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Trend changes in sympatric Subantarctic and Antarctic fur seal pup populations at Marion Island, Southern Ocean

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Abstract

Recent pup population estimates of sympatric Subantarctic (*Arctocephalus tropicalis*) and Antarctic fur seals (*A. gazella*) at Marion Island are presented. Published pup population estimates of *A. tropicalis* (1995 and 2004) with an unpublished total island count in 2013, and annual counts on subsets of rookeries (2007–2015) were analyzed using a hierarchical Bayesian model. The pup population declined by 46% (95% credible interval CI: 43%–48%) between 2004 (mean = 15,260, CI: 14,447–16,169 pups) and 2013 (mean = 8,312, CI: 7,983–8,697), mirrored by a 58%–60% decline at rookeries counted annually (2007–2015). Population decline was highest at high-density west and north coast rookeries, despite negligible change in female attendance patterns, pup mortality or median pupping date over the previous 25 yr. A better understanding of foraging behavior and its effects on reproductive success and survival in this *A. tropicalis* population is needed before we can attribute population decline to any external factors. In contrast, total island counts of *A. gazella* pups in 2007, 2010, and 2013, suggest that this population is still increasing although the annual intrinsic rate of population growth decreased from 17.0% (1995–2004, 744 pups) to 4.0% (2010–2013, 1,553 pups). The slowed growth of *A. gazella* is likely the result of saturation at the main rookery.

Key words: *Arctocephalus*, Subantarctic fur seal, Antarctic fur seal, population estimate, Marion Island, hierarchical Bayesian model, detection probability, sympatry, density, count.

Population size assessments are central to ecological studies. Quantifying population trend change is crucial to evaluate its current state, facilitating decisions related to conservation or management interventions (Sutherland and Norris 2002). Monitoring recovery in previously exploited populations allows for quantification of the four phases (survival, establishment, recolonization, and maturity)

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of population growth (Bester 1980, Roux 1987) and provides insight into population growth dynamics (Sinclair 1996). Monitoring consequently permits investigation into underlying mechanisms of how environmental fluctuations influence population growth.

All fur seals (family Otariidae) were hunted for their furs; several species, including the Southern Hemisphere species (genus *Arctocephalus*), were hunted close to extinction (Bonner and Laws 1964). Small populations survived on a few subantarctic islands, which facilitated subsequent recovery (Bonner and Laws 1964). Similar to other subantarctic islands, Marion Island was subjected to sealing from the 17th century. Sealing continued intermittently until 1931 when only a small population of Subantarctic fur seals (*Arctocephalus tropicalis*; SAFS) remained (Kerley 1987). Marion Island is currently home to the largest sympatric populations of Subantarctic and Antarctic fur seals (*A. gazella*) (Hofmeyr *et al.* 2006). The first population census at Marion Island was done in 1952 (Rand 1956) but regular population censuses only commenced in 1974 (Condy 1978; Kerley 1987; Wilkinson and Bester 1990; Hofmeyr *et al.* 1997, 2006) and started opportunistically at neighboring Prince Edward Island in 1981 (Kerley 1987; Wilkinson and Bester 1990; Bester *et al.* 2003, 2009).

Between 1952 and the late 1970s the SAFS population on Marion Island followed the first stage of the classic population recolonization trajectory: a period of survival, where population numbers remained low and increased slowly (Bester 1980, Roux 1987). From the late 1970s until the late 1980s a phase of rapid recolonization and exponential increase was recorded (12.9% per annum; Wilkinson and Bester 1990), but from the end of the 1980s to 1995, annual population growth slowed to 2% (Hofmeyr *et al.* 1997). Although it was suggested that the population had reached the maturity phase, a 2004 census showed an annual rate of population increase of 5.2% over the intervening 9 yr (Hofmeyr *et al.* 2006). Therefore, the population might not have been in the maturity phase as yet but had certainly passed the peak period of population increase by 2004 (Hofmeyr *et al.* 2006). The largest rookeries (mostly on the western aspect of Marion Island) showed slowed growth, while smaller rookeries elsewhere on the island increased in number and size. Hofmeyr *et al.* (2006, 2007) argued that the overall reduced population growth was probably due to limited breeding space at the source rookeries, rather than a lack of resources at sea. It is not known whether Antarctic fur seals (AFS) used to breed on Marion Island prior to sealing (Rand 1956). AFS numbers were last shown to increase at 17% annually (1995–2004); thus in the exponential growth phase (Hofmeyr *et al.* 2006). The end point of these trends corresponded to the most recent increased abundance estimates of both species at Marion Island of *ca.* 80,000 SAFS and *ca.* 5,800 AFS in 2004 (Hofmeyr *et al.* 2006).

The synchronous breeding of high-latitude fur seals (*e.g.,* Payne 1977) and the presence of aggressive territorial males make direct counts on the beach during peak breeding season impossible (Shaughnessy 1986). Counting is often done from a vantage point above the beach (*e.g.,* Bester *et al.* 2003, 2009; Gibbens and Arnould 2009); from a ship, counting adult females ashore (Boyd 1993); through aerial surveys, or some combination of these (*e.g.*, Pemberton and Kirkwood 1994, Hucke-Gaete *et al.* 2004). All these methods have inherent counting errors, and often depend on the density of animals on the beach (*e.g.*, Boyd 1993). Alternatively, population trends can be estimated through pup population changes (*e.g.*, Chapman and Johnson 1968, Bonner 1968, Guinet *et al.* 1994, Shaughnessy *et al.* 1995, Hofmeyr *et al.* 2007). Pups are easily distinguishable from other age classes and most importantly remain at colonies for months after birth (Pemberton and Kirkwood 1994). In contrast, adult individuals spend time both at sea and on land during this period, while subadult individuals are not present on land during this period (Kerley 1983). This makes comprehensive population counts of separate age classes infeasible (Shaughnessy 1986). Pup production can also serve as an indicator of environmental pressures on the population. Precipitous declines in pup production have been linked to El Niño events in several otariid species (Trillmich and Ono 1991, Guinet *et al.* 1994). Declines have been correlated with positive sea-surface temperature anomalies in AFS (Forcada *et al.* 2005) and have been negatively correlated with sea-surface temperature and positively correlated with female body condition for Australian fur seals (*A. pusillus doriferus*; Gibbens and Arnould 2009). Australian sea lion (*Neophoca cinerea*) pup production was negatively influenced by adult sea lion bycatch of shark fishery activities (Shaughnessy *et al.* 2013).

In this paper, we reassess the pup population status of *Arctocephalus* spp. at Marion Island and provide revised estimates of pup numbers and trends for the period 2004–2013. To achieve this, for SAFS we use (1) annual pup count data from a subset of rookeries on Marion Island (2007–2015), (2) total island surveys (2004 and 2013), and (3) minimum pup mortality. Changes in AFS pup numbers are represented by triennial total island surveys (2007, 2010, and 2013).

Methods

Marion Island is part of the Prince Edward archipelago in the Indian sector of the Southern Ocean. Marion Island is approximately 300 km^2 in area, with a coastline of *ca.* 107 km (Meiklejohn and Smith 2008). On Marion Island, AFS have a median pupping date of 5–7 December, whereas the median pupping date for SAFS is 16–20 December (Hofmeyr *et al.* 2007). AFS pups wean at 110 d and SAFS pups at 300 d (Kerley 1983). Breeding seasons span from the end of one calendar year into the next and are referred to by the year in which the pups wean, for example, “2007” refers to pups born in December 2006 and weaned in 2007.

Subantarctic Fur Seal Pup Counts: Field Methods

SAFS prefer to breed on boulder/jumbled rocky beaches (Bester 1982). At Marion Island, pup numbers are predominantly estimated by direct counting while observers traverse beaches on foot (but by capture-mark-recapture at Fur Seal Peninsula, the largest breeding area). Previous studies indicated that direct counts underestimate pup numbers but that it is colony specific due to topography (Shaugnessy *et al.* 1995, Kirkwood *et al.* 2005).To account for imperfect observation of pups during direct counts (*e.g.*, pups hiding out of sight underneath boulders), we use (1) capture-mark-recapture (CMR) methods in combination with direct counts at a single beach to estimate detection probability when counting directly (Shaughnessy *et al.* 1995), and (2) cliff-top counts in combination with direct counts at a single beach to estimate the detection probability when beaches could only be counted by direct observation from the top of a cliff (lower detection expected in this case). Each of these counting methods is explained in more detail below.

Annual (2007–2015) and island-wide direct counts (2004, 2013)—The coastline of Marion Island is made up of a series of distinct, naturally segregated beaches interspersed with sheer cliffs that drop directly into the ocean. An observer can easily move on foot between and across beaches and record the number of pups present on these. In each year, all counts were made by a single, experienced observer moving on foot across each beach. Live and dead pups were counted by systematically searching beaches and vegetated areas adjacent to beaches. Where over 100 pups were counted on a beach, multiple (2–4) counts were done. Annual counts were made along a small stretch of coastline (Fig. 1) at the conclusion of the pupping season from the middle to the end of January (Kerley 1983); total island counts extended into early February. Consistent with all previous total population estimates of SAFS at Marion Island (Condy 1978; Kerley 1983; Wilkinson and Bester 1990; Hofmeyr *et al.* 1997, 2006), pups on the entire coastline were counted in 2013 with the exception of inaccessible stretches of four bays (Crawford, Rooks, Goodhope and part of Triegaardt

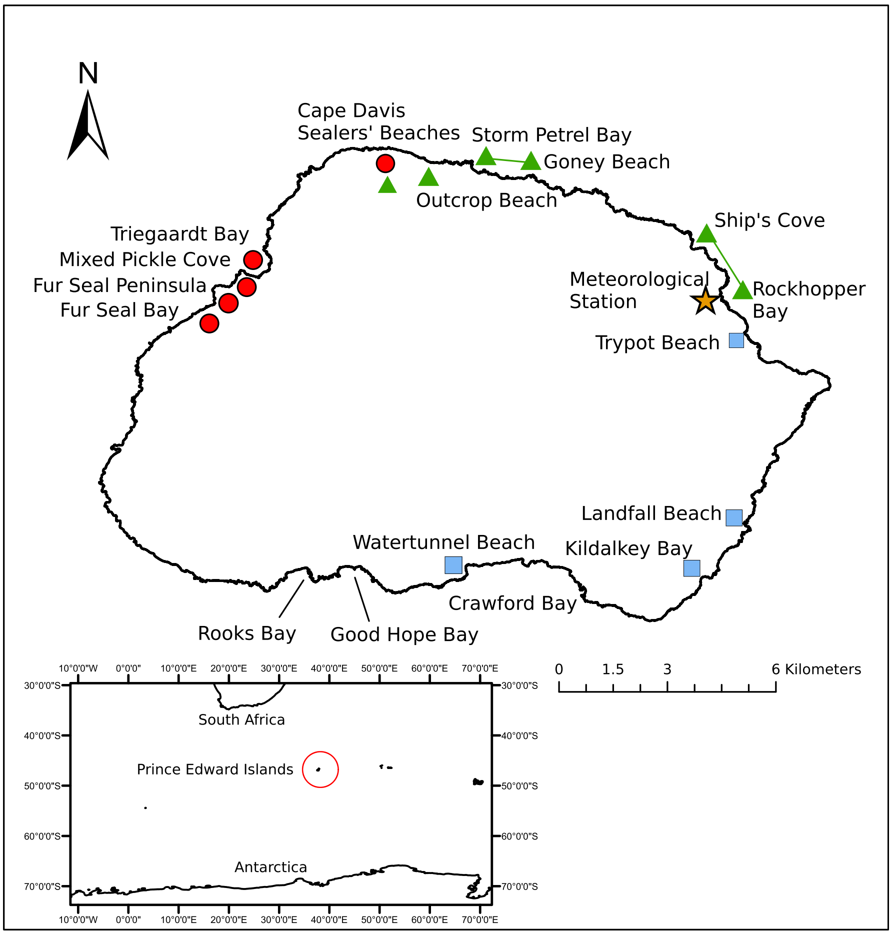

Figure 1. Marion Island. The five high density Subantarctic fur seal rookeries (circles), four high density Antarctic fur seal rookeries (squares) and Meteorological Station (star) are shown. The annual Subantarctic fur seal pup count beaches are between the Cape Davis Sealers' Beaches and Outcrop Beach, between Storm Petrel Bay and Goney Beach and from Ship's Cove to Rockhopper Bay, represented by triangles. Insert: The Prince Edward Islands' location in relation to South Africa and Antarctica.

Bay; Fig. 1). Situated at the foot of precipitous cliffs, these narrow stretches of coastline are presumed to contribute little to overall pup numbers.

Fur Seal Peninsula CMR study (2004, 2013)—Given the large number of pups born at Fur Seal Peninsula (Fig. 1) and the size of the area, CMR is more suitable than direct counts to estimate pup numbers for this area (Hofmeyr *et al.* 2006). In 2004 (9–10 February 2004), 500 pups (with a 50:50 sex ratio) were clearly marked with long lasting (>6 d) road paint across the shoulder blades. Similarly, in 2013, 735 pups were marked (21–23 January 2013). To avoid paint washing off, no wet or swimming pups were marked and freshly painted pups were prevented from swimming for ~30 s after release (*i.e.*, enough time to let the paint settle in the fur). Pups were allowed to reintegrate into the rookery for more than 1 d before "recaptures" started by way of a single observer moving slowly along parallel transects that covered the whole peninsula. In 2004, the peninsula was divided into five transects; whereas in 2013, 12 shorter transects were used. All marked and unmarked live and dead pups were counted within 3 m of the observer. Each transect was counted three times over two consecutive days. Transects were evenly spaced to cover the entire area.

CMR study to estimate detection probability: Cape Davis (1995, 2007–2015)—To estimate detection probability during direct counts, pup numbers at Cape Davis Beach (Fig. 1) were estimated annually by both direct counting and CMR. Logistical constraints prevented us from estimating detection probability at multiple beaches, but Cape Davis is topographically representative of an assortment of beaches at the island with large boulders, backed by a vegetated area. In each year, between 150 and 200 pups were caught by hand and marked as described above. Pups were allowed to reintegrate into the rookery for one full day before "recaptures" started (as above) along 7–9 transects covering the entire beach and backing vegetated area. Each transect was counted three times over two consecutive days. In addition to CMR counts, pups at Cape Davis were counted directly. Detection probability was estimated by comparing the CMR estimate and number of pups directly counted (refer to hierarchical Bayesian model methods sections below for a comprehensive explanation). No CMR study was done at Cape Davis in 2004. However, the same observer counted pups in 1995 and 2004, thus the detection probability estimated from the 1995 CMR study was used as a proxy for that in 2004 (Hofmeyr *et al.* 2006).

Estimating detection probability of cliff-top counts (2004, 2013)—Several beaches along Marion Island's coastline are backed by high cliff-faces, making them inaccessible. During total island counts in 2004 and 2013, pups at these beaches were carefully counted with binoculars from a clear vantage point at the top of the backing cliff. To account for a lower detection probability at beaches only counted from the cliff-top compared to direct counts, a unique cliff-top detection probability was also obtained at three of the Cape Davis Sealers' Beaches (including Cape Davis Beach and two neighboring beaches). These cliff-lined beaches are also accessible on foot, and were first counted with binoculars from the top of the cliff and thereafter directly while walking across the beach. This was repeated three times for each of the beaches. The difference between direct and cliff-top counts was subsequently used to determine detection probability from cliff-tops (refer to hierarchical Bayesian model methods sections below for a comprehensive explanation).