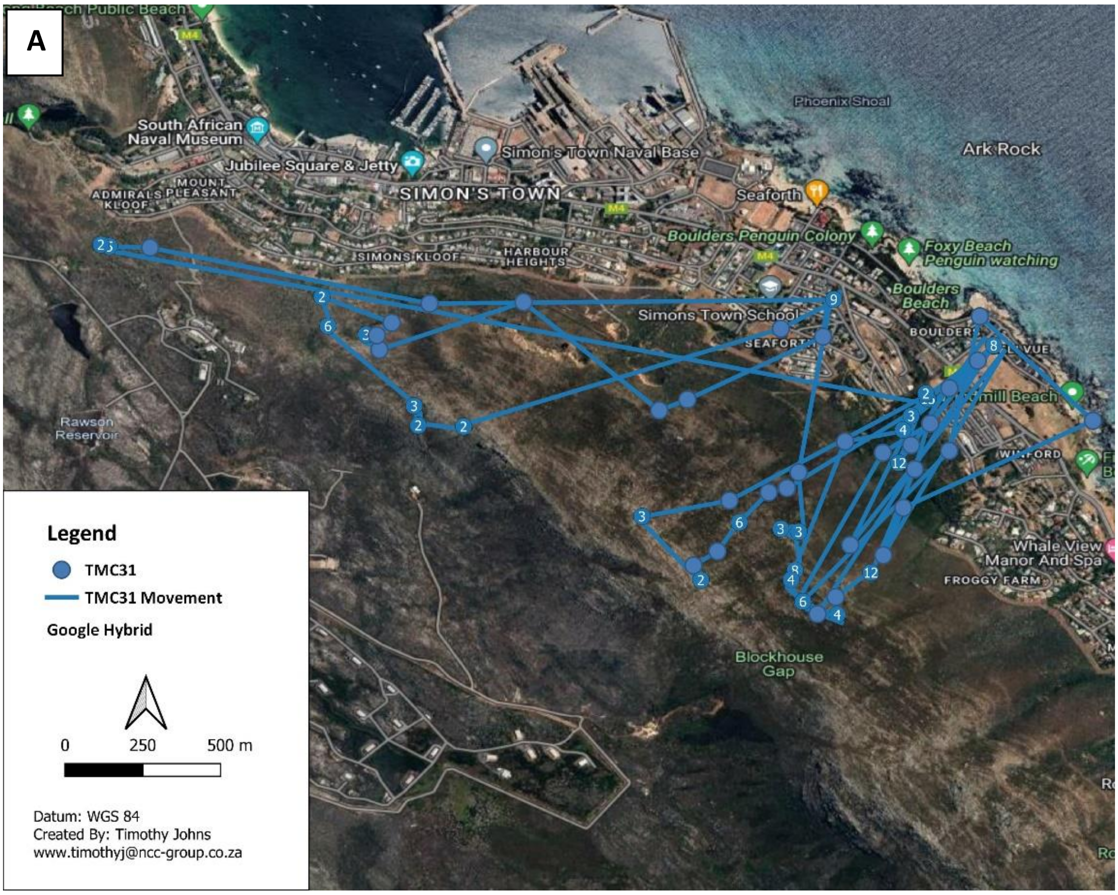

Figure 11. The movement patterns (blue lines) of Caracal 3M (classified as TMC31 by Urban Caracal Project) after it collared and released within Simon's Town. The blue circles have more than one point at each location**.**

Figure 12. The movement patterns (blue lines) of Caracal 2 (classified as TMC31 by the Urban Caracal Project) after it had been captured for a second time at the Simon's Town colony (B) and was released within False Bay Nature Reserve. The blue circles have more than one point at each location.

Shock or electronic aversive collars are not supported by welfare groups in South Africa, according to section 2(F) of the Animals Protection Act No 71 of 1962 (as amended). Extract of Section 2(F) of the Animal Protection Act No 71 of 1962 (as amended): 2. "*(I) Any person who- (f) uses on or attaches to any animal any equipment, appliance or vehicle which causes or will -cause injury to such animal or which is loaded, used or attached in such a manner as will cause such animal to be injured or to become diseased or to suffer unnecessarily".* Based on this act, it is deemed illegal by the legislative bodies, and would thus not work in this situation, either until the legislation has changed, or until it is approved as accepted by the welfare organization responsible for enforcing the Animals Protection Act.

If aversive collars were an option, a young male approaching the colony could be fitted with an aversive collar. This would allow the caracal to fill the niche, while the collar linked to a geo-fenced area could prevent the caracal from entering the colony or predate on the penguins. When the caracal becomes settled in the home range, it would hopefully keep other young males away from the breeding colony, and the result will be a lower need for euthanasia or translocation of young males being pushed out to find a home range.

Discussion

African penguin population dynamics and managing caracal predation risk

African penguin numbers have declined by 65% over the last 30 years, from an estimated 51,500 pairs to a historical low of 17,700 pairs in 2019 (Sherley *et al.,* 2020). Apart from a brief recovery period from the 1990's to early 2000, numbers have declined by an average of 4.8% per year (Sherley *et al.,* 2020). Shelton *et al.,* (1984) state that African penguin numbers halved between 1956 and 1978 alone because of collapses in the pilchard populations, while Duffy *et al.,* (1987) suggest that competition with the commercial purse-seine fishery is the main cause of the decrease in the population of African penguins off the coast of southern Africa. By contrast many mainland colonies showed an increase in numbers over the same period (Figure 4), with for example, the Simon's Town colony increasing from only a few pairs to *ca.* 366 pairs (Crawford *et al.,* 1995), to the most recent estimate of *ca.* 850 pairs (Vanstreels *et al.,* 2019). This growth relative to west coast island populations was largely attributed to recent reductions in commercial pelagic trawling in False Bay which allowed young birds to source food close to the colony (Geldenhuys, 2018). Around 2011, the colony growth rate was nearing 60%, suggesting immigration from other colonies, and it is important to note that the start of this colony coincides with the start of the decline of the Marcus Island population. Similar peaks in growth rate were recorded at Stony Point (Figure 8) which was attributed to immigration of first-time breeders from Dyer Island (Figure 4A).

The success of both the Simon's Town and Stony Point colonies revealed the importance of mainland breeding sites for the species but the demise of both the Marcus Island and De Hoop colonies served as a warning that mainland colonies need human intervention to ensure their continued persistence. All mainland colonies have suffered high levels of terrestrial predation, but it seems likely that high human density surrounding both the Simon's Town and Stony Point colonies, buffered them from terrestrial predators that typically avoid urban areas (Nattrass & O'Riain, 2020). By contrast the remoteness of both the De Hoop and Marcus Island colonies meant that predators could attack and feed on penguins while relatively undisturbed by humans or associated human activities. Despite the buffering effect of urban development around both Stony Point and Simon's Town they have nevertheless been vulnerable to episodic predation events by predators that have become habituated to the presence of people and urban infrastructure and entered the colony by passing through or close to the urban edge.

Most recorded predations at Stony Point were by grey mongoose, followed by Cape fur seals and then caracal, while in Simon's Town caracal were the primary predators followed by seals and domestic dogs (Table 1). Both colonies experienced repeated supernumerary predation events linked to both leopard (Stony Point) and caracal (Simon's Town and Stony Point) with 65 penguins killed by a single leopard over two days in Stony Point. In Simon's Town, eight caracal have killed *ca.* 300 penguins over a 6-year period (Figure 6) with a single female killing 131 penguins in 2016, and in 2017, a single male killed 122 penguins. These mortality data reveal that individual predators will continue to consume penguins once they have discovered a colony and that many more are killed than eaten, often in one evening. Such supernumerary killing events are well established in the literature, having been documented in feral cats (*Felis catus*), common bushtail possums (*Trichosorus vulpecula*) and Tasmanian devils (*Sarcophilus harisii*) all of which have led to the local extinction of short-tailed shearwater (*Puffinus tenuirostris*) on select island colonies (Scoleri *et al.,* 2020).

Terrestrial predation events at both Stony Point and Simon's Town have been primarily managed by capturing and relocating the predators to nearby PA's. Relocated predators include leopard, caracal, water mongoose, small grey mongoose and large-spotted genet at Stony Point and caracal in Simon's Town. While the fate of the smaller predators is unknown as there was no attempt at post-release monitoring, the leopard returned to Stony Point and resumed predation as did three of the caracals relocated from Simon's Town (Figure 9). Only one caracal, an adult female, successfully established a new home range elsewhere on the Peninsula (Figure 10), and two of the relocated male caracals were killed by vehicles soon after their release and one was euthanised. The leopard was shot by a private landowner outside of the context of penguins. It is common for predators to return to their home range after being relocated (Stander, 1990) with some covering remarkable distances in doing so, including lions in Zimbabwe covering more than 27 km (Stander, 1990) and cougars moving up to 494 km (Ruth *et al.,* 1998), while wolves have travelled up to 282 km in Alaska post-translocation (Bradley *et al.,* 2005).

At Stony Point a mesh fence was installed, which prevented the colony from expanding into residential areas where they are at risk of vehicular deaths in addition to reducing human and domestic animal disturbance within the colony. However, this fence did not stop smaller predators such as small grey mongoose and water mongoose from passing through and under the fence. Caracal are capable of climbing or jumping the fence and otters and seals can approach the colony from the seaward side (Whittington *et al.,* 1996). The Stony Point colony is more isolated by urban development than Simon's Town which has larger coastal and terrestrial corridors leading into the colony. Caracal are less of a threat at Stony point than at Simon's Town, but this could be due to the presence of leopard in the Stony Point area, which are known to suppress caracal (Drouilly *et al.,* 2018). Scoleri *et al.,* (2020) found that smaller predators could adopt risk-sensitive behaviour to avoid encountering larger predators, and these behaviours could alter habitat use or shift their diet.

Translocations

High levels of mortality for translocated individuals are also common (Weise *et al.,* 2015) and have been linked to both gender and age. Miller *et al.,* (1999) found than mortality rates are higher in older pumas (*Puma concolor*); while Gedir *et al.,* (2018) found that female black rhinoceroses (*Diceros bicornis*) had a higher mortality post translocation. Vehicle collisions are a major cause of mortality for all caracal on the Peninsula (Leighton *et al.,* 2020), particularly for subadult males at dispersal age. TMNP on the Peninsula is surrounded by residential suburbs serviced by a dense network of roads. As a result, animals moving through the PA's must traverse numerous roads (Serieys *et al.,* 2019). Vehicle mortality is similarly high for other medium-sized mammals on the Peninsula including Cape Clawless otters (Schnetler *et al.,* 2021) and chacma baboons (Mormile *et al.,* 2017), and for other medium sized felids living in peri-urban landscapes such as bobcats in the USA (Fraser *et al.,* 2017) and lynx in Europe (Mengüllüoğlu *et al.,* 2021).

Not all captured caracal in Simon's Town were relocated immediately, with the second individual captured, collared, and released back into what was assumed to be the edge of its home range (Figure 10). This decision was reached following a workshop with a diverse group of stakeholders including the relevant management authorities. Here it was agreed that the routine capture and relocation of caracal out of the area would create a local population sink and thus it may be better to capture, collar and monitor the movements of the caracal to understand the access routes to the colony from the mountain and to actively deter the caracal from approaching the colony using barriers and aversive conditioning. If this non-lethal approach was unsuccessful, and the caracal resumed predation in the colony, then it was agreed by all stakeholders that the individual would be recaptured and either euthanised or translocated elsewhere. The use of *in situ* non-lethal methods to prevent predation and to only consider lethal outcomes if the former fails is consistent with best international practice (Treves, 2009) and mirrors the current management of chacma baboons on the Peninsula (van Doorn & O'Riain, 2020; Beamish & O'Riain, in press). The caracal did return to the colony and resumed predation, killing twelve individuals in one night before being recaptured and translocated to a small CoCT protected area (False Bay Nature Reserve; see Figure 12) where it persisted for 10 days before being killed in a vehicle accident on a busy road adjacent to the reserve. Although ultimately a conservation failure as the intervention resulted in both more penguin deaths and the death of the caracal, important information was realised including the caracal's preferred route from the mountains of the national park down into the penguin colony. Secondly, it became apparent that actively attempting to deter a caracal that is already habituated to urban areas, frequented by people, was exceptionally difficult. Staff who attempted to 'walk in' on the caracal as it was moving down towards the colony were unsuccessful in deterring the caracal which proved adept at evading them. This may explain why previous human foot patrols within the colony that sought to prevent caracal from entering the main colony were also only partially effective.

Other high ranking non-lethal methods for preventing caracal from predating on penguins in Simon's Town (Table 10) included: 1) CCTV cameras or camera traps placed in movement corridors for the early detection of caracal approaching the colony, 2) barriers placed across movement corridors to deter the caracal or funnel them into a cage trap should they persist in attempting to circumvent the barrier and 3) the translocation to a suitable protected area which would benefit from the arrival of a caracal of a particular sex. The use of camera traps along a 1.8 m high mesh fence barrier has since proven to be an effective method for detecting caracal before they entered the colony. The barrier has similarly proved to be successful at funneling them into a cage when they did seek to circumvent it. However, the failure of all but one relocation on the Peninsula resulted in CN declining further permits to relocate caracal on the Peninsula. In the absence of tried and tested non-lethal measures to prevent further penguin predations by caracal, the last three individuals captured while approaching the colony were all euthanized *in situ* by a veterinarian. It is argued that the rigorous testing of non-lethal methods near the colony cannot be justified at the risk of losing more Endangered penguins.

Caracal-penguin interactions within and around the Simon's Town penguin colony is trans-jurisdictional with penguins breeding on private properties, public open space managed by the CoCT, and PAs managed by SANParks. A key outcome of the stakeholder engagement process was the decision to invite existing management agencies (e.g., SANParks, CoCT), welfare organizations (e.g., Societies for the Prevention of Cruelty to Animals; SPCA), public stakeholders, media, scientists and interested public parties to collaborate on a way forward that 1) does not rely solely on lethal management but prioritizes the protection of Endangered penguins from terrestrial predation, 2) supports the trial-and-error processes of adaptive management, and 3) continues to hold conservation management accountable to a high ethical and ecological standard while allowing research to drive much needed practical experience and knowledge-based development. With the city officials opposed to routine killing of caracal that approach the colony, they agreed to pursue the option of translocations to City Nature Reserves (CNRs) within the Greater Cape Town (GCT) region. The Peninsula is geographically isolated from most CNRs by urban sprawl and most reserves are themselves isolated from each other and may thus benefit from the introduction of caracal. To achieve this however, considerable research would be required to first identify suitable city reserves for receiving caracal and second, to manage the itinerant risks including disease transmission.

Developing a caracal translocation management plan

In devising a translocation management plan for caracal threatening penguins in Simon's Town, I reviewed *ca.* 100 translocation studies to establish the main reasons for translocations, the IUCN status of the species, the success and/or failure rate as well as the various definitions of measuring success and if/how post release monitoring was conducted. The literature review showed that 67% of the translocations were for conservation objectives, including assisted re-colonisation and ecological replacement outside the indigenous range (Appendix E, Figure 16). While 93% of the studies included post-release monitoring, not all of these had clear monitoring methods. The IUCN Guidelines stipulate that all translocation programs should have realistic goals and objectives and the monitoring of results should specify what evidence will be used to measure progress towards meeting the objectives and ultimately the success or failure of the translocation (Appendix E, Figure 18). Of the studies reviewed, 45% of the translocations had 75% success rate, and only 4% indicated complete failures (Appendix E, Figure 19). According to Germano (2009), many conservation managers have a reluctance to report failed translocations, and this may have led to an overestimation of true success rates. The inability to completely rehabilitate DCAs and the lack of adequate habitat were major drivers for failed translocations. Another reason for low success could also be that certain researchers add the mortality of captures and transportation as part of the translocation success or failures, while others only measure the success post release.

There are often practical limitations to translocation, such as the difficulty of identifying target individuals, the costs and welfare concerns of capture and transfer of these animals, the selection of recipient sites and the importance of post-release monitoring (Weise *et al.,* 2015). In Canada, where grizzly bears (*Ursus arctos*) are listed locally as Threatened, many conservation-driven translocations have been undertaken and although Milligan *et al.,* (2018) reported 77% of the events failed, these translocations were still considered a success as the findings were used to aid managers in decision making when considering translocations as a tool for managing human-bear conflict. The primary objective of such translocations is eliminating or limiting the conflict caused by wildlife and secondarily, securing the welfare of the individuals involved (Fernando *et al.,* 2012). For instance, threatened brown hyaenas (*Parahyaena brunnea*) often experience negative interactions with farmers and are either lethally controlled or translocated (Weise *et al.,* 2015). According to Weise *et al.,* (2015) a GPS-monitored brown hyaena that was classified as a DCA was captured and translocated over 63 km away, where it was reported to have settled into a new home range and caused no further damage to the farmer.

Translocations of Non-Threatened species is an accepted conservation intervention, though less common. For instance, a population of howler monkeys (*Alouatta seniculus*) in French Guiana were translocated as their home range was destroyed by a hydroelectric reservoir (Richard-Hansen *et al.,* 2000) and in Kenya two troops of baboons were successfully translocated from farmland, where they were negatively impacting farmers, to a protected area (Strum 2005). Red squirrels (*Sciurus vulgaris*) are another Least Concern species (IUCN/SSC, 2002) that have been translocated due to forest patch isolation with the objective of increasing the distribution of red squirrels in Ireland (Poole & Lawton, 2009). Supplementary feeding at the recipient site was used, but the squirrels also fed on the natural food available, and once established, many were observed lactating and producing offspring (Poole & Lawton, 2009). Fukuda *et al.,* (2019) found that translocated saltwater crocodiles (*Crocodylus porosus*), a Least Concern species that has negative interactions with people in Australia, were translocated primarily to reduce such negative interactions but many returned to their original capture sites suggesting only partial success.

Germano (2009) found that translocations initiated as a reactive response to negative interactions by a particular species or individuals had a higher failure rate than those motivated by proactive conservation objectives. Although such conservation-driven translocations have been conducted for many years, the relative success and failure of these interventions has been poorly documented and is likely case-, species- or landscape-specific. This raises the concern that those charged with resolving negative interactions between wildlife and other species or restoring species range distributions by reintroduction are regularly required to provide approval or instruction on translocations with little direct data to support such decisions. Despite a general lack of data to substantiate either outcome, translocations are generally viewed with scepticism by the conservation community due to the 'known' failures (Weise *et al.,* 2015) which are inherently easier to measure (e.g., conflict and mortality) than translocation success (e.g., behavioural establishment and effective breeding). There is very little evidence available to assess the efficacy of Non-Threatened species translocations; this is generally attributed to the high costs of assisted dispersal which demands that the conservation benefits are proportionately high, as is the case for Endangered species (IUCN/SSC, 2013).

The historical translocation results showed that a translocation program should include a feasibility study, a preparation phase, a release phase, and a monitoring phase. Several biological questions should be addressed during the feasibility study (Kleiman, 1989; IUCN/SSC, 2002). For example, is there is a need to reintroduce or restock a wild population? Does the species occur as a viable population in the proposed release area? If restocking is a possibility, would it pose a threat to the existing wild populations? Have the causes of the population decline or extirpation been eliminated? Is there sufficient protected habitat for the translocated animals to survive? Are there suitable animals available that are surplus to the genetic and demographic needs of the source population? Is there sufficient knowledge to formulate a plan of action and evaluate its success? (Miller *et al.,* 1999).

In the face of rapid biodiversity decline and loss, translocations serve as a vital conservation tool to restore and promote species in particular habitats and with that improve ecosystem functioning (Bubac *et al.,* 2019). Larger carnivores are often the first species to disappear from small PA's and natural corridors that are disrupted by urban sprawl, which makes the natural re-colonization of such areas very difficult (Miller *et al.,* 1999). Urban nature reserves are often small and geographically isolated and hence wildlife within them are vulnerable to inbreeding, genetic drift, and demographic stochasticity with the possibility of catastrophic events (e.g., an extensive fire) threatening to deplete their numbers or even leading to local extirpation (Haddad *et al.,* 2015). Supplementing numbers between small reserves or restoring a species presence is consistent with a metapopulation approach to wildlife management that is increasingly important as natural habitat is fragmented and isolated (Armstrong, 1995). Given the important role that predators play in top-down interactions among trophic levels they should always be a priority for reintroductions to PA's.

Miller *et al.,* (1999) suggest that maximizing the genetic diversity of released animals is the best strategy to ensure the genetic health of geographically isolated species and would reduce the risks of inbreeding depression and enable the population to better adapt to the local environment. Caracal on the Peninsula and in nearby CNRs are the same species and prior to recent extensive urbanisation would have been interbreeding. Releasing males from the Peninsula into smaller CNRs that have been isolated due to urban development will restore likely historical movement patterns and reduce the risk of inbreeding depression in isolated reserves. According to Miller *et al.,* (1999) many carnivore species would historically disperse over long distances, and this would have resulted in a large unrestricted gene flow throughout their distribution. Patterns and studies of mitochondrial DNA variation suggest that gene flow may occur across the continent and suppress genetic differentiation among populations (Mercure *et al.,* 1993). For example, some species like coyotes (*Canis latrans*) show little differentiation even if widely separated, while kit foxes (*Vulpres marotis*) with limited dispersal show significant genetic differences between populations with geographic barriers (Miller *et al.,* 1999).

Demographic management of the receiving population should also be considered, and Miller *et al.,* (1999) recommend releasing animals to restore the sex ratio to approximate those of wilder populations without restricted movement, and so ensure optimal reproductive encounters. Most of the caracal approaching the Simon's Town colony are young males of dispersing age that are thus likely to be exploring areas to establish a territory (Serieys *et al.,* 2019). Young males are also the most likely age and sex category to disperse from urban reserves where they are more likely to experience anthropogenic causes of mortality. Thus, these reserves may benefit from assisted immigration of males. It is also important to ensure the receiving location meets the habitat requirements of the species and that they are not forced to occupy alternative (but adequate) habitats or range beyond the reserve boundaries to meet their needs (Armstrong, 1995).

CapeNature currently has policies in place to permit and guide the translocation of game and fish species. These policies clearly state the process to get a permit for translocation as well as the species and the conditions under which the permit will be issued. The current translocation policy for carnivore predators states that no damage-causing or nuisance territorial wild animals can be translocated. In these instances, CN evaluate the mitigation measures taken by the landowner, and if damage persists, they permit the farmer to euthanise the animal using an approved method. However, permits are nevertheless issued to NGO's that allow the translocation of damage-causing leopards that are 'territorial wild animals'. For some species, a translocation permit may be approved if it is accompanied by an approved management plan (e.g., baboons on the Cape Peninsula) and if it is linked to research supported by a tertiary institution and ethics approval for that research has been granted by that institution (e.g., leopards in the Western Cape). CapeNature have already permitted the relocation of a diverse array of predators that were posing a threat to mainland penguin colonies and thus have created precedent for such interventions. SANParks have a Wildlife Management Policy as well as a Damage Causing Policy, although they are not available to the public. With any translocation of animals by TMNP, there will be an operational staff member involved that ensures the internally approved policies and guiding principles are followed with the appropriate documentation and risk analysis. At both the provincial and national level, a proposal is tabled, and risk assessments are conducted before a decision is made on translocations or euthanasia. This process allows experts to evaluate the situation on a case-by-case basis.

Although the IUCN/SSC (2013) guidelines on translocation do not specifically address moving a Non-Threatened species because of the threat it poses to an Endangered species, translocation guidelines (Appendix A - Box 1) state clearly when and under which conditions translocations should be approved and further stipulate that there must be a conservation benefit at the ecosystem level, not only for the individual(s) being moved. These guidelines stipulate that all translocations should be fully documented to inform future conservation planning, and their outcomes should also be publicly accessible to allow for broader stakeholder engagement. By documenting each translocation, a body of evidence emerges allowing for an empirical assessment of the viability and costs of translocation as a conservation and conflict mitigation strategy.

In this study I have collected and collated available information on all caracal relocations carried out on the Peninsula thus far and I have used these data to develop a management plan which I have condensed into a decision matrix with an accompanying Standard Operating Procedure. This management plan seeks to protect penguins in Simon's Town from caracal predation while providing an alternative to lethal management of these caracal and an opportunity for them to be assisted in moving to small, isolated CoCT nature reserves which have either depleted caracal numbers or lack individuals of a particular sex. Thus, the plan proposes to benefit penguins, individual caracal, and small isolated PA's and in so doing satisfies the IUCN guidelines for translocation. To achieve the above goals requires both the application of criteria relevant to the receiving environment and the individual caracal that is to be captured and moved, in addition to routine data collection that will ensure the criteria are directly informed by relevant facts on the ground. These include:

1) Identifying a list of CoCT nature reserves (see below) which would be classified as suitable for receiving a caracal. Criteria would include whether caracal were historically present or are currently present in the reserve, the size and connectivity of the reserve, the presence of prey species and the levels of anthropogenic risks to caracal. Deriving the list requires input and approval from CoCT biodiversity managers.
2) Routine monitoring of approved CoCT nature reserves using the methods developed by Schnetler *et al.,* (2021), to allow for an estimate of the presence, abundance, and adult sex ratio of caracal in each reserve.
3) Collecting and collating all records of caracal mortalities within and adjacent to suitable CNRs to inform the levels of risk to translocated caracal in each reserve.
4) The weight, sex, reproductive status, morphometrics and health of all caracal captured and assessed by a veterinarian.

Provided the captured caracal is not a lactating female, is in good health, and a suitable reserve has been identified that would benefit from the addition of a caracal of that sex then it will be collared and transported to the reserve. Thereafter:

5) The movement patterns, residency within the reserve and survival of the caracal will be monitored for a minimum of six months post-release or until it disappears or is killed.

The success of each translocation will be assessed according to the following criteria:

i. The survival of the translocated caracal for at least six months, which in reserves with no caracal or depleted caracal numbers is a step towards the restoration of medium-sized predators in those reserves, and with that the assumed ecological benefits.
ii. Re-establishment of breeding events in reserves which only had individuals of the opposite sex to the translocated individual.

The criteria for a failed translocation would include:

i. Death or serious injury to an individual during capture, transport, and release.
ii. Death or serious injury by anthropogenic causes to a caracal shortly after (1–30 days) release.
iii. Rapid decline or local extirpation of prey species in the receiving reserve.
iv. Sustained adverse impacts on neighbouring urban communities (e.g., the regular killing of domestic animals).

The programme would also consider and attempt to control for:

i. Potential disease transfer to caracal in the receiving population. This risk would be minimised by only translocating individuals that are in good health in the programme and provided the attendant veterinarian has completed the CoCT Wildlife veterinarians "basic caracal disease health checklist" (see Appendix B).
ii. Potential for genetic impacts; while the geographic isolation of the Peninsula caracal population may have reduced their genetic variation this is unlikely to negatively impact receiver populations, nor is it considered likely that differences between Cape Peninsula caracal and caracal in local CNRs would have diverged significantly as to be incompatible.
iii. The behaviour of the individual at the release site; the animal will be monitored using a GPS collar and unusual behaviour such as moving along a busy road network or into dense residential areas will require that the animal be recaptured and either euthanised or moved to another suitable reserve.
iv. Successful translocations do not signal the end to exploring non-lethal interventions at the source of the 'problem', namely at the penguin colony.

Selecting suitable City of Cape Town Nature Reserves as potential release sites

One of the IUCN requirements for translocations is that they should be part of a regional management program and that the receiving population(s) should benefit from the introduction of translocated individuals. To satisfy this requirement I firstly reviewed the available data on the current and historical presence of caracal in all of the CNRs, following which I collated information on the size, perimeter length, neighbouring land uses and level of connectivity with suitable natural land before engaging in a series of discussions with CoCT biodiversity managers to identify which of the City's 12 reserves could be classified as suitable for caracal introductions or reintroductions where they have been locally extirpated and thus where routine monitoring for caracal presence, abundance and sex ratio should be prioritised.

Caracal were detected at six of the twelve surveyed reserves (Schnetler *et al.,* 2021), the smallest of which was Tygerberg at 388 ha and the largest, Steenbras at 8400 ha. Reserves in which caracal were detected were those with higher species richness ($\geq$ 6 species), large with a high area to perimeter ratio, high habitat heterogeneity, and good connectivity scores (see Table 13). The one exception is Steenbras NR where caracal were not detected despite this being the largest reserve, with the highest area to perimeter ratio and levels of connectivity of all the CNRs. Other camera trap surveys have detected caracal in the Biosphere Nature Reserve which is contiguous with this reserve and thus it may be that the density of caracal is lower here in part because of the presence of an apex predator, the leopard.

The CoCT biodiversity management staff were provided with these data and each of the 12 reserves were discussed with reference to its attributes and potential as a site for receiving a caracal translocated away from the Simon's Town penguin colony. Below I briefly describe the suitability of each reserve as a potential site for the release of a caracal from Simon's Town:

1. Uitkamp Wetland Nature Reserve (32 ha)

Narrow seasonal wetland with hard developed edges, high levels of human and domestic animal activity. Too small for a caracal that would be likely to move into adjacent agricultural area after release. Not a suitable site.

2. Bracken Nature Reserve (36 ha)

Good connectivity to agricultural/rural land, 50% hard edge, but too small. Very few areas of cover with most of the reserve characterised by open vegetation. Not a suitable site.

3. Kenilworth Racecourse Conservation Area (52 ha)

Too small with no connectivity to any other natural or agricultural land. Hard edges comprising dense residential developments with high levels of human and domestic animal activity (i.e., horses, domestic cats). Not a suitable site.

4. Zandvlei Estuary Nature Reserve (200 ha)

Has connectivity to the Peninsula but most caracal detected here have been transitory, moving into the area during the dry season when the water levels are low and out again during wet season when much of the land is inundated. Hard urban edges with high levels of human and domestic animal. Not a suitable site.

5. Wolfgat Nature Reserve (262 ha)

Initially considered large enough with suitable habitat and prey species but during the COVID-19 lockdown period the reserve was invaded and occupied by many informal dwellings. Not a suitable site.

6. Steenbras Nature Reserve (8400 ha)

Largest of the CNRs, with the highest percentage of perimeter connected to the largest natural area (Kogelberg Biosphere Reserve and surrounds). No caracal were recorded in the survey, but previous camera trap surveys have confirmed the presence of caracal which are likely suppressed by the presence of leopard which are frequently detected in this reserve. Habitat and prey availability are ideal, and top-down trophic pressure is a normal component of a functional protected area. High levels of connectivity increase the chances of successful establishment of a home range and low levels of spatial overlap with people and domestic animals. A suitable site.

7. Tygerberg Nature Reserve (388 ha)

Sufficiently large with good connectivity along the northern perimeter with agricultural land. Relatively high levels of caracal activity (capture frequency 19 of 112 survey days) suggesting it is suitable habitat but perhaps already saturated. A large portion of the perimeter borders residential areas with anecdotal reports of predation on domestic cats. Potentially suitable site.

8. Helderberg Nature Reserve (402 ha)

Large enough with suitable habitat and good connectivity to natural land. Low activity recorded (2 of 127 camera days), possibly because of the presence of leopard in the area. A suitable site.

9. False Bay Nature Reserve (632 ha)

Large core area with suitable habitat and connectivity to the east. Moderate activity recorded (7 of 67 days) and moderate levels of human presence but limited domestic animals. A suitable site.

10. Table Bay Nature Reserve (880 ha)

Large enough with suitable habitat and good connectivity. High caracal activity (25 of 84 days). Small core area (changes seasonally) and connectivity only along river course with hard edges. A portion of the perimeter border residential areas with anecdotal reports of predation on domestic cats. A suitable site.

11. Blaauwberg Nature Reserve (1445 ha)

Sufficiently large area with some connectivity. Relatively high levels of caracal activity (21 of 67 days). Adjacent to agriculture and residential areas and the R27 freeway with high traffic volumes (caracal mortalities have been recorded on this road). A suitable site.

12. Witzands Aquifer Nature Reserve (3000 ha)

Large reserve with good connectivity to the north and south. Low capture frequencies (7 of 92 days). Adjacent to natural/rural land uses with some subsistence farming resulting in moderate levels of human activity. Potential of risk from snares in north, but good connectivity. A suitable site.

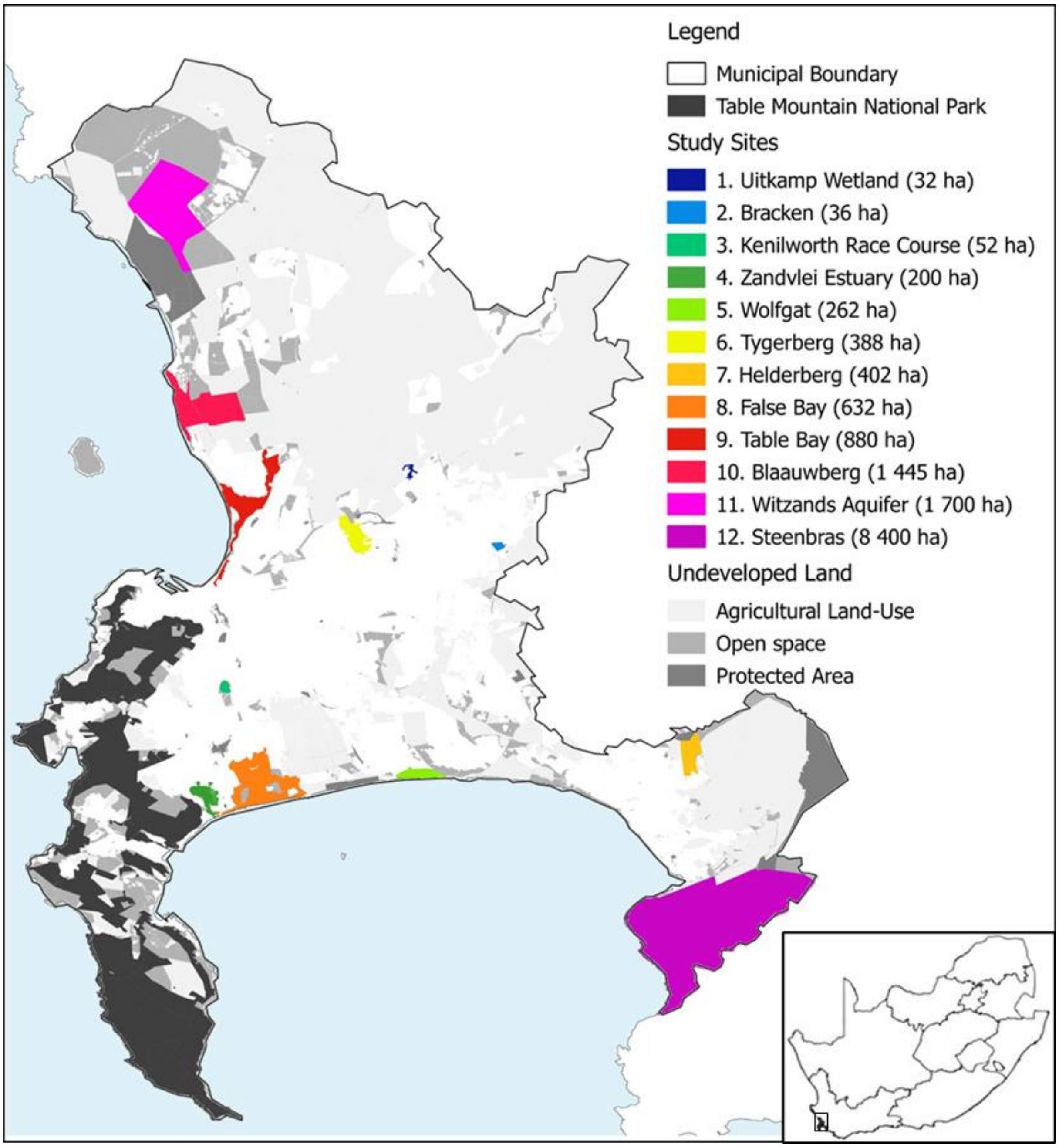

Figure 13. City nature reserve (CNRs) and land use within the City of Cape Town municipal area. "PA's" refer to formally protected conservation areas. "Open space" refers to the remainder of undeveloped land, some of which may be managed as conservation areas, but which are not protected by any formal legislation, and may include private property. Blank areas indicate urban land use zones within the municipal boundary.

Table 13. Key variables for the City of Cape Town nature reserves. Area-perimeter ratio (APR) was calculated using reserve size (km^2) relative to boundary length (km), habitat heterogeneity of the respective reserve is the proportional representation of five different habitat types within each reserve and expressed as a Shannon-Wiener diversity index value, the presence-1 or absence-0 of permanent freshwater aquatic habitat for aquatic or semi-aquatic mammals is indicated under freshwater habitat (see reserve descriptions for more detail). Connectivity scores were calculated according to criteria detailed in Appendix D following Schnetler *et al.,* (2021).

Site	Reserve Size	APR	Heterogeneity	Aquatic Habitat	Connectivity Score
Uitkamp	32	0.05	0.54	1	1
Bracken	36	0.14	0.57	0	1
Kenilworth	52	0.14	0.84	1	0
Zandvlei	200	0.11	0.89	1	1
Wolfgat	262	0.29	0.00	0	2
Tygerberg	388	0.22	0.62	1	3
Helderberg	402	0.36	0.29	1	5
False Bay	632	0.28	1.28	1	2
Table Bay	880	0.24	0.51	1	1
Blaauwberg	1445	0.61	0.90	0	4
Witzands	1700	1.09	0.13	0	4
Steenbras	8400	1.69	0.46	1	5

All the sites suggested as suitable for translocation of caracal are larger than 30 ha (male caracal home range size is highly variable and is dependent on habitat and prey suitability but is generally around 30 km^2; Avenant & Nel, 1998) and historically had caracal present.

Table 14. Native medium and large mammal species present (marked "X") and estimated species richness at each of the 12 City of Cape Town nature reserves included in this study. Species are listed in order of most common occurrence. Reserves are listed in order of species richness (Table adapted from Schnetler *et al.,* (2021).

Species	Common Name	Kenilworth	Uitkamp	Bracken	Zandvlei	Wolfgat	Table Bay	False Bay	Blaauwberg	Tygerberg	Steenbras	Helderberg	Witzands
Raphicerus melanotis	Cape grysbok	X		X	X	X	X	X	X	X	X	X	X
Hystrix africaeaustralis	Cape porcupine		X	X	X	X	X	X	X	X	X	X	X
Galerella pulverulenta	Small grey mongoose			X	X	X		X	X	X	X	X	X
Genetta tigrina	Large-spotted genet				X	X		X		X	X	X	
Caracal caracal	Caracal						X	X	X	X		X	X
Sylvicapra grimmia	Common duiker								X	X	X	X	X
Lepus spp.	Cape/scrub hare					X		X			X	X	X
Herpestes ichneumon	Large grey mongoose		X				X			X		X	X
Mellivora capensis	Honey badger								X	X	X	X	X
Atilax paludinosus	Water mongoose		X		X		X	X		X			
Aonyx capensis	Cape clawless otter						X	X		X	X		
Ictonyx striatus	Striped polecat			X					X			X	X
Raphicerus campestris	Steenbok			X					X				X
Genetta genetta	Small-spotted genet								X	X			X
Panthera pardus	Leopard										X	X	
Papio ursinus	Chacma baboon										X	X	
Oreotragus oreotragus	Klipspringer										X		
Pronolagus saundersiae	Hewitt's red rock rabbit										X		
Vulpes chama	Cape fox												X
Observed species richness		1	3	5	5	5	6	8	9	11	12	12	12

Ultimately the collaborative Management Strategy Workshop (MSW) approved three sites for translocation of caracal from Simon's Town, namely the Steenbras Nature Reserve; False Bay Nature Reserve and Witzands Aquifer Nature Reserve based on their overall suitability, ecological needs, existing risk factors and capacity for caracal. Some sites that were found suitable were not chosen, as management felt that three sites should be adequate to test the translocations.

Management decision matrix for caracal threatening mainland penguin colonies

I developed a flowchart (Figure 14) that summarizes recommendations and operational flow for immediate to long-term management intervention should a caracal be detected near or approaching the Simon's Town African penguin colony. This Long-term Management Plan (LMP) shows the proposed infrastructure and interventions to be strategically developed in the area over time, while the Aversion/Translocation Response Plan (A/TRP) suggests a step-by-step management decision-making tree to follow the next detection, attempted predation, or predation event. It is suggested that these measures be attempted to the extent indicated, before resorting to lethal management. Management intervention response is 'triggered' by any CCTV or camera trap caracal detection in the surrounding area (Figure 15).

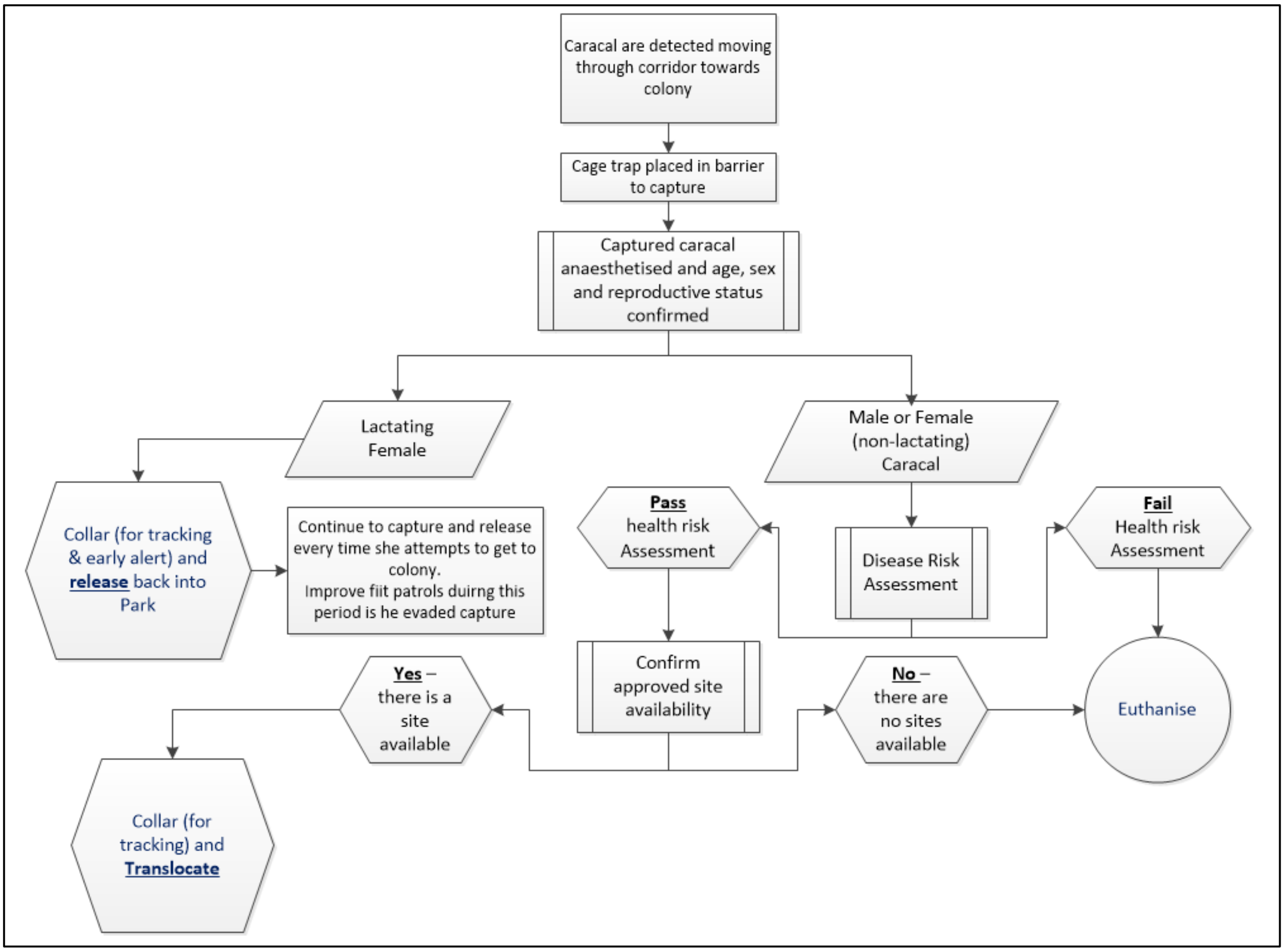

Figure 14. A decision flowchart for the management of caracal detected approaching the Simon's Town African penguin colony.

Assessing disease risks associated with translocations

Diseases form part of the natural environment and serve as important selective agents on natural populations of wildlife. Human induced changes to the environment and exposure to domestic animals and wildlife can alter natural disease processes (Viljoen *et al*., 2020) and have negative impacts on protected populations (Kock *et al.,* 2014). Currently no routine in-field testing or vaccination of lions is practiced by SANParks when translocating between PA's, except when lions originate from Kruger National Park where tuberculosis is prevalent in lions (pers. Comm. Dr Dave Zimmerman, SANParks). By contrast, cheetahs which are more sensitive to capture stress have a poorer translocation success rate are typically vaccinated against multiple diseases including rabies, Feline immunodeficiency (FHV), Puma lenti virus (FHV), Puma lenti virus (PLV), calicivirus, Feline leukemia virus (FeLV) and distemper virus (Miller *et al.,* 2014).

Caracal are susceptible to diseases that affect felids including domestic cats (Miller *et al.,* 2014). Caracal may also be susceptible to diseases transmitted to other animals like canine distemper, rabies virus and tuberculosis (caused by Mycobacterium bovis) and protozoal diseases such as toxoplasmosis (caused by *Toxoplasma gondii*) (Thalwitzer *et al.,* 2010; Veals *et al.,* 2020). Caracal predate on domestic cats and therefore are likely to be exposed to most diseases that cats may carry (Viljoen, *et al.,* 2020). Caracal populations in CNRs are likely exposed to very similar diseases to those on the Peninsula, but with exposure risk likely to be lower in larger, more remote nature reserves such as Steenbras and Witsands Nature Reserve. There is also a risk of exposing other felids, like leopards on CNRs that may predate on caracal, and to a lesser extent other smaller carnivore species. A cautionary approach is recommended to mitigate any risk to the receiving population. It is important to note that disease may develop in translocated caracal due to capture and release stress and thus it is important to improve the survivability of translocated individual by treating them for known high risk pathogens as it may be physiologically more vulnerable post-translocation while adapting to the new environment.

Standard Operating Procedures (SOPs)

Animal Selection: caracal in good health that are not lactating and are persisting in attempting to approach and enter the Simon’s Town penguin colony.

Capture method: walk-in cage traps with a bar frame and expanded mesh sides covered by vegetation. Trap cages should be set and ready at least 40 minutes before dark to coincide with peak crepuscular and nocturnal activity patterns (Serieys *et al.,* 2021). Traps should be monitored through a GPS enabled camera trap providing immediate notification of the presence of a caracal or other animals within the trap (Figure 15). If a non-target species or individual is detected in the trap, it should be released immediately, and the trap reset. A capture team, including a veterinarian with relevant experience, should be on standby to respond immediately to a captured caracal and so reduce the total time spent in the cage. If the targeted individual is in the trap, the trap must be approached quietly by one person only and covered with an opaque tarpaulin or blanket. The gate mechanism must be cable tied or wired closed so that there is no chance of the door being manipulated from within and the animal escaping. Bright lights, loud noises, and approaches to the front of the cage should be strictly prohibited.

Figure 15. A photograph of a young adult male caracal in a walk-in trap, minutes after being captured.

Collaring and ear tagging: following immobilization by a veterinarian, the weight, sex and health (see below for disease risk assessment) of the animal should be recorded. If the animal is a lactating female, then the animal should be collared and released back into its home range. This will allow the female's den to be located and if the individual succeeds in circumventing the barrier and predates on penguins then it will be possible to capture both the adult and the kittens. If the animal is either a male or a non-lactating female in good health and there is a site available in the CNRs, then the veterinarian must affix a GPS enabled collar to allow for the remote monitoring of the cat post-release. The weight of the tracking device should not exceed 5% of the host's bodyweight to avoid detrimental effects to behaviour (Gursky, 1998). This is confirmed by Moseby (2012) who state that the South Australian Wildlife Ethics Committee's maximum approved proportional collar weight is 5%. The collars should include very high frequency (VHF) technology to allow for active tracking of the individual or it is killed and the body needs to be retrieved. Most GPS collars can provide approximately 2000 GPS locations (valid and invalid readings), and thus if the collar is used to provide coarse (6 readings per 24 hrs, 05h00am every three hours, with the last reading being at 20h00) daily movement patterns then it would provide approximately nine months of data on a translocated caracal which is adequate for assessing post-release success. The collar must have a cotton insert in the neck belting that will 'rot-off' after a year and ensure that the animal will not wear the collar for much longer than the maximum duration of the battery.

Disease risk assessment: a clinical examination by the veterinarian will be conducted *in situ* and if the individual is in poor health, euthanasia is recommended. If the animal is in good health then it is recommended to administer a prophylactic treatment with a long-acting macrocyclic lactone like selamectin e.g., Revolution® to prevent possible notoedric mange and ascarid infection that may manifest after release because of the acute stressors capture and translocation (Thalwitzer *et al*., 2010). Tests in field for FeLV Feline immunodeficiency virus (FIV) and Distemper during immobilisation and prior to release are required and vaccines to be administered for rabies, FHV, FPLV and calicivirus and FeLV e.g., rabies (Merial), Nobivac Tricat Trio (MSD) and Leucogen (Virbac). Routine post-mortems should be performed on all caracal carcasses found within the CNRs and urban areas to better understand health risks and so adjust the health assessment protocol. Biodiversity management staff, SPCA and researchers have been requested to report deaths and keep carcasses for veterinary evaluation. The receiving population and wildlife should also be monitored and any specific disease occurrences in the translocated caracal or the local fauna should be monitored and reported by reserve staff. Where possible, testing to obtain a disease diagnosis should occur, and samples stored to allow for a retrospective analysis if required. This will assist with evaluating any disease incidents that may occur and the importance thereof.

Need for ongoing penguin-caracal research on the Cape Peninsula

The translocation of caracal from the Simon's Town penguin colony to CNRs and follow-up monitoring presents a unique opportunity to study the efficacy of such translocations as one of many alternative interventions to lethal management. Moreover, monitoring these individuals and their movements will continue to inform caracal behaviour, ecology and conservation research in the peri-urban landscape that has been initiated by the Urban Caracal Project (Leightin *et al*., 2021; Serieys *et al*., 2019, 2021). In particular it would be important to perform 1) a comparative study of the density of caracal between TMNP and Kogelberg Biosphere Reserve, which have similar habitats, but the latter includes leopard which are hypothesised to suppress caracal presence, 2) research on the genetic and demographic population-level benefits of adding a young male caracal to isolated nature reserves, 3) a rolling site selection model, as reserve managers will be asked to start recording caracal presence as well as mortality, and 4) a study on how prey species such as Cape grysbok (*Raphicerus melanotis*) respond to these reintroductions, particularly in reserves were caracal have been absent for a number of years.

While active intervention and ongoing management is essential for implementing the three high scoring non-lethal methods detailed above, many of the uncertainties and therefore risks associated with these interventions, stem from a lack of knowledge regarding both caracal and penguin behaviour in peri urban environments. It is thus essential to continue research and explore novel methods that might alleviate the need for the capture and translocation of caracal as proposed above. Research priorities would include: 1) ensuring the routine monitoring of the penguin population to provide annual estimates of mortality events, survival, and reproduction. These data can be used to conduct a Population Viability Analysis (PVA) of the penguin colony at regular intervals. Not only to monitor the status of the colony but also to develop a reasonable threshold of mortality, caracal-driven or otherwise, for this Endangered population; 2) routine testing of barriers and deterrents around the penguin colony, and 3) routine monitoring of the caracal population in natural land above and south of Simon's Town, including mortality events, relative abundance, and reproduction. Strategically placed camera traps that are left *in situ* in perpetuity and checked routinely will allow for relative changes in abundance and demographic parameters (e.g., ratio of males to females, and kitten /juveniles to adults) to be monitored. Camera traps will also provide an index of medium-sized caracal prey abundance available in these landscapes.

In addition to ongoing research, it is imperative to improve communication among conservation authorities and stakeholders. Regular forums must seek to inform and update all parties concerning the ongoing challenges of managing predation on penguins and seek consensus on short and long-term management options. Only such an engagement approach will garner and guarantee the trust and support of all parties. Most importantly, this includes directly informing the public of predation and attempted predation events on penguins by caracal and the management outcome including euthanasia where relevant. Such transparency with stakeholders and release of relevant information following each intervention, whether successful or not will ultimately minimize conflict amongst stakeholders, ensure trust and secure support in long-term management and is crucial to the success of any conservation intervention.

Conclusions

Mainland breeding colonies of the endangered African penguin are largely a consequence of the overexploitation of island colonies including the historical harvesting of adults and their eggs for food, the destruction of nests through the harvesting of guano for fertiliser, and the overexploitation of their pelagic food resources for both human and domestic animal consumption (Ritchie & Johnson, 2009). Once colonies were established on the mainland, the threat of terrestrial predators emerged with single predation events greatly exacerbated by supernumerary killing of penguins due to a poorly evolved anti-predator response on land. While the emergence of caracal as apex predators on the Peninsula is also linked to anthropogenic disturbances, larger predators such as leopard also engage in supernumerary killing events and many smaller predators such as mongoose and genet have learnt to include mainland penguins in their diet.

Other bird species have suffered similar levels of human impacts including Sooty Terns (*Sterna fuscata*) that were subject to the unregulated exploitation of adult birds and their eggs, with numbers further decimated by the introduction of terrestrial predators to their island refugia (Feare *et al.,* 2007). Similarly, when island breeding short-tailed shearwaters (*Puffinus tenuirostris*) were exposed to an introduced terrestrial predator, the Tasmanian devil (*Sarcophilus harrisii*), occupancy reached zero after only four years (Scoleri *et al.,* 2020). Where other penguin species, such as Little penguins (*Eudyptula minor*) in Australia, have established breeding sites on the mainland they too have proven vulnerable to terrestrial predators with foxes killing 12 adult penguins and a domestic dog killing eight penguins in one night (Priddel *et al.,* 2008). Consequently, these sites have attempted to restrict access to predators (Priddel *et al.,* 2008) as has been recommended in this study.

It seems probable that mainland colonies of penguins and other ground nesting marine birds can only become established in areas with active predator suppression or exclusion. Coastal development may buffer colonies from source areas of predators with only individual predators habituated to human presence and being confident enough to traverse human modified landscapes to enter the colonies. Habituation of wild animals to a transformed landscape is a gradual process and following the removal of individual caracal from Simon's Town, it takes approximately six to nine months before another caracal is detected in the area. This may be the time it takes for caracal to move into vacant territories or the time it takes for individuals to habituate to developed areas and to move through and amongst residential areas with lights, dogs, vehicles and people, to access penguins on the coast.

What is clear is that caracal entering the Simon's Town colony will continue for as long as there are caracal and penguins on the Peninsula. Permanent exclusion zones using barriers are simply not possible in this heterogenous urban landscape with much of the edge comprised of private residential properties, the owners of which can refuse such structures on their property and furthermore retain the right to grow vegetation that predators can use to circumvent barriers on public land. The fence that has been constructed in De Hoop Nature Reserve is in an open undeveloped area characterised by small shrubs and rocks and thus the specifications were not subject to aesthetic concerns raised by people but rather with the sole objective of keeping all predators out. Even a leopard managed to exploit a weak point and traverse the barrier, revealing the need for ongoing adjustment and maintenance of the fence.

The one certainty in this conservation conflict involving caracal, penguins and people is that the penguins are to be protected given their precarious conservation status. Where there is less consensus is whether routine killing of caracal that predate on penguins should be accepted. This study recommends that caracal should be translocated to CNRs provided all the criteria detailed in the flowchart and SOP have been satisfied. Translocations provide an immediate respite for the penguins and well-designed translocations benefit both the individual predator and potentially the receiving populations too. Assisted dispersal of individuals between isolated protected areas through translocation is an integral component of many successful wildlife management strategies, particularly for endangered species such as cheetah and wild dog. Such assistance is however seldom afforded to 'Least Concern' species under the IUCN despite similar benefits to the isolated populations. This inconsistency is attributed to the high costs of assisted dispersal which demands that the conservation benefits are proportionately high, as is the case for endangered species. However, if resources are readily available and the translocation can resolve negative impacts on a critically endangered species then assisted dispersal of least concern species should at least be considered (particularly as an alternative to lethal management) provided all other criteria for successful translocation have been satisfied. Population persistence without interference for both the African penguins and the caracal will be a win-win situation on the Cape Peninsula but given the scale of anthropogenic impacts will require ongoing adaptive management.

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List of abbreviations

CFR	Cape Floral Region	15
CN	CapeNature	18
CNRs	City Nature Reserves	51
CoCT	City of Cape Town	3
CP	Cape Peninsula	11
CTA	Conditioned Taste Aversion	35
DCA	Damage Causing Animal	8
DEFF	Department of Forestry and Fisheries	18
DRA	Disease Risk Analysis	3
FeLV	Feline Leukemia Virus	62
FIV	Feline immunodeficiency	65
GCT	Greater Cape Town	18
HWC	Human-Wildlife Conflict	10
iCWild	Institute for Communities and Wildlife in Africa	1
IUCN	International Union for Conservation of Nature	8
PAs	Protected Areas	6
PLV	Puma Lenti Virus	62
PH	Professional Hunter	36
RAG	Radio-activated Guards	8
MAG	Movement-activated Guards	8
MPA	Marine Protected Area	15
MSW	Management Strategy Workshop	20
SANParks	South African National Parks	18
SANCCOB	Southern African Foundation for the Conservation of Coastal Birds	19
SOPs	Standard Operating Procedures	3
SPCA	Societies for the Prevention of Cruelty to Animals	51
TMNP	Table Mountain National Park	11
UCP	Urban Caracal Project	18
UCT	University of Cape Town	19
VHF	Very high frequency	59

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Appendices

***Appendix A**. Box1: IUCN translocation guidelines:*

IUCN TRANSLOCATION GUIDELINES

The International Union for Conservation of Nature (IUCN) considers conservation translocation the deliberate movement of organisms from one site for release in another (IUCN/SSC, 2013). It must be intended to yield a measurable conservation benefit at the levels of a population, species, or ecosystem, and not only provide benefit to translocated individuals (IUCN, 2013). In this context, two primary concepts are considered:

- **Population restoration:** by increasing population size, by increasing genetic diversity, or by increasing the representation of specific demographic groups or stages (IUCN/SSC, 2013); and
- **Reintroduction:** the intentional movement and release of an organism inside its indigenous range from which it has disappeared (IUCN/SSC, 2013).

The conservation translocations in the case of this penguin-caracal conflict, could directly contribute to both caracal population restoration in areas without caracal or males specifically and reintroduction into areas in which the species is currently extirpated. Indirectly these actions would also serve to restore the Endangered African penguin population.

The IUCN guidelines for the placement of confiscated animals (IUCN/SSC, 2013) confirm that the prevailing legislation, cultural practices, and economic conditions will influence decisions on appropriate disposition of animals, and within the conservation context the following are available options:

- to maintain the animals in captivity for the remainder of their natural lives.
- to return the animals to the wild.
- to euthanize the animals (i.e., humanely destroy them).

The IUCN guidelines (IUCN/SSC, 2013) further state that if animals are returned to the wild, it should be consistent with IUCN conservation principles and practice. It should therefore:

- only be into a site outside of the species' natural range if such an action is in accordance with the IUCN guidelines for reintroductions for a conservation introduction (IUCN/SSC, 2013); and
- only be practiced in cases where the animals are of high conservation value and/or the release is part of a management programme. Any release to the wild must include the necessary screening and monitoring to address potential negative impacts

Within a conservation context, and the confines of national and international law, the ultimate decision on placement of confiscated animals must achieve three goals:

1. to maximise the conservation value of the animals without in any way endangering the health, behavioural repertoire, genetic characteristics, or conservation status of wild or captive populations of the species or any other wild living organism.
2. to discourage further illegal or irregular trade in the species; and
3. to provide a humane solution, whether this involves maintaining the animals in captivity, returning them to the wild, or employing euthanasia to destroy them.

Although the proposed translocations are not as a confiscation, second party guidelines (i.e., where the non-threatened species is relocated due to the threat it poses to an Endangered species) have not yet been developed, thus it is argued that the key principle and requirements for returning animals removed from their natural habitat to other areas are relevant to caracal translocated away from where they are posing a threat to penguins. The translocation of caracal from the Simon's Town penguin colony to other protected areas in and around Cape Town, would thus satisfy these requirements and meet the three overarching goals stipulated in the IUCN conservation context.

Appendix B.

Table 15. The most important diseases, identified from literature, that were considered for this analysis (prepared by Dr Dorothy Breed, veterinarian for CoCT).

Disease	Risk assessment	Risk management
1. Viral pathogens: Feline immunodeficiency (FIV), puma lenti virus (PLV) and Feline leukemia virus (FelV)	Although FIV is usually species-specific, domestic cat FIV has been reported in other felids (O'Brien *et al.,* 2012). PLV has been reported in caracal but not detected by domestic cat FIV ELISA tests in study. This test is not specific for subtypes of FIV that occur in wild felids (Thalwitzer *et al*., 2010). This test would this not fully exclude the disease in caracal but can be used as a screening test. FIV type viruses appear more prevalent in social felids like lions as the disease is thought to be transmitted through saliva i.e., grooming and fighting (Pecon-Slattery *et al.,* 2008). FIV type viruses are likely to be endemic and occur in both subpopulations of caracal as the lentiviruses in wild felids evolved over millennia prior to urbanisation (O'Brien et al., 2012). It has also not been recorded to cause clinical disease in most wild felids except for the Pallas' cat (Brown, *et al.,* 2010).	(1) Clinical examination for disease – euthanasia if present. (2) Field test for FIV/FeLV. *Vaccine for FIV is no longer available due to low efficacy, and use would be doubtful in wild felids.
2. Viral pathogens: Feline Leukemia Virus (FeLV)	FeLV was not considered to cause disease in non-domestic felids until an outbreak occurred in the Florida panther population. The FeLV strain detected was a highly virulent strain in domestic cats (O'Brien *et al.,* 2012).	(1) Field test for FIV/FeLV. (2) Vaccinate for FeLV (dead) only in species considered at risk (Miller *et al.,* 2014). *Due to the high exposure risk of caracal in the urban space there is a reasonable disease risk to caracal and other felid species (African wild cat and leopard), especially if translocating to more remote nature reserves on the periphery of the city boundaries.
1. Viral pathogens: Feline panleukopenia virus (FPLV (Lane *et al.,* 2016.) Feline calici virus (FCV), feline herpes virus (FHV), canine distemper virus (CDV), feline corona virus (FeCoV) (Thalwitzer *et al.,* 2010)	A seroprevalence study in caracal showed seropositivity. Other viral diseases did not, at the time of collection, cause clinical disease in free ranging caracal. One clinical case of FPLV has been recorded. CDV is known to cause clinical disease and mortality in large felids and many other species, but has not been recorded in free ranging caracal (Appel *et al.,* 1994; Packer *et al.,* 1999). Capture and stress may increase susceptibility to diseases (Dickens *et al.,* 2010).	(1) Clinical examination for infectious disease. (2) Vaccinate against FHV, FPLV, calicicirus (killed, e.g., Tricat or Fel-o-Vax PCT Plus vaccine). (3) The available canine CDV vaccine is live attenuated and not recommended as it may cause disease (pers. comm. Dr Silke Pfizer, specialist wildlife veterinarian & Miller *et al.,* 2014).

Tick borne diseases (Viljoen *et al.,* 2020).	A study indicated increased diversity on the Peninsula due to exposure to urban environments (Viljoen *et al.,* 2020). Unlikely to differ remarkably between translocation sites proposed. Unlikely to exhibit clinical signs of disease unless immunocompromised through disease, captivity and/or stress.	(1) Clinical examination for disease – euthanasia if present. (2) Prophylactic treatment not indicated as receiving populations likely have similar tick-borne diseases and similar exposure to urban environments, albeit a variable extent depending on geographical location.
2. *Notoedres cati* (cat mange)	Highly contagious. Clinical cases in bobcats and mountain lions appeared to be more prevalent in immunosuppressed animals that has been associated with warfarin exposure (Riley *et al.,* 2007). Caracal are known to have increased warfarin exposure (Serieys *et al.*, 2021) and a clinical case was recorded in a caracal post translocation in CCT (pers. observation). Stress of capture and translocation could render more vulnerable to infection.	Prophylactic treatment with macrocyclic lactones like selamectin, ivermectin or dectomax could mitigate risk of developing notoedric mange and at the same time reduce parasitic load and shedding that during periods of stress (like translocation) may occur.
3. Rabies	Not a typical species for the disease to appear in. Rabies cases were not reported for last 15 years within the CoCT until 2020 (pers. Comm. Dr Lesley von Helden). In 2020, 2021 and 2022 a few cases of rabies were reported in domestic animals (pers. Comm Dr Dorothy Breed). Numerous recordings of rabies cases have been reported just outside the CoCT boundaries e.g., Atlantis, Malmesbury, Paarl and Wellington.	Vaccination indicated as controlled disease and increased risk of exposure on more remote CNRs e.g., Witzands Aquifer Nature Reserve albeit a very small risk of introduction.
4. Tuberculosis (TB)	Cases of TB in the CoCT: 1. A wild baboon in Franschhoek (2021). 2. A domestic dog in Plattekloof (2019). 3. Capuchin monkeys in captivity in Joostenbergvlakte (2019). 4. A domestic dog in Hout Bay (2018). All appeared to be because of close contact with humans infected with TB. No sign of TB circulating in wildlife in the area or the province (pers. comm. Dr L von Helden, Western Cape State Veterinarian Epidemiologist). Solitary behaviour also reduces risk of contracting and transmitting tuberculosis. Caracal are unlikely to come into contact with human tuberculosis as behaviour and feeding habits do not increase risk of exposure.	Risk negligible and testing not indicated. *Testing would require captivity for three days that would vastly increase the stress of translocation and likely affect the health and welfare of the animal with little benefit to disease mitigation.
5. Toxoplasmosis	Kittens and immunocompromised felids develop clinical signs. Many healthy felids are seropositive.	Limit stress and captivity period.

	Can cause problems in the captive setting but not recorded in natural settings.	
6. Ascarid e.g., *Toxocara* and *Toxascaris*	Problematic in captive cats. Stress of capture or translocation could reduce immunity and render more vulnerable to infection.	(1) Limit stress and time in captivity. (2) Prophylactic anti-parasitic (macrocyclic lactones e.g., selamectin, ivermectin or dectomax).

Appendix C. *Site selection tool.*

CANDIDATE SITE:	Steenbras Nature Reserve		
Note that this site selection tool and its criteria are applied as a research technique to determine the feasibility of translocation as a management tool for caracal-penguin conflict on the Cape Peninsula only. These serve to determine the relative suitability and therefore ranking of potential translocation sites among CNRs. Suitability criteria here apply to a maximum of 3 (three) individuals translocated to these sites within the study duration and site suitability should be re-assessed every 3 (three) years since first assessment, with the option for rolling status updates considering new information gathered during the research period.			
1. Administration, costs, and logistical constraints (any red answers disqualify the site). Insufficient funding or a lack of resources and skilled personnel are often the primary reasons why non-protected species are not considered for translocation and these factors will contribute significantly to translocation failure if attempted. Aspects for consideration:			
1.1. Funds to secure capture, handling, and monitoring.		No	Yes ●
Notes (if any):			
1.2. Physical resources secure capture, handling, and monitoring.		No	Yes ●
Notes (if any):			
1.3. Skilled personnel to secure capture, handling, and monitoring.		No	Yes ●
Notes (if any):			
1.4. Other (if any):			
Notes (if any):			
2. Relocation site suitability (red and orange answers require justification and may disqualify the site). Direct interventions necessitate consideration of the ecological parameters that will maximise the likelihood of successful translocation and establishment, especially for caracal as they are not formally threatened in their source environment. Relocation site suitability should therefore play a key role in site selection. Aspects for consideration:			
2.1. Sufficient size/area given home-range requirements.	Unlikely	Unknown	Likely
Notes (if any):			
2.2. Sufficient vegetation or cover for adequate shelter.	Unlikely	Unknown	Likely
Notes (if any):			

2.3. Access to fresh water.	Unlikely	Unknown	Likely
Notes (if any):			
2.4. Sufficient prey abundance.	Unlikely	Unknown	Likely
Notes (if any):			
2.5. Adequate conservation status and management.	Unlikely	Unknown	Likely
Notes (if any):			
2.6. Connected with surrounding suitably protected habitat.	Unlikely	Unknown	Likely
Notes (if any):			
2.7. Historical (≥ 5 years) evidence of caracal at this site.	None	Unknown	Some
Notes (if any):			
2.8. Recent (< 5 years) evidence of caracal at this site.	None	Unknown	Some
Notes (if any):			
2.9. Evidence of a theoretical 'vacancy' via local mortality.	None	Unknown	Some
Notes (if any):			
2.10. Recent (< 5 years) habitat restoration or improvement.	Unlikely	Unknown	Likely
Notes (if any):			
2.11. Recent (< 5 years) habitat disturbance (e.g., fire).	Unlikely	Unknown	Likely
Notes (if any):			
2.12. Other (if any):			
Notes (if any):			

3. Threats posed to caracal (red and orange answers require justification and may disqualify the site). Persistent and new threats (either through injury or mortality) should play a key role in site selection. Aspects for consideration:			
3.1. Exposure to major roads and transport networks.	High	Unknown	Low
3.2. Exposure to domestic animal conflict.	High	Unknown	Low
3.3. Exposure to human harvest or conflict.	High	Unknown	Low
3.4. Exposure to intraspecies (caracal-caracal) conflict.	High	Unknown	Low
3.5. Exposure to interspecies (caracal-other) conflict.	High	Unknown	Low
3.6. Other (if any):			
4. Threats posed by caracal (red and orange answers require justification and may disqualify the site). Direct interventions necessitate consideration of the threats (either through injury or mortality) posed by the caracal to the new environment. Aspects for consideration:			
4.1. Exposure to domestic animal conflict.	High	Unknown	Low
Notes (if any):			
4.2. Exposure to livestock animal conflict.	High	Unknown	Low
Notes (if any):			
4.3. Exposure to threatened species.	High	Unknown	Low
Notes (if any):			
4.4. Other (if any):			
Notes (if any):			

5. Ongoing monitoring and adaptive management. Direct interventions require consideration of management capacity in facilitating ongoing monitoring and adaptive responses at the new relocation site.			
5.1. Capacity to continuously monitor the animal for the study duration.		No	Yes ●
Notes (if any):			
5.2. Other (if any):			
Notes (if any):			
OVERALL DETERMINATION OF SITE SUITABILITY:	Low	Moderate	High
Summary:			

Evaluation completed by:
Name & Surname: …………………………………………
Title: ………………………………………..
Biodiversity Management Branch
Environmental Management Department
CoCT

DATED: …………………………….

Signature: ………………………………………..

Three sites were put through the site evaluation tool.

Appendix D.

Table 16. Reserve connectivity categories, category descriptions and the reserves allocated to each of the categories.

Category	Description	Nature reserves
1	Corridors that might allow connectivity less than 0.1 km wide at places. Corridors flanked by urban structures. Connection leads to agricultural or conserved land. Movement considered to be highly restricted, if not impossible for most medium and large mammals.	Bracken, Zandvlei Estuary, Uitkamp Wetland, Table Bay
2	Connectivity through corridors of natural vegetation 0.1 to 1 km wide. Corridors provide connectivity between reserves and isolated agricultural land (32 km^2 of predominantly vegetable patches, but also some natural pastures). Movement within this landscape matrix of reserves, agricultural land and even the False Bay beach front likely, but connectivity to other natural habitat very limited.	Wolfgat, False Bay
3	Connectivity through corridor wider than 1 km. Connection leads to large tracts of agricultural land (dominated by wheat fields) within which small patches of functional habitat exist. Movement of most species into a vast mosaic of agricultural and, further afield, natural land possible.	Tygerberg Nature Reserve
4	Direct connectivity to agricultural pastureland across shared boundaries of >5 km. Agricultural pastureland comprises large tracts of natural habitat that can facilitate movement to extensive proclaimed conservation areas.	Witzands Aquifer, Blaauwberg
5	Direct connectivity (>5 km shared boundary) with an extensive biosphere reserve complex exceeding 80 000 ha.	Steenbras, Helderberg

__Appendix E.__ Literature review to guide the drafting of a translocation management plan

I reviewed translocation projects published between 1985 and 2021 for more than 100 studies. Of the 27 mammal translocations, 67% consisted of translocations for Conservation, and 33% Human wildlife conflict.

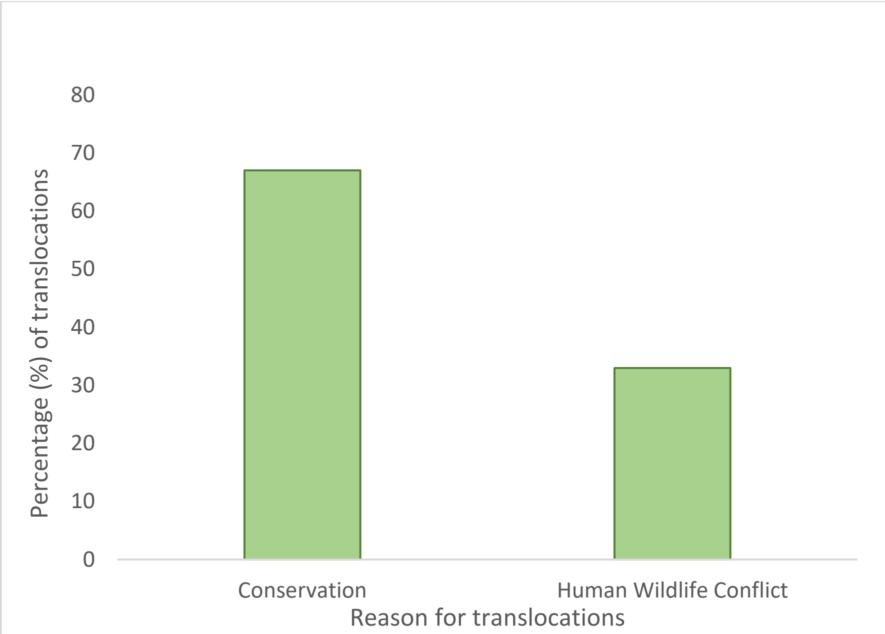

Figure 16. Reasons for mammal translocations for the period 1985 to 2021 from the 100 papers reviewed during the literature review.

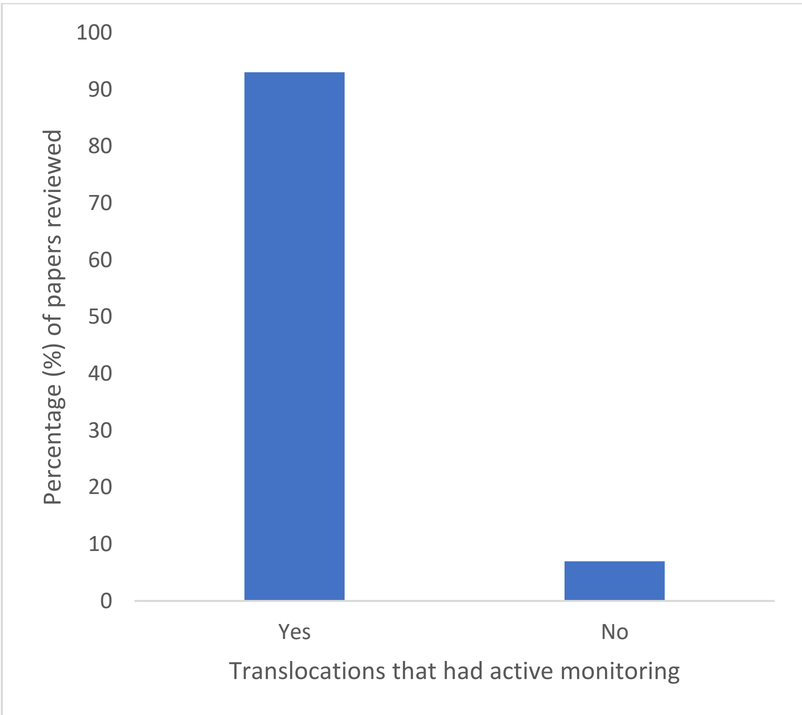

Figure 17. Showing percentage (%) of papers reviewed that had active monitoring post translocation release for the period 1985 to 2021.

Ninety-three percent of projects had monitoring post release, and it fluctuated from ear tagging and tattooing, radio collar tracking, antennae, and mortality sensors. The duration and outcome of the monitoring differ from study to study and or it was unclear.

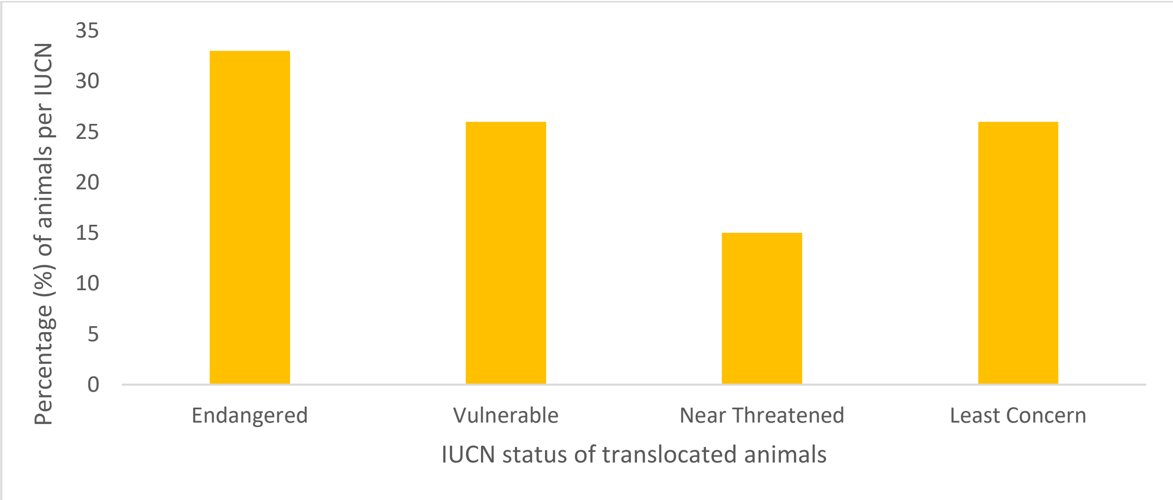

Figure 18. The IUCN status of the animals in the case research papers.

The research found that almost 33% of the species that were translocated were Endangered and 26% were of least concern species, the author found that all the species that had least concern status were translocated due to habitat related factors, like development or deforestation.

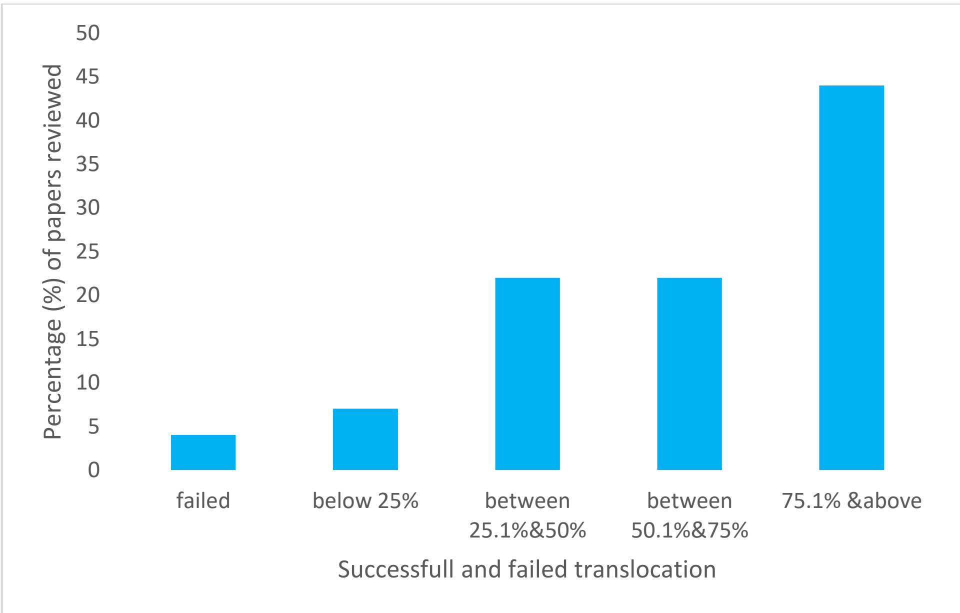

Figure 19. The percentage (%) of studies that had successful translocation.

This measure is not consistent as each project and species had different criteria for success. For example, the 100% success for damage causing animals only had one measure - whether they escaped their translocated site of not. The measures for success included successful reproduction, the establishment of home ranges (in release area) and refraining from livestock predation. Reasons for success were attributed to the fidelity of release site, the size of habitats and whether it is released into free ranging environments and what competition they had. For many individual translocations, the animal's sex, age and health had a major impact on their survival.

***Appendix F.** Summary of scoring for strategies for reducing predation by caracal on mainland breeding colonies.*

1. **Early detection**

a. Encourage residents to assist in securing the area against caracal incursions

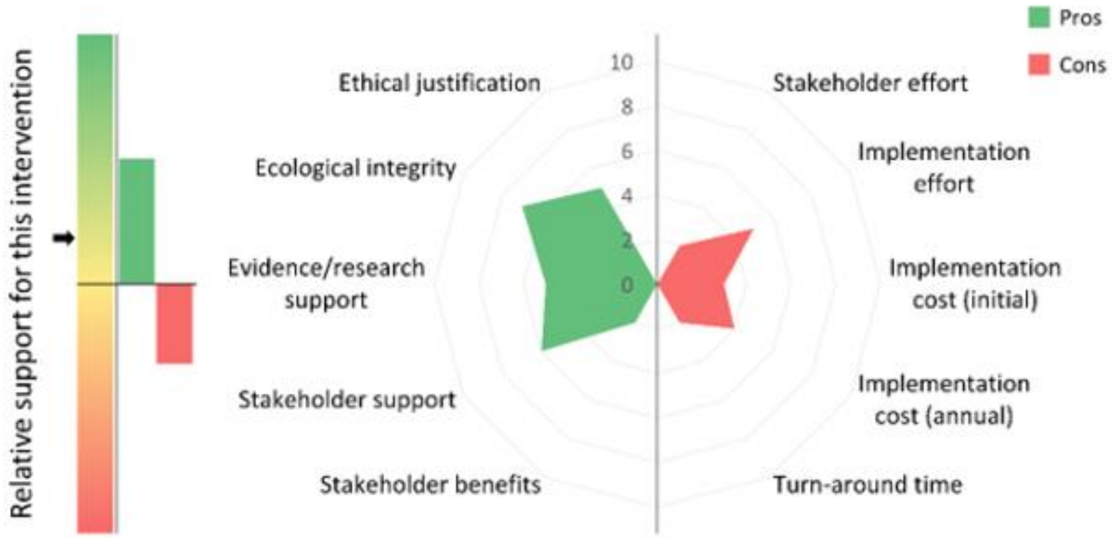

Figure 20. Relative support for encouraging residents to assist in securing the area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Deploy CCTV cameras for the early detection of caracals entering the penguin colony

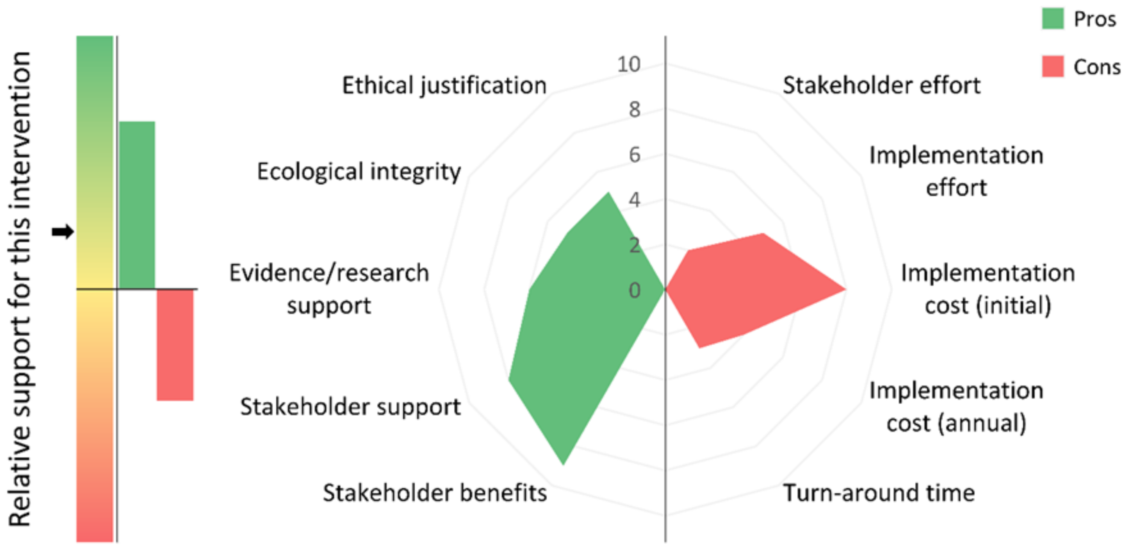

Figure 21. Relative support for deploying CCTV cameras for the early detection of caracals entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

c. Deploy camera traps directly linked to a cellular manager alert system

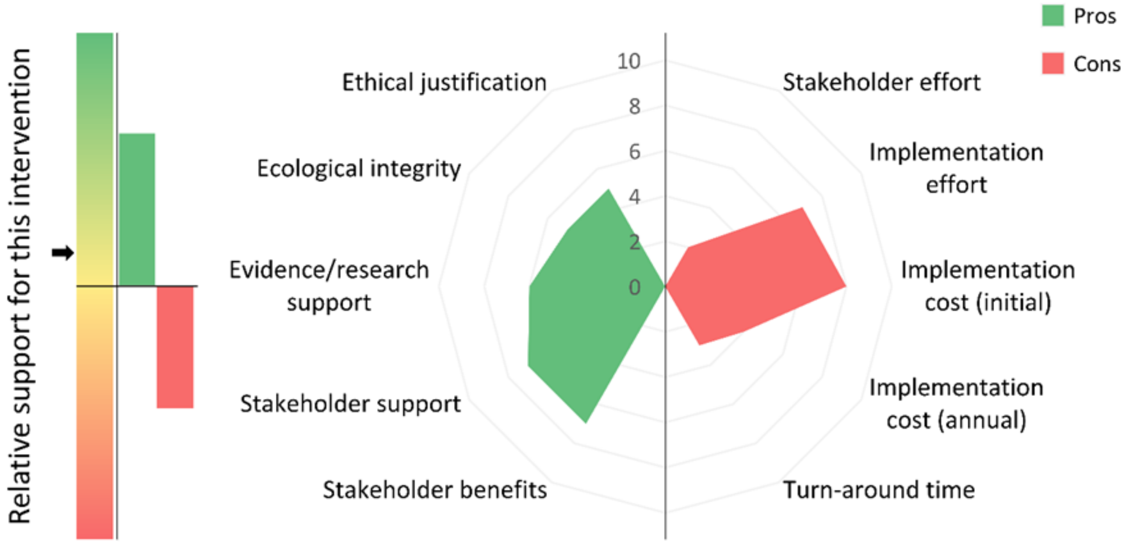

Figure 22. Relative support for deploying camera traps directly linked to a cellular manager alert system for the early detection of caracals entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

2. Barriers

a. Erect a metal fence to exclude and secure the penguin colony against caracal incursions

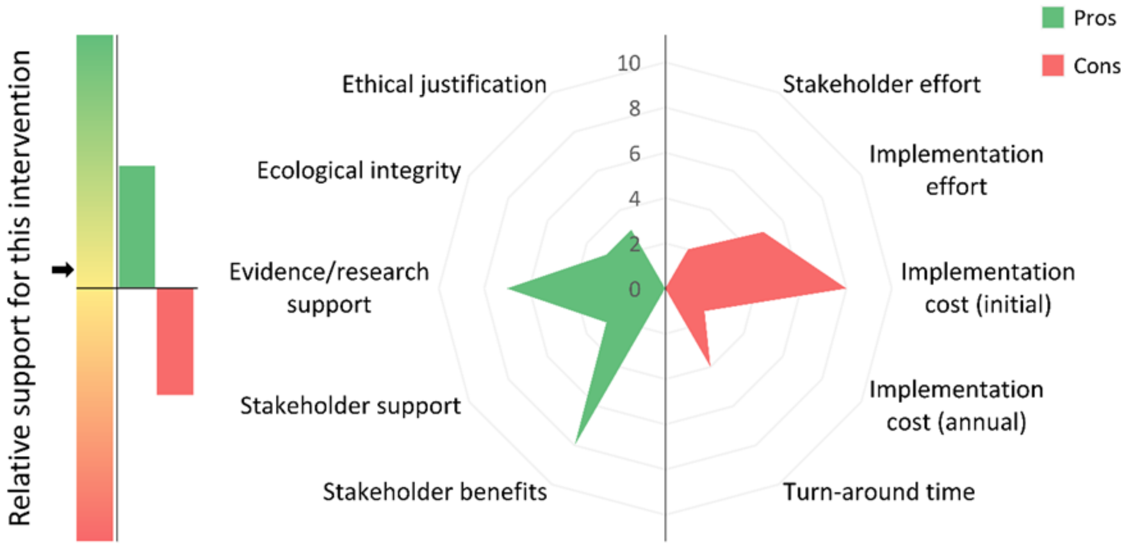

Figure 23. Relative support for erecting a metal fence to exclude and secure the penguin colony area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Erect an electrified fence to exclude and secure the penguin colony against caracal incursions

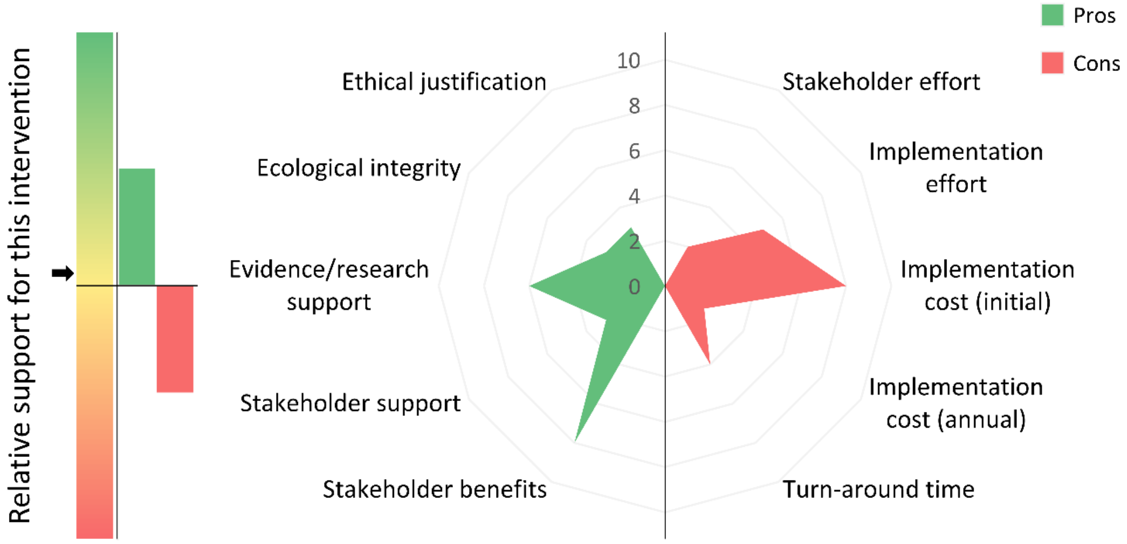

Figure 24. Relative support for erecting an electrified fence to exclude and secure the penguin colony area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

c. Erect a mesh netting fence to exclude and secure the penguin colony against caracal incursions

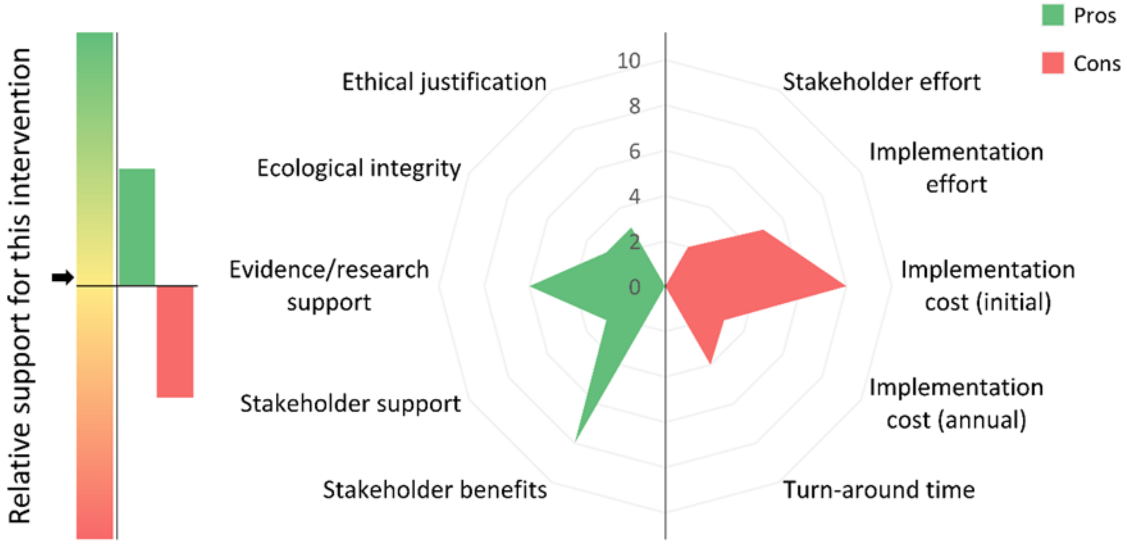

Figure 25. Relative support for erecting a mesh netting fence to exclude and secure the penguin colony area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

d. Erect a combination fence to exclude and secure the penguin colony against caracal incursions

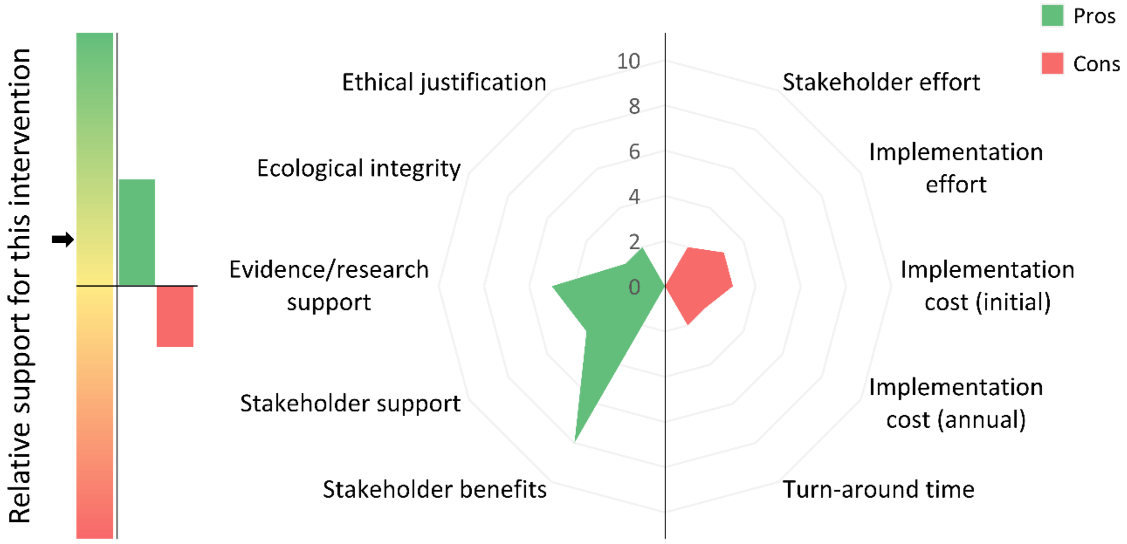

Figure 26. Relative support for erecting a combination fence to exclude and secure the penguin colony area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

e. Erect a virtual fence to exclude and secure the penguin colony area against caracal incursions

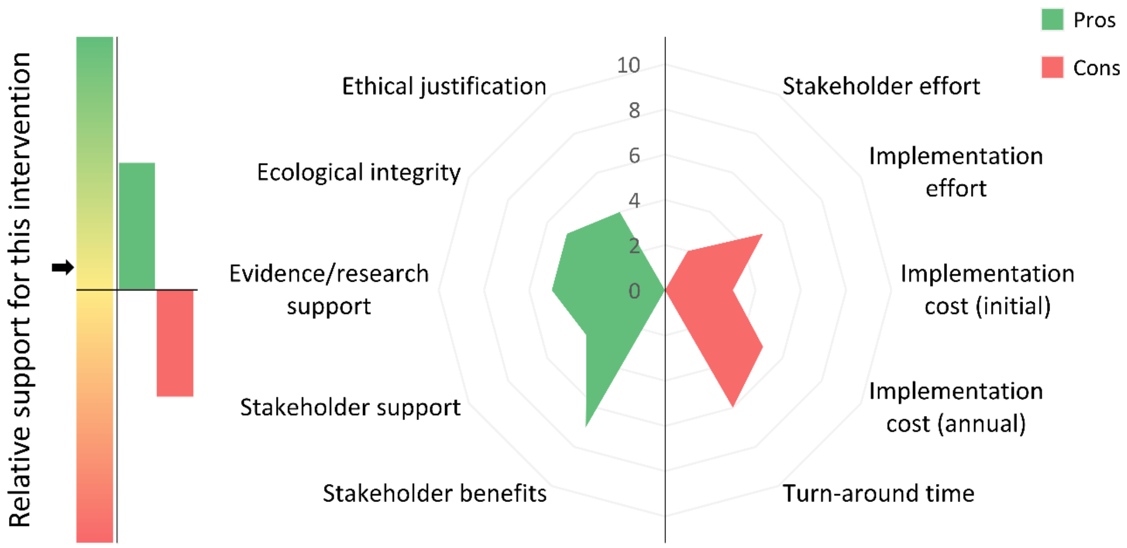

Figure 27. Relative support for erecting a virtual fence to exclude and secure the penguin colony area against caracal incursions as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

3. Guards

a. Employ rangers to haze and deter caracal from entering the penguin colony

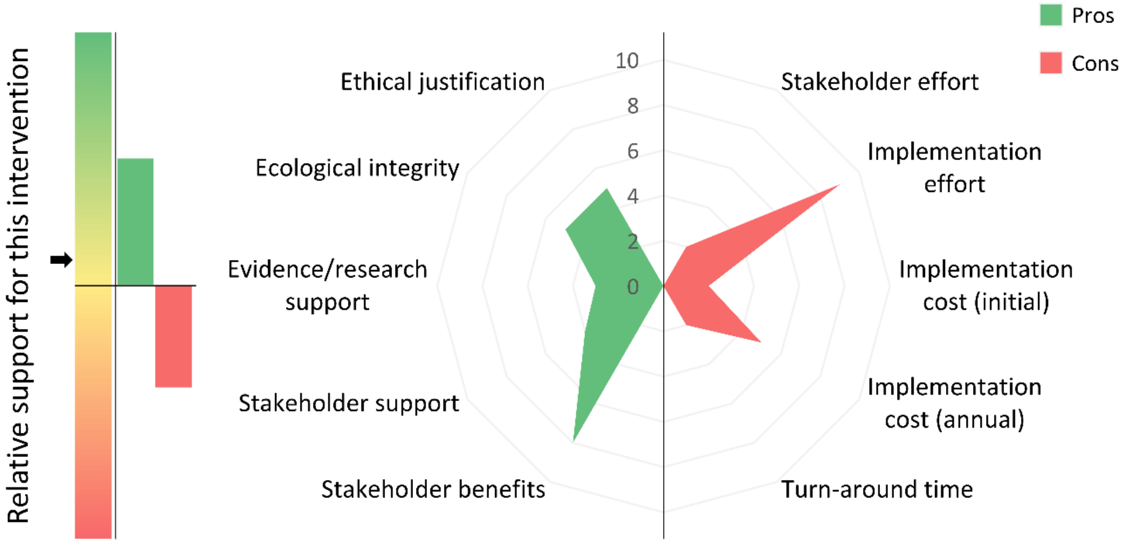

Figure 28. Relative support for employing night rangers to haze and deter caracal from entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Deploy guard dogs to haze and deter caracal from entering the penguin colony

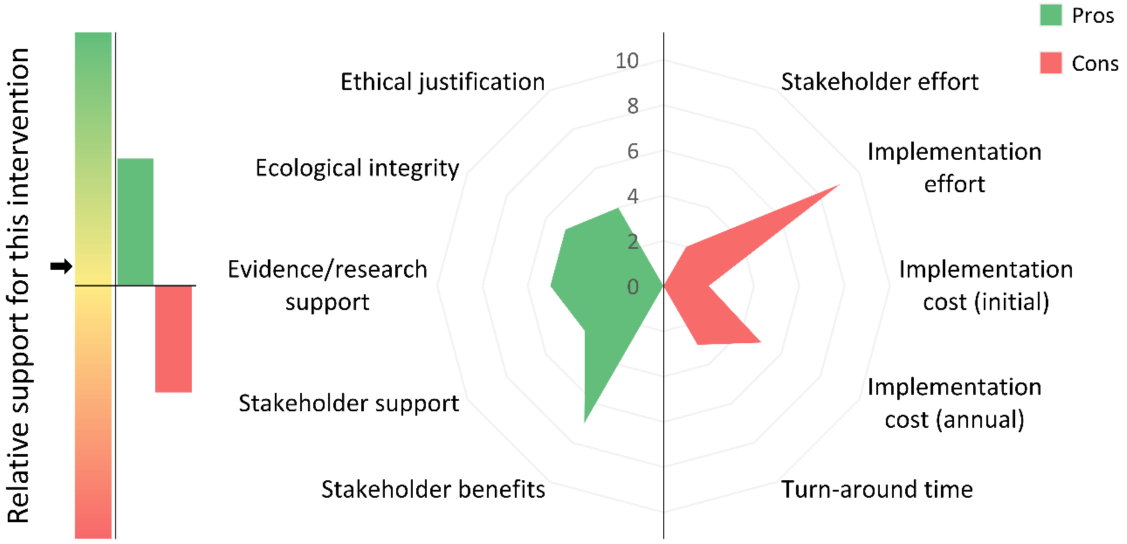

Figure 29. Relative support for deploying guard dogs to haze and deter caracal from entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

4. Aversive measures

a. Deploy light and sound aversion to deter caracal from entering the penguin colony

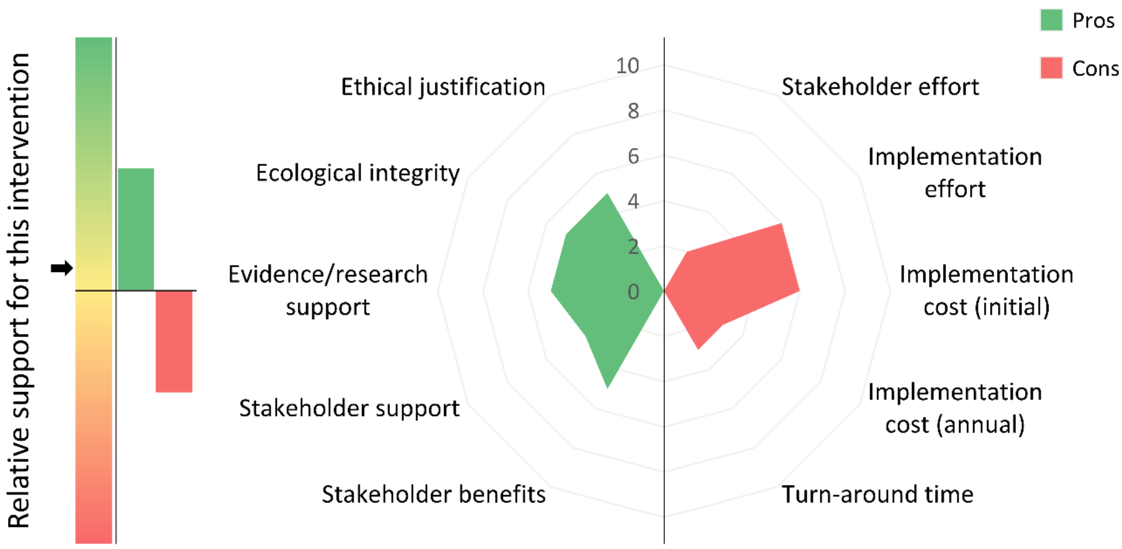

Figure 30. Relative support for deploying light and sound aversion to deter caracal from entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Employ conditioned taste aversion (CTA) to deter caracal from entering the penguin colony

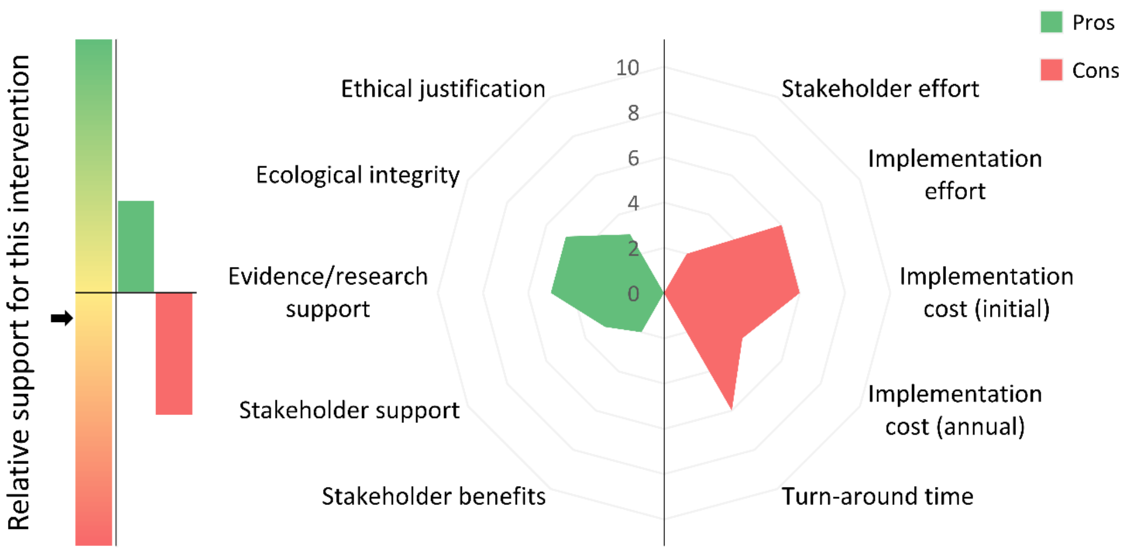

Figure 31. Figure x Relative support for employing conditioned taste aversion (CTA) to deter caracal from feeding on penguins as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

c. Employ a bio-fence boundary to deter caracal from entering the penguin colony

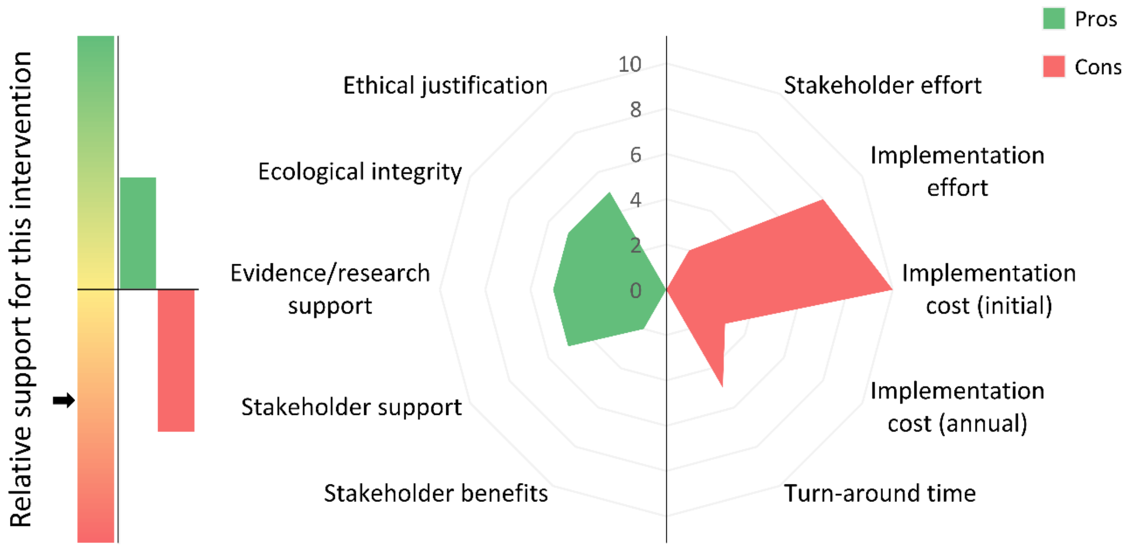

Figure 32. Relative support for employing a bio-fence boundary to deter caracal from entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

5. Non-lethal control

a. Trap and translocate 'damage-causing' caracal before entering the penguin colony

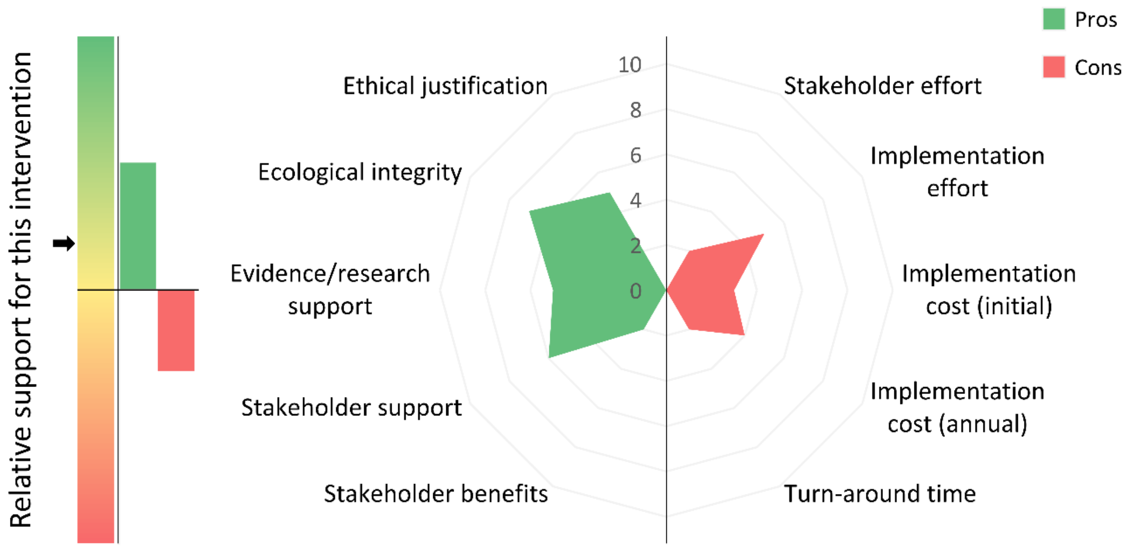

Figure 33. Relative support for trapping and translocating 'damage-causing' caracal before entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Artificially control caracal fertility to limit their predatory pressure on the penguin colony

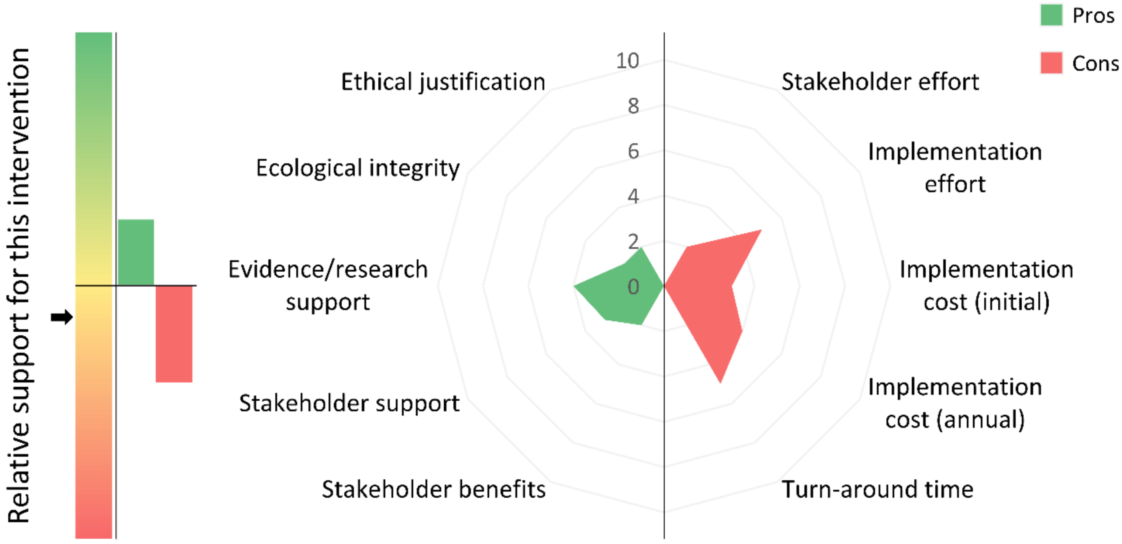

Figure 34. Relative support for artificially controlling caracal fertility to limit their predatory pressure on the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

6. Lethal control

a. Trap and euthanise 'damage-causing' caracal upon entering the penguin colony

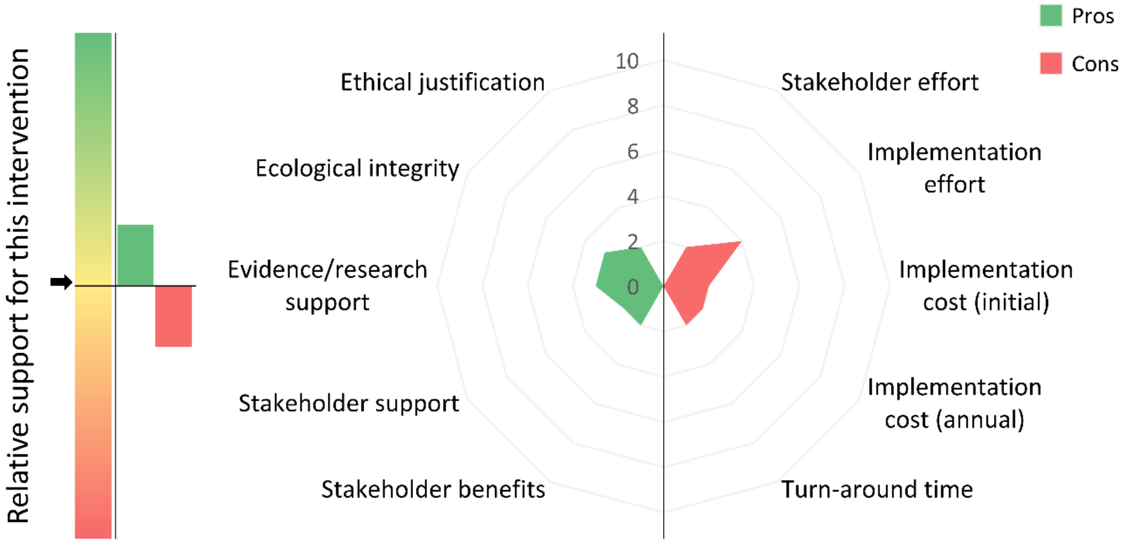

Figure 35. Relative support for trapping and euthanising 'damage-causing' caracal upon entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

b. Without trapping, shoot 'damage-causing' caracal before entering the penguin colony

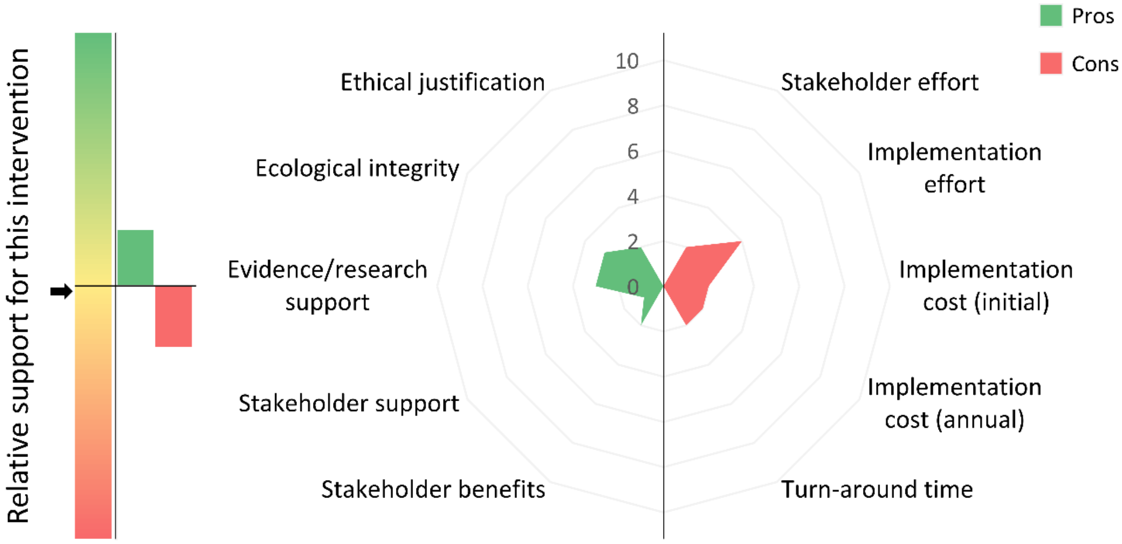

Figure 36. Relative support for shooting the 'damage-causing' caracal without trapping before entering the penguin colony as a mitigation strategy, considering 12 key aspects as either pro (green) or contra (red) to the strategy. Each aspect is given a combined (green high, red low) relative value score out of 10.

Appendix G - Summary of the strategies for reducing predation by caracal on mainland breeding colonies.

The first form of early detection (Table 6) considered was resident vigilance. The public would be requested to caracal-proof their properties and so limit the number of access points for caracals to enter the penguin colony. Detailed pros, cons and costs were discussed (Appendix F1a). This strategy places a financial and management burden on the residents, does not impact the current ecological integrity of the landscape, with little evidence and research to support the efficacy of such efforts, relies heavily and consistently on resident support, with few additional benefits. Turnaround time on such an intervention would be high as it requires substantial stakeholder education, private funds, collective support, and effort. The overall relative support score for this intervention was therefore zero (Table 12), as the pros and cons are quite evenly matched.

The second form of early detection (Table 6) considered was CCTV cameras for the early detection of caracals entering the penguin colony. CCTV cameras are an increasingly important and sophisticated component of crime prevention in urban areas and inadvertently detect wild animals moving along fence lines and through the same green corridors that criminals use. Strategically placed CCTV coverage could be used to monitor human and caracal presence and movement in the area, providing an early warning detection system before a caracal enters the colony. This only locates the caracal and would need to be linked to another intervention such as actively deterring the detected caracal or translocation. Detailed pros, cons and costs were discussed (Appendix F1b). While there is much evidence to substantiate its efficacy, the additional benefits of improved security will likely engender strong resident support. The overall support score for this intervention was +22 (Table 12), as the pros (especially evidence of efficacy and stakeholder benefits and support) strongly outweighed the cons (mostly cost).

The third form of early detection (Table 6) considered was camera traps directly linked to a cellular manager alert system which can be deployed remotely in natural habitat and could detect caracal in TMNP before they move into corridors that lead to the penguin colony. Using camera traps which are GSM enabled allows detections to be constantly monitored remotely using the cell phone network. This only locates the caracal and would need to be linked to another intervention such as actively deterring the caracal from moving towards the colony or translocation. Detailed pros, cons and costs were discussed (Appendix F1c). There would be some delay in turnaround time and a substantial amount of annual cost and regular implementation effort after significant initial implementation costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +12 (Table 12).

The first form of barrier to exclude caracal (Table 7) was a metal bar fence. A cat-specific example (CAT FENCE-IN™) includes an angled or horizontal mesh platform on top of the fence that prevents cats/caracal from jumping over or balancing on the fence and jumping over. Detailed pros, cons and costs were discussed (Appendix F2a). This strategy excludes non-target species which poses ethical and ecological risks and while there is much evidence of its efficacy and benefit to residents (mostly security), the unsightly nature and limitation on access would not engender support. There would be some delay in turnaround time and little annual cost with much initial implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +6 (Table 12).

The second form of barrier (Table 7) considered was a multistrand electrified fence designed to physically prevent caracals from attempting to climb the barrier. Detailed pros, cons and costs were discussed (Appendix F2b). This strategy excludes and endangers non-target species which poses ethical and ecological risks and while there is substantial evidence of its efficacy and benefit to residents (mostly security), the unsightly nature and limitation on access would not engender support. There would be some delay in turnaround time and little annual cost with much initial implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +4 (Table 12), as pros (mostly efficacy and resident security benefits) generally outweigh cons (mostly cost of installation and ethical or ecological concerns).

The third form of barrier (Table 7) considered was a mesh netting fence similar to a volleyball net designed to physically prevent caracals from gaining a purchase and, hence climbing the barrier. Detailed pros, cons and costs were discussed (Appendix F2c). This strategy excludes and endangers non-target species which poses ethical and ecological risks and while there is substantial evidence of its efficacy and some benefit to residents (mostly security), the unsightly nature and limitation on access would not engender support. There would be a short delay in turnaround time and some annual cost (including monitoring of tangled non-target species and major maintenance resulting from theft) with fair initial implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +2 (Table 12), as pros (mostly efficacy and resident security benefits) generally outweigh cons (mostly cost of installation and ethical or ecological concerns).

The fourth form of barrier (Table 7) considered was a combination fence made of various materials such as wooden posts, trawl netting, an angled overhang, electric strands (solar-powered), a gabion roll and anchovy netting on the ground. Where the bottom electrified strand could be removed to avoid harming animals that become entangled in trawl mesh. Detailed pros, cons and costs were discussed (Appendix F2d). This strategy excludes and endangers non-target species which poses ethical and ecological risks and while there is substantial evidence of its efficacy and a distinct benefit to residents (mostly security), the somewhat unsightly nature and limitation on access may not engender support. There would be a short delay in turnaround time and some annual cost (including monitoring of tangled non-target species) with minimal initial implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +18 (Table 12), as pros (mostly fit-for-purpose design, efficacy, and resident security benefits) mostly outweigh cons (mostly cost of installation and ethical or ecological concerns).

The fifth form of barrier (Table 7) considered was a virtual fence where a non-physical boundary that serves as a barrier to caracal incursion are installed and a GPS collar would send an alert to a cell phone in real-time when the collared animal passes through a 'geofence' (a virtual line of GPS points). A monitor can respond by alerting night guards who can then haze the caracal away from the penguin colony. Traversing the fence can emit noise from a speaker triggered by the collar and be used to deter or locate the caracal. Detailed pros, cons and costs were discussed (Appendix F2e). This strategy specifically targets problem individuals and poses some ethical risks but is ecologically sound and while there is substantial evidence of its efficacy and a distinct benefit to residents (mostly interest), collars on caracal are somewhat unsightly and may not engender support. Collaring and monitoring of targeted individuals may mean a relatively long turn-around time with substantial annual cost (mostly capture and re/collaring) with some initial implementation effort and costs; however, it requires relatively little resident effort. The overall relative support score for this intervention was +8 (Table 12).

The first form of guarding (Table 8) considered was night and hazing rangers where a guard or monitor would be employed to patrol Burghers' Walk and Boulders boardwalk creating a noise (e.g., clapping or playing a recording) throughout the night, creating a noise deterrent for any nearby caracal and establishing a permanent human presence in the area surrounding the penguin colony. Detailed pros, cons and costs were discussed (Appendix F3a). This strategy specifically targets problem individuals, posing few ethical and ecological risks and while there is substantial evidence of its efficacy (provided the caracal does not get into the colony, in which case it is very difficult to haze it out effectively) and a distinct benefit to residents (mostly security), the potential for noise disturbance may not engender support. While there would be a rapid turnaround time, full-time employment requires some implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +10 (Table 12), as pros (mostly fit-for-purpose design, efficacy, and resident security benefits) generally outweigh cons (mostly annual employment costs).

The second form of guarding (Table 8) considered was guard dogs as domestic dogs pose a predation threat to caracal and can thus be used as a patrolling deterrent to caracal in the area surrounding the penguin colony. Guard dogs (generally neutered males) must be socialised with humans and penguins to keep them tame, following the 'Warrnambool Method' to avoid dangerous and feral behaviour. Detailed pros, cons and costs were discussed (Appendix F3b). This strategy specifically targets problem individuals, posing few ethical and ecological risks and while there is substantial evidence of its efficacy and a distinct benefit to residents (mostly security), the potential danger to penguins, dogs and people may not engender support. While there would be a good turnaround time, full-time employment requires some implementation effort and costs, however, it requires relatively little resident effort. The overall relative support score for this intervention was +8 (Table 12).

The first form of aversive measures (Table 9) considered were light and sound (to discourage the presence of nuisance animals (caracal)). These devices are either placed in a stationary location and activated by a sensor, or are hand-held and activated manually (e.g., bear bangers have been used successfully against baboon raiding on the Cape Peninsula). This also exploits the landscape of fear such as the use of Action Stations using lion roars or other distress audio (e.g., air horns) in non-residential areas like Windmill Beach to scare caracal away. Detailed pros, cons and costs were discussed (Appendix F4a). This strategy is more poses few ethical and ecological risks and while there is good evidence of its efficacy, there are few specific benefits to residents who may not be comfortable with the light or noise pollution, especially at night. While there would be a good turnaround time and few annual costs (maintenance and theft) implementation effort and initial costs are high, however, it requires relatively little resident effort. The overall relative support score for this intervention was +8 (Table 12), as pros (mostly proven efficacy given simplicity) generally outweigh cons (mostly initial implementation costs and effort).

The second form of aversive measures (Table 9) considered was conditional taste. It entails treating baits with chemicals so that when a caracal eats the bait, they become nauseous and are behaviourally deterred from killing penguins. There is an option to treat killed penguins with bitter compounds that make caracal temporarily ill the day after it has been killed. Next time, the smell alone may be enough of a deterrent. Detailed pros, cons and costs were discussed (Appendix F4b). This strategy is more accepted in predator aversion, posing both ethical and ecological risks and while there is some evidence of its efficacy, there are few specific benefits to residents who may not be comfortable with captive aversive conditioning. The process carries a long turnaround time (assuming caracal can be safely released), with relatively high initial and annual implementation cost and efforts, however, it requires relatively little resident effort. The overall relative support score for this intervention was -12 (Table 12), as pros (mostly some evidence of efficacy) are generally outweighed by the cons (mostly a long turnaround time, as well as substantial initial and annual implementation cost and efforts, in addition to ethical and ecological concerns).

The third form of aversive measures (Table 9) considered was bio-fencing this entails placing artificial caracal scent around the penguin colony to deter immigrant caracal males from entering the colony. Caracal are territorial and hence are predicted to respond to territorial cues in the environment. The scent should be artificially manufactured as obtaining real urine would require long-term captivity of a dominant caracal, which is ethically questionable. Detailed pros, cons and costs were discussed (Appendix F4c). This strategy is more accepted in its predator aversion, posing few ethical and ecological risks and while there is good evidence of its efficacy, there are few specific benefits to residents. The process carries a long turnaround time (assuming a suitable artificial substitute can be synthesised), with extremely high initial implementation cost and efforts, however, it requires relatively little resident effort and the subsequent annual costs of implementation are low. The overall relative support score for this intervention was -12 (Table 12), as pros (mostly evidence of efficacy and hopeful simplicity of implementation after development) are generally outweighed by the cons (mostly a long turnaround time, as well as substantial initial implementation cost and efforts).

The first form of non-lethal control (Table 10) considered was translocation of the predator from the area where penguin losses occur. Caracal have been observed returning to the kills made the preceding evening. The use of penguin carcasses from the previous night's hunt as bait inside walk-in traps has seen a subsequent 100% capture rate. Detailed pros, cons and costs were discussed (Appendix F5a). This strategy is highly specific to 'damage-causing' individuals, posing few ethical and ecological risks and while there is excellent evidence of its efficacy, there are few specific benefits to residents. It has a short turnaround time (assuming capture), with some initial implementation costs and effort, however, it requires relatively little resident effort and the subsequent annual costs of implementation are relatively low. The overall relative support score for this intervention was +18 (Table 12), as pros (mostly evidence of efficacy, as well as permanence and simplicity of implementation) significantly outweigh the cons (mostly an annual implementation cost and effort).

The second form of non-lethal control (Table 10) considered was fertility regulation which entails using surgery or chemical contraceptive to temporarily prevent caracal in the region from having offspring, hardening territorial boundaries and predatory pressure by limiting population growth and dispersal. Detailed pros, cons and costs were discussed (Appendix F5b). This strategy, though highly specific to 'damage-causing' individuals, is invasive, posing both ethical and ecological risks and while there is some evidence of its efficacy, it has yet to be tested in caracal and there are few resident-specific benefits. The process carries a long turnaround time (assuming the majority of one sex on the Cape Peninsula can be captured), with substantial implementation costs and effort, however, it requires relatively little stakeholder effort. The overall relative support score for this intervention was -12 (Table 12), as pros (mostly evidence of efficacy) do not outweigh the cons (mostly a lack of research and uncertainty, the long turnaround time, as well as implementation cost and efforts).

The first form of lethal control (Table 11) considered was injection. The caracal would be cage trapped, following predation of penguins. The trapped caracal is then removed and destroyed via lethal injection, which is administered by a veterinarian, and the body is donated to research. This is the current management protocol. Detailed pros, cons and costs were discussed (Appendix F6a). This strategy, though highly specific to 'damage-causing' individuals, poses some ethical and ecological risks and while there is clear evidence of its efficacy, there are few resident-specific benefits and lethal management may not engender support. The process carries a short turnaround time (assuming the correct 'damage-causing' caracal is caught immediately) with some implementation cost and effort, however, it requires relatively little stakeholder effort. The overall relative support score for this intervention was 0 (Table 12), as pros (mostly evidence of efficacy) are at parity with cons (mostly a public perception of lethal control, a lack of research/uncertainty and stakeholder/donor support).

The second form of lethal control (Table 11) considered was shooting such that when a 'damage-causing' caracal is detected by a penguin predation event, the animal is identified and shot by an approved professional hunter (PH) the following evening without capture, where the kill of the previous evening is used as bait. Detailed pros, cons and costs were discussed (Appendix F6b). This strategy, though highly specific to 'damage-causing' individuals, poses some ethical and ecological risks and while there is clear evidence of its efficacy, there are few resident-specific benefits and lethal management may not engender support. The process carries a short turnaround time (assuming the correct 'damage-causing' caracal is shot immediately) with some implementation cost and effort, however, it requires relatively little stakeholder effort. The overall relative support score for this intervention was -2 (Table 12), as pros (mostly evidence of efficacy) are outweighed by cons (mostly a public perception of lethal control, a lack of research/uncertainty and stakeholder/donor support).