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# Industrial fishing, no-take zones and endangered penguins

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Industrial fishing can profoundly alter marine environments, and no-take zones are an important tool to achieve sustainable fishing and re-establish ecosystem integrity. However, the potential benefits for vagile species such as top predators are still questioned. The numbers of endangered African penguins *Spheniscus demersus* have halved since 2004. They depend on small pelagic fish, also targeted by a purse-seine industry in South Africa. We studied penguin foraging behaviour and breeding output at two colonies supporting 60% of the global population in relation to fishing activity by purse-seine vessels. In 2008, both sites were open to fishing, but in 2009 and 2010 waters within 20 km of the world's largest colony were closed to fishing, while waters around the neighbouring colony, 50 km away, remained open. Birds' foraging effort increased with the size of catches around their colonies and decreased with the implementation of a reserve. Total fishing catches in the bay remained constant, but shifted toward the boundaries of the reserve in 2010. While the no-take zone significantly reduced penguin foraging effort, intensified fishing pressure at the reserve boundaries ("fishing the line") in 2010 limited this benefit. The decrease over time of both adult body mass and chick growth rates from both colonies, suggested that the 20 km-closure is too small to reverse penguin population decreases. Therefore, stronger fishery management measures, such as larger no-take zones, buffer zones around reserves, or local reduction of fishing quotas, seem necessary to increase food availability for penguins around their colonies. The collapse of Africa's only breeding penguin species adds urgency to the wider implementation of such measures.

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## 1. Introduction

The intensity of marine fishing has increased dramatically since the middle-ages, in response to pollution of freshwater ecosystems, cultural changes, human population increase and improved technologies (Roberts, 2007). Archaeological records show early signs of local depletion of marine resources by aboriginal tribes (Jackson et al., 2001), as is also apparent in European waters over the past millennium (Longhurst, 2010). The development of industrial fishing in the 20th century has reduced the biomass of predatory fish globally to <10% of pre-industrial levels (Myers and Worm, 2003) and profoundly altered marine environments (Boehlert, 1996). Marine Protected Areas (MPAs) are crucial to re-establish ecosystem integrity and to allow sustainable fishing (Roberts et al., 2005; Worm et al., 2009). To date however, less than 1.5% of the ocean is formally protected (Spalding et al., 2010), despite the Biodiversity Convention in Rio in 1992 calling for at least 10% of the oceans to be protected through a network of MPAs. Furthermore, there is little protection for marine top predators despite their pivotal role in the stability of marine food webs (Baum and Worm, 2009). Their populations are declining world-wide (BirdLife, 2010; Lotze and Worm, 2009) through a combination of direct exploitation, mortality from fishing gear and competition with fisheries (Tasker et al., 2000; Lotze and Worm, 2009). MPAs are increasingly promoted as beneficial for top predators (Hooker et al., 2011). Development in technologies facilitated the assessment of the use of marine ecosystems by threatened species (Ballard et al., this issue; Le Corre et al., this issue) as well as identifying threats specific to life stages or species (Montevecchi et al., this issue) to model the design of potential MPAs (Grecian et al., this issue; O'Brien et al., this issue). While it is necessary to work with governmental institutions for enforcement and compliance of such protected zones (Arcos et al., this issue; Lascelles et al., this issue), it is of crucial importance to assess the effectiveness of established MPAs to protect targeted species (Yorio, 2009; Ludynia et al., this issue; Garthe et al., this issue).

Numbers of African penguins (*Spheniscus demersus*), endemic to southern Africa, decreased by roughly 90% during the 20th century (Crawford, 1999). During the first decade of the 21st century, what was left of the population more than halved, with only 26,000 breeding pairs remaining in 2009 (Crawford et al., 2011). This recent decrease led to the species being down-listed from vulnerable to endangered in 2010 (BirdLife, 2010). African penguin survival

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and breeding success are closely tied to the availability of sardines (*Sardinops sagax*) and anchovies (*Engraulis encrasicolus*) within 20–30 km of their breeding sites (Crawford, 1999; Pichegru et al., 2009). These fish are also targeted by an important commercial purse-seine fishery in South Africa, which developed after World War II (Griffiths et al., 2004). Exploitation of the fishery remained relatively low and stable until the mid-1990s, but increased steadily post 2000 (Griffiths et al., 2004). Since the 1980s, this fishery has been regulated by a Total Allowable Catch (TAC) that is set annually by the Department of Agriculture, Forest and Fisheries (DAFF), to match *ca* 20% of the pelagic fish biomass estimated every year by fishery-independent acoustic surveys off the South African coast (Coetzee et al., 2008). Recently, small pelagic fish availability decreased off the west coast of South Africa, where most penguin colonies are situated, due to a south-eastward shift in their distribution (van der Lingen et al., 2005; Roy et al., 2007). This shift is probably linked to changing environmental conditions, but also to a lack of spatial management of the competing purse-seine fishery as heavy fishing pressure persists in areas with low fish abundance due to the location of ports and land-based processing plants (Coetzee et al., 2008). This spatial mismatch resulted in local competition between birds and fisheries (Okes et al., 2009; Pichegru et al., 2009).

To assess the potential effect of fishing exclusions (MPAs) on penguins, an area of 20 km-radius was experimentally closed to purse-seine fishing around the world's largest African penguin colony at St. Croix Island (7200 pairs, Crawford et al., 2011), Nelson Mandela Bay, South Africa, in January 2009. The waters around Bird Island, another penguin colony (2900 pairs, Crawford et al., 2011) 50 km away in the same bay, remained open to fishing. These two islands support >60% of the global population of African penguins, but their numbers also halved since 2001, following a decrease in small pelagic fish biomass (Crawford et al., 2011). Purse-seine fishing started in the Nelson Mandela Bay area in 1990s, and catches have increased fivefold since 2000 (Department of Agriculture, Forest and Fisheries, unpubl. data). Historically, most pelagic fish catches occurred around St. Croix Island, which is closer to Port Elizabeth harbour than Bird Island (Pichegru et al., 2009). In the first year after closure, the birds from St. Croix Island decreased their foraging effort, saving daily energy expenditure, while the birds from Bird Island increased their effort, probably in response to reduced food availability (Pichegru et al., 2010). The value of these preliminary results in suggesting potential benefits of small no-take zones for African penguins was, however, debated (Coetzee, 2010; Ryan et al., 2010). Here, we report the foraging behaviour of adult penguins raising chicks at both sites in the second year of fishing exclusion around St. Croix Island. We relate their at-sea behaviour in the year before closure and the two years after closure with the distribution and abundance of purse-seine fish catches. We also compared the penguins' breeding success and chick growth at the two colonies after the closure.

## 2. Materials and methods

### 2.1. Foraging parameters

The foraging behaviour of adult penguins raising chicks of 1–3 weeks old was studied at St. Croix Island (33°48′S, 25°46′E) and at Bird Island (33°50′S, 26°17′E), in May–June 2008 and April–May 2009 (see Pichegru et al., 2010), and April–June 2010. Most African penguins breed at the islands between March and August. Members of each breeding pair share the care of their brood of 1–2 chicks, with one adult attending the nest while the partner is at sea. Birds were equipped with GPS-TD loggers (a GPS recorder combined with a time-depth recorder; $96 \times 39 \times 26.5$ mm; Earth&Ocean Technologies, Germany), that record latitude and longitude at 1 min-intervals to an accuracy of <10 m, and depth at 1 s intervals to the nearest 0.1 m. The devices weighed <2.5% of adult body mass and were housed in streamlined fibre-composite containers (~1.5% cross-sectional area of a penguin). They were attached to the penguins' lower back feathers with waterproof tape, causing no damage to the plumage. Handling lasted <6 min from capture to release, and these methods were approved by University of Cape Town's animal ethics committee. After deployment, nest sites were monitored until the instrumented birds returned, allowing them to be recaptured and the logger removed. Previous studies showed no significant difference in the trip duration of instrumented versus control African penguins (Petersen et al., 2006; Pichegru et al., 2010).

On retrieval of the devices, trip duration, path length at sea (at the surface), maximum distance from the colony and diving effort (total Vertical Travel Distance (VTD) defined as the sum of depth of all dives multiplied by two to obtain distance, *sensu* Horning and Trillmich, 1997) were calculated to estimate the birds' foraging effort. We also estimated the diving behaviour of the birds (diving rate, average dive depth and duration). Data were only recorded for a single foraging trip per bird to limit pseudo-replication. A GPS position was associated with each feeding dive (>3 m and diurnal, as defined by Wilson and Wilson (1990)). Adaptive kernel analyses were conducted on the entire GPS position dataset for each colony/year, using Arcview GIS 3.1 with the smoothing factor chosen according to the least-squares-cross-validation method (Worton, 1989) to estimate isolines incorporating 50%, 75% and 75–90% of foraging locations.

### 2.2. Diet

Diet samples from adult penguins were collected from random birds returning from the sea at dusk, so that the samples were likely to reflect the diet fed to chicks. The birds' stomachs were flushed with water poured down a tube into the stomach (Wilson, 1984) and birds were then released. To limit disturbance, we did not flush the entire stomach contents, so could not compare the mass of food between years as a proxy for prey capture per trip. Prey items were identified, usually to species level, weighed for each sample and pooled to estimate the contribution by mass of different species to the diet of penguins from each island. Logger birds were not sampled to reduce disturbance to these birds.

### 2.3. Purse-seine fishing catches

The positions of purse-seine vessels were monitored constantly via satellite telemetry, ensuring compliance within the experimental closure around St. Croix Island in 2009 and 2010. The weight (tonnes) of pelagic fish (anchovies and sardines) caught by the fishery between 2008 and 2010 was obtained from catch data recorded per $10 \times 10$ nautical mile ($18.5 \times 18.5$ km) grid cell by the DAFF. Not all empty hauls are recorded, so we could only estimate total catches and catch per unit area rather than catch per unit effort (CPUE). The closed area around St. Croix Island overlaps with six reporting blocks (Fig. 1), but the core area falls within four blocks, with <10% of the two southernmost blocks closed to fishing. We compared the catches in the entire bay (Fig. 1) with catches occurring in these six blocks around St. Croix Island (i.e. block numbers 4600, 4605, 4650, 4655, 5610 and 5615, Fig. 1) and four blocks around Bird Island where the penguins from that island primarily forage (block numbers 4702, 4703, 4752 and 4753, Figs. 1 and 2). We chose these blocks as the area exploitable by fishing boats (>20 m deep, A. Badenhorst, pers. comm.) was equivalent between the two zones when St. Croix was closed to fishing (690 $km^2$ around St. Croix Island and 620 $km^2$ around Bird Island). When

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