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Abstract

Understanding the relative contributions of different sources of mortality and survival in predator populations can improve ecosystem models and management of marine ecosystems. Within the Antarctic bottom-up processes are widely cited for explaining penguin population declines, whereas for Antarctic fur seals, top-down processes are most cited as the primary driver for declining pup production. This has led to an under emphasis of the role of bottom-up drivers for controlling fur seal production within the system. We review the historical data in Antarctic pup production and provide annual pup production estimates from 2002-2012 for Cape Shirreff, Livingston Island. Age-specific natality rates are provided as an indicator of bottom-up drivers and we contrast these with early season neonate mortality and leopard seal predation rates. Fur seal pup production has undergone a dramatic declines in the last decade (12.1% per annum since 2002). Since 1998, natality rate has also declined 14%, largely driven by poor recruitment and an aging population. However, age-specific natality rate has also declined. Predation rate has increased 4% per year since 2002. We discuss the relative roles of bottom-up and top-down contributions to the decline in fur seals.

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Squeezed from both ends: Decline in Antarctic fur seals in the South Shetland Islands driven by both Top-down and Bottom-up processes

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ABSTRACT Understanding the relative contributions of different sources of mortality and survival in predator populations can improve ecosystem models and management of marine ecosystems. Within the Antarctic bottom-up processes are widely cited for explaining penguin population declines, whereas for Antarctic fur seals, top-down processes are most cited as the primary driver for declining pup production. This has led to an under emphasis of the role of bottom-up drivers for controlling fur seal production within the system. We review the historical data in Antarctic pup production and provide annual pup production estimates from 2002-2012 for Cape Shirreff, Livingston Island. Age-specific natality rates are provided as an indicator of bottom-up drivers and we contrast these with early season neonate mortality and leopard seal predation rates. Fur seal pup production has undergone a dramatic declines in the last decade (12.1% per annum since 2002). Since 1998, natality rate has also declined 14%, largely driven by poor recruitment and an aging population. However, age-specific natality rate has also declined. Predation rate has increased 4% per year since 2002. We discuss the relative roles of bottom-up and top-down contributions to the decline in fur seals.

INTRODUCTION

The marine waters of the western Antarctic Peninsula region are characterized by highly dynamic oceanography influenced primarily by the Antarctic Circumpolar Current, changing patterns of ice cover and a highly variable bathymetry (Ducklow et al. 2012, Hofmann et al. 2004.) This area is among the most productive waters of the Southern Ocean and has historically high krill biomass that supports large populations of both local and seasonally migrating predators. Throughout the last several decades this region has undergone a rapid warming that has led to large areas of the northern Antarctic Peninsula to now be ice-free year round (Stammerjohn et al. 2003). The South Shetland Islands, located at the northern tip of the peninsula, in just two decades went from being seasonally ice-covered to being ice free every winter. Its diverse fauna of both polar and sub-polar species is changing as well. Many polar species (Adélie penguin, Weddell, Leopard and crabeater seals) are at the northern extent of their range while many sub-polar species (Gentoo penguin, Antarctic fur seal and Southern elephant seal) are at the southern extent of their range. Simple predictions of how species will respond to warming based upon whether they are polar or sub-polar, or prefer ice versus ice-free habitat have proven to be more complex than expected.

The three species of brush-tailed penguins that breed in the area are a good case in point. Population trends in the two most common Antarctic species, Adélie and Chinstrap penguins have been reviewed by Trivelpiece et al. (2011). Early predictions in how these species would respond to reduced ice-cover suggested that the pagophilic Adélie penguin would decline and the Chinstrap penguin which prefers ice-free polar waters would increase. However, both species have undergone significant declines in the past two decades (Trivelpiece et al. 2011, Lynch et al. 2012) owing to reduced survival in the period between fledging and recruitment. While Adélie and Chinstrap populations have declined breeding populations of, the sub-polar Gentoo penguin have increased as it expands its range in the region (Lynch et al. 2012).

The apparent direct effect of climate change on the population response by these three species to warming in the Peninsula region suggests a strong role of bottom up forcing on the observed population dynamics. The response by pinniped populations is less well known. The Antarctic fur seal is perhaps one of the most conspicuous and abundant land-based predators in the Antarctic Peninsula ecosystem. Like the Gentoo, it has a circumpolar distribution and breeds on most sub-Antarctic islands and is at the southerly extent of its breeding range in the South Shetland Islands. This suggests that the population may increase and expand its range as conditions continue to ameliorate. The Antarctic fur seal was extensively harvested by the fur trade in the early 1800s. It was virtually extirpated from the Antarctic Peninsula region by the 1870s (Kellogg 1943). Soon after recolonization began in the early 1960s (O'Gorman 1961), it made a dramatic recovery increasing at between 11 and 17% per year until the early 2000s (Hucke-Gaete et al. 2004). This suggests high rates of natality and high survival rates of pups drove the early recruitment success and population growth of this species.

In this paper we examine recent trends in natality, pup production, early-season neonate mortality, and pre-weaning predation mortality of pups by an important predator, the Leopard seal (*Hydruga leptonyx*). We use data from annual surveys at Cape Sherriff, Livingston Island to examine the relative role of top down and bottom processes. Pre-weaning mortality is examined to partition sources of production and mortality that could arise from either top-down or bottom-up processes. Fur seals, unlike the Pygoscelid penguins which remain entirely on shore until they fledge en masse, require sheltered nursery reef areas where they learn to swim and play. This makes them more vulnerable to predation mortality as they venture into waters prior to weaning and before post-weaning dispersal. Top-down predation is known to have a large impact on survival (Boveng et al. 1998, Schwarz et al. 2013). It is dramatic, and because it occurs close to shore, and is easily quantifiable. This has led to an over-emphasis on the influence of top-down processes in describing population trends in the South Shetland population of Antarctic fur seals. However, not all early pre-recruitment mortality is predation. Reproduction and total pup production are expected to vary annually and are also influenced by bottom-up processes. For example, annual pup production can also be affected by interannual variability in natality rates (the number of young produced per reproductively mature female) and changing demographics as the age structure of the adult female population changes. Natality rate, an important life history parameter, can be an important indicator of nutritional status.

We show that, unlike the gentoo penguin with similar breeding range and distribution, the breeding population of Antarctic fur seals in the South Shetlands is undergoing a rapid decline. We attribute these declines to a decrease in productivity in the pelagic environment, effecting natality that is driven by the southerly retreat in the ice impacting their main prey Antarctic krill, more than top down effects driven by leopard seal predation on fur seal pups.

METHODS

Study site

The South Shetland Islands are situated south of the Drake Passage, 450 nautical miles south southeast of Cape Horn off the northern flank of the Antarctic Peninsula, from which they are separated by the Bransfield Strait. They range from 54.0°W to 63.0°W longitude and from 61.0°S to 63.5°S latitude (Figure 1). There are numerous small colonies of breeding fur seals from Elephant Island in the northern reaches of the Archipelago to Smith Island, the most westerly island. However, in past archipelago-wide surveys of Antarctic fur seals, Cape Shirreff, Livingston Island (62.459°S 60.789°W) and its offshore islands represented on average 81% (77.0-85.5%) of all pup production (five surveys from 1992 through 2008; reviewed in Goebel et al. 2008). Cape Shirreff is therefore consider representative of the entire SSI.

Cape Shirreff is entirely ice-free, 3.22 km^2 in area, and aside from small patches of *Deschampsia antarctica*, Antarctic hair grass, is vegetation free. There is no tussock or large boulder areas. The open terrain

and low density of Antarctic fur seals (~1-2 pups per m^2) facilitates direct counts of all animals. Pups are born from late November to late December. Females arrive on shore approximately 1-2 days before giving birth. After tending to their pups for about a week they depart to sea to begin a series of foraging trips. Pups do not begin entering the water until approximately month old (late-December to early January) and then only in intertidal areas. Once pups molt in mid- to late-February they spend increasing amounts of time in the water just offshore of their suckling beaches. They do not depart natal rookeries until they are weaned in early April. Juveniles and adults are continually arriving and departing and their abundance onshore is influenced by numerous factors (primarily the foraging environment and inclement weather) that cannot be controlled for. Thus, pups represent the only portion of the population that are entirely present onshore and can be easily censused. Pup production is, therefore, the best index of population size and trends in population numbers over time.

Historical data

To provide the historical context of population trends prior to 2007 we have included pup production estimates for Cape Shirreff from national programs' field season reports, status of stocks reports to the Scientific Committee on Antarctic Research, and earlier submissions to WG-EMM (see Table 1 for list of references).

Pup production and census

A Cape-wide census of pups (live and dead) occurs every year once pupping is over, in the last days of December and when conditions and visibility are favorable. All counts conducted by the US-AMLR program (1997-2012) used at least three observers hiking the entire shoreline of fur seal breeding areas counting pups. Observers use thumb counters and are instructed not to discuss their counts while the census takes place. Areas are standardized but pups can move between some areas while counts are conducted. All observers have prior experience in counting pups, and in most years, before the census, a pre-determined colony of approximately 500-1000 pups is selected for each observer to count three times in order to estimate intra-observer variance in counts. These are practice counts and are not reported here.

On-land mortality

In most years Cape Shirreff is snow covered at the start of the fur seal pupping and snow cover persists through the period of breeding. Pup mass at birth can range from 3.8-7.9 kg and many pups are born on snow. Temperatures at the peak of pupping (the first week of December) range from -1.0 – 1.0°C. Storms during this time of year can result in peaks in exposure related mortality. Early season, on-land mortality is estimated by counting fresh dead pups daily for an area that accounts for approximately a third of all pup production on the Cape. Because of the presence and abundance of scavenging seabirds and tides, dead pups can disappear quickly resulting in an

underestimate of mortality at the time of the Cape-wide census. Total pup production estimate is adjusted for each year using the cumulative dead pup counts from the sub-area counts.

Natality

Natality rate for the population was estimated based on daily surveys of a marked population of females. Females are tagged on both fore flippers with Dalton jumbo tags. Since 2000, percent of the marked population of adult females pupping within the boundaries of the U.S. AMLR study site at Cape Shirreff has ranged between 6-15%. Daily surveys of tagged females were conducted from the arrival of the first female in November through late-February from 1998-2013. Date of arrival and pregnancy status are recorded for each female and reproductive success is monitored throughout the season (i.e. November through late-February).

Age-related natality rate was calculated based on annual returns of known-aged animals. Animals are aged either because they were tagged as pups or by using post-canine tooth cementum aging techniques. All teeth were aged by an independent tooth aging laboratory (Matson Lab, Milltown, MT). Blind estimates using teeth from animals tagged as pups are used each year to confirm accuracy.

Leopard seal predation

Annual Leopard seal predation up to 75d after the median date of parturition (MDP) was estimated based on daily surveys recording the presence (or absence) of marked mother pup pairs. Tagged females were recorded as present or absent and whether they were with or without pup. Failures (pup mortality) up to 30d post-MDP when pups begin entering the water were considered non-Leopard seal mortality. Failures after 30d post-MDP when pups are making daily forays into the water were assumed to be the result of Leopard seal predation. Females present on shore for four or more consecutive days without her pup were logged as failed. Any female whose status as failed or successful was undetermined was excluded from calculations of reproductive success. An estimate of Leopard seal mortality was calculated using the rate of failed mother-pup pairs at 75d post-MDP adjusted for the annual rate of on-land neonate mortality.

RESULTS

Pup production

The first pups to be born in the South Shetland Islands after local extinction by the 19th century fur trade occurred in 1959/60. From 1966 to 1986 there were three surveys for Antarctic fur seals at Cape Shirreff with increases in pup production reported for each. Annual surveys of pup production began in 1991/92 by the Instituto Antartica de Chile (INACH). There were 2973 pups reported in the 1991/92 census (Table 1). From 1991/92 through 1999/2000 pup production on the Cape increased on average 10% per annum (Figure 2). Pup production

then entered a five year period of stabilization with only a mean annual change of less than 1%. The current decline began in 2004/05 and has averaged 12.1% (±3.1) per annum. Peak pup production occurred in 2001/02 with 6,453 pups counted.

Pup production on the US-AMLR study site followed the same trends as for the entire Cape. This is despite having a daily human presence from November-March and on average 106 (±32.5, range: 61-190) adult female and juvenile captures and >1000 pup captures per year.

Age-specific natality rates

From 1998 through 2012 we collected 2,687 records of parturition status for 571 tagged females. Once animals of unknown age were excluded we had 2,469 records (91.9%) for 479 females (83.9%) age 4-20. Sample size by age ranged from 75-193 (Figure 2). Females 4-6 years of age had a mean natality rate of <0.85. By age 7 females had 93.5% (±5.21) probability of giving birth. From age 8 through 16 females' mean natality rate was 0.90 (±0.017). For this study we categorized females age 8-16 as prime breeders and used them for calculations of annual natality rate.

Natality rates 1998-2012

Age structure of the Cape Shirreff fur seal population changed from 1998-2012. The proportion of females in the population >17 years old has steadily increased from 0.013 in 1999 to 0.348 in 2011 (Figure 3). The mean proportion of prime breeding aged females (8-16 years old) for calculating an annual index of natality was 0.547 (±0.122; range: 0.20-0.73).

Fur seal natality rate fell on average 1% per year from 1998-2012 (Figure 4). Much of the decline can be explained by senescence and lack of recruitment as the mean age of the population has increased. However, even among prime age breeders there has been 0.3% decline per year (Figure 4). From 1998 through 2004, when the current decline began, natality rate for prime age breeders was reflective of that of the population as whole (Figure 4). Once the decline began natality for the population as whole fell faster than for prime aged breeders. Nonetheless, falling natality rate of prime age breeders has significantly influenced pup production and has contributed to the decline.

Pre-weaning pup mortality

On-land mortality, as measured by counts of dead pups throughout the pupping period, ranged from 2.2-9.0% from 1998 through 2012 (Figure 5). The mean annual mortality rate for the 15 year period was 0.043 (SD: 0.015).

The peak mortality rate occurred in 2002/03, a year of exceptional snow cover and poor maternal foraging conditions (US-AMLR, unpublished).

Pup predation mortality

Predation mortality varied considerably and increased from 2003-2012. Annual predation rate from birth to 75d of age averaged 0.473 (SD: 0.140; range: 0.250-0.696). The peak predation rate measured was in 2009/10 (Figure 5). Predation mortality increased by 3.47% per year from 2003 to 2012.

DISCUSSION

Resolving the relative importance of top down and bottom up processes controlling Antarctic fur seal population dynamics is critical to projecting their future response to climate change in the Antarctic Peninsula region. We documented the changes in Antarctic fur seal natality, pup production, and sources of mortality prior to post weaning dispersal that might explain changes in population dynamics at this site. The Antarctic fur seal population at Cape Sherriff, which represents about 80% of the population in the South Shetland Islands, has declined rapidly and is similar to the decline in other krill-dependent predators (chinstrap and Adélie penguins) in the region (Trivelpiece et al. 2011, Lynch et al. 2012). Yet top down processes, occurring prior to post weaning dispersal, are hypothesized to be responsible for the population dynamics and Cape Sherriff (Schwarz et al. 2013)

While bottom up processes, in particular declines in prey, have been used to explain the declines in penguin species, top-down processes are often attributed to limiting population growth and recovery in Antarctic fur seals (Boveng et al. 1998, Schwarz et al. 2013). Schwarz et al. (2013) for example, modelled the role of leopard seal predation on fur seals at Cape Sherriff and concluded that leopard seal predation was a substantial source of mortality controlling population growth rate of Antarctic fur seals. However, the modelled rates of predation appear too low to explain the observed rate of decline subsequent to that study period.

A number of assumptions used by Schwarz et al. (2013) may lead to overestimates of predation rates. First, modelled leopard seal predation rates were held constant over the first year of life from pre-weaning through dispersal and continuing until age 1. Using a predation rate derived from estimates measured at pre-weaning and continued for a year would certainly over-estimate the impact of predation for at least two reasons. Fur seal pups are only 1-2 months old at the time predation rate is being measured. Limits on occupancy at the study site prevents continued measurements of predation mortality through to weaning but it is clear that pups can and do learn to avoid predation and leopard seals are most capable of taking advantage during this naïve period of development. Second, until pups wean, they are behaviorally tied to areas that make them more accessible to the predator. Though predation on juvenile fur seals by leopards has been observed and recorded (Walker et al. 1997)

the rate of predation would decline once the period of nutritional dependence was over and fur seal young of the year were able to disperse and presumably migrate out of the Antarctic. Thus using a predation rate measured in the first 75 days of life and extrapolating it to age one would bias the impact of predation.

The decline in the fur seal breeding population and in fur seal pup production began almost a decade later than declines in both chinstraps and Adélies reproducing in the same locations but has been more dramatic (3-10 times greater per annum than chinstraps and Adélies). The delay in the decline of fur seal populations relative to other krill-dependent predators reflects several important differences in the biology and ecology of fur seals. Importantly, the long lifespan of fur seals relative to penguins (e.g. longevity of 20+ years with high adult survival) provides a population momentum to delay the effects of poor recruitment. Adult females also leave Antarctic waters for foraging areas north of the polar front for 6-9 months. As a consequence of this migration fur seals may be less dependent on krill than Adélie or chinstrap penguins during pregnancy, and may be able to augment their diets with fish or squid as foraging conditions in the Antarctic, where penguins forage prior to reproduction, may have deteriorated.

The rapid change in other life history characteristics that are independent of predation include estimates of natality and post weaning survival (recruitment). The influence of bottom-up processes would likewise be underestimated if annual estimates of survival and natality were measured only up until 2006/07 as they were in Schwarz et al. (2013). Our estimates of natality rate from 1998/99 through 2012/13 show that for the period 2005/06-2008/09 natality rate for prime breeders was above the long-term mean (see Figure 4). Thus, the last two years of data used in model estimates reported by Schwarz et al. (2013) for the shorter time period would dampen any measured effect of bottom-up contribution to the decline.

Failure to account for these factors would serve to over-emphasize the role of top-down predation in limiting fur seal populations breeding in the South Shetlands. A typical life history characteristic of vertebrate predators, such as penguins and seals, is the low rate of first year survival. In fur seal populations, post-weaning survival (i.e. survival to age 1), even in the absence of pre-weaning predation, is typically less than 50% (Lander 1981; Promislow and Harvey 1990) suggesting that recruitment is largely tied to post-dispersal processes. We can also assume that when predation occurs on a highly polygynous species, such as the Antarctic fur seal, (given probability of predation by sex of pups is equal and parity in sex ratio) that 50% of the observed predation (i.e. the predation on male pups) is inconsequential to future pup production and population trends. So when predation occurs prior dispersal, predation may not drive the future recruitment rates. In other words, the predator is exploiting prey that would not survive anyway. While we know little about the post-weaning environment of juvenile fur seals to understand what degree pre-weaning mortality is additive or exclusive. We can assume,

however, that with regards to top-down versus bottom-up sources of mortality, selection processes would be different.

Many factors influence fur seal pup production and resulting population trends. In an ecosystem management context it is important to understand the relative contributions of different factors to mortality and survival. Figure 7 outlines a conceptual model of the sources of mortality and survival that influence annual total pup production and ultimately population trends. Perinatal mortality (or on land mortality) are a significant, but relatively small, source of mortality. Leopard seal mortality is by comparison much more substantial but is largely confined to an early naïve stage in pup development. These on land sources of mortality are easy to observe and quantify and may lead researchers to overemphasize pre-weaning mortality in explaining population trends for Antarctic fur seals in the South Shetland Islands. Post-weaning dispersal and mortality, on the other hand, are more challenging to address but are necessary to fully understand population trends and from a CCAMLR perspective project future trajectories of predator populations. Declining recruitment and natality rates are the signals that declining productivity within the system is having a dramatic affect and are likely the driver for the observed increase in top-down changes.

With regards to other krill-dependent predator populations like penguins, whose declines are attributed mostly to bottom up processes (e.g. sea ice, changing krill biomass), the role of top-down factors like predation is more difficult to observe and measure because it occurs after the period of nutritional dependence away from shore. This does not mean predation is any less important or that it has not increased during the same period or is not a significant and increasing source of mortality for other species like penguins.

Fur seals, unlike penguins, have evolved in the absence of the kind of neonate predation that we observed in the South Shetlands. For that reason and because they are a sub-polar species at the southern limits of their breeding range, we would expect the relative proportion of predation mortality to be greater than in penguins. However, we would also expect, given the increased presence and predation leopard seals that predation on fledgling and adult penguins has also increased in the last two decades.

This paper does not address why leopard seals and predation have increased but we hypothesize that the change is driven by same environmental drivers and reductions in krill biomass as hypothesized for the declines in pelagic foraging penguin populations. If true it suggests that all these predator populations are being impacted by bottom-up processes. The changing physical environment and lower productivity in the pelagic environment are driving community structure and predator biomass within the system.

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Table 1. Pup production at Cape Shirreff, Livingston Island (62°28'S, 60°46'W) with % annual rate of change. Pup production on the US-AMLR study area, a subset of the total Cape pup production are included for comparison of disturbed and undisturbed areas. Early-season neonate mortality from dead pup counts within the US-AMLR study area and predation rate estimated from daily tag resights of marked mother-pup pairs.

Year	Cape Shirreff pups	SE	Ref.	%Annual rate of change	Pup production (US-AMLR study site)	SE	On-land neonate mortality rate	Estimated predation rate
1965/66	8		1					
1972/73	199		1	341.1				
1986/87	718		2	18.6				
1991/92	2973		1	62.8				
1992/93	3672		1	23.5				
1993/94	3474		1	-5.4				
1994/95	4036		1	16.2				
1995/96	4968		1	23.1				
1996/97	5689		1	14.5				
1997/98	4943		3	-13.1				
1998/99	5497		4	11.2	1935	12.2	0.025	
1999/00	5865		5	6.7	1968	13.7	0.028	
2000/01	5951		6	1.5	2202	25.7	0.030	
2001/02	6453		7	8.4	2411	22.7	0.055	
2002/03	5868		8	-9.1	2154	19.6	0.090	
2003/04	6428		9	9.5	2191	27.7	0.050	0.386
2004/05	6000		9	-6.7	2250	11.6	0.047	0.361
2005/06	5791		9	-3.5	2086	12.2	0.032	0.250
2006/07	6119		9	5.7	2067	19.4	0.048	0.359
2007/08	4172		10	-31.8	1735	5.8	0.042	0.522
2008/09	4722	112		13.2	1513	13.4	0.027	0.435
2009/10	4268	89		-9.6	1385	2.9	0.076	0.708
2010/11	3758	19		-12.0	1188	11.6	0.033	0.544
2011/12	3428	96		-8.8	1048	6.6	0.044	0.501
2012/13	2879	96		-16.0	875	14.0	0.047	0.650

Source references: (1) Hucke-Gaete et al. 1997; (2) Bengtson et al. 1990; (3) Hucke-Gaete et al. 1998; (4) Hucke-Gaete 1999; (5) Vallejos et al. 2000; (6) Hucke-Gaete et al. 2001; (7) Acevedo et al. 2002; (8) Vallejos et al. 2003; (9) Unpublished; Data for 2003/04-2006/09 were extracted from websites CCAMLR Publications (http://www.ccamlr.org/pu/E/e_pubs/ma/06-07/chl07.pdf) and SCAR Expert Group on Seals – status of stocks (http://www.seals.scar.org/pdf/statusofstocs.pdf); (10) Torres (pers. comm.).

List of Figures

Figure 1. Pup production for Cape Shirreff, Livingston Island, South Shetlands Islands (62.45°S 60.78°W) estimated from periodic counts from 1959/60 (when the first pup born at Cape Shirreff was observed) until 2012/13. Annual surveys began in 1991/92 and the red line is a 3-year running mean. For comparative purposes, annual pup production for the U.S.-AMLR study site at Cape Shirreff, Livingston Island from 1998-2012 are included. The U.S.-AMLR study site comprises 40% of total pup production at Cape Shirreff and 24% of the pup production of the entire archipelago. It is a site of focal research requiring on average 106 (±32.5) captures of adult females per year. Since 2004/05 there has been on average a 12.1% (±3.1) per year reduction in pup production.

Figure 3. Age-specific natality rates for the Cape Shirreff population of Antarctic fur seals based upon longitudinal records of reproductive success of 579 females from 1998/99-2012/13.

Figure 2. The proportion of females of unknown age and known-age for three age categories (ages 4-7, 8-16, and ≥17).

Figure 4. Annual natality rate for female Antarctic fur seals ages 8-16 and for the entire breeding population (irrespective of age).

Figure 5. Two sources of mortality for Antarctic fur seal pups from birth until 75d after the median date of pupping. Those surviving to 75d after the median date of pupping are deemed survivors. Calculations are based upon daily surveys of marked mother pup pairs.

Figure 6. Estimated Leopard seal predation up to late-February (75d after the median date of pupping) at Cape Shirreff, Livingston Island, 2002/03-2012/13. Leopard seal predation increased four percent per year over the last decade.

Figure 7. Sources influencing pup production, mortality, survival and population trends in Antarctic fur seals.

Figure 1.

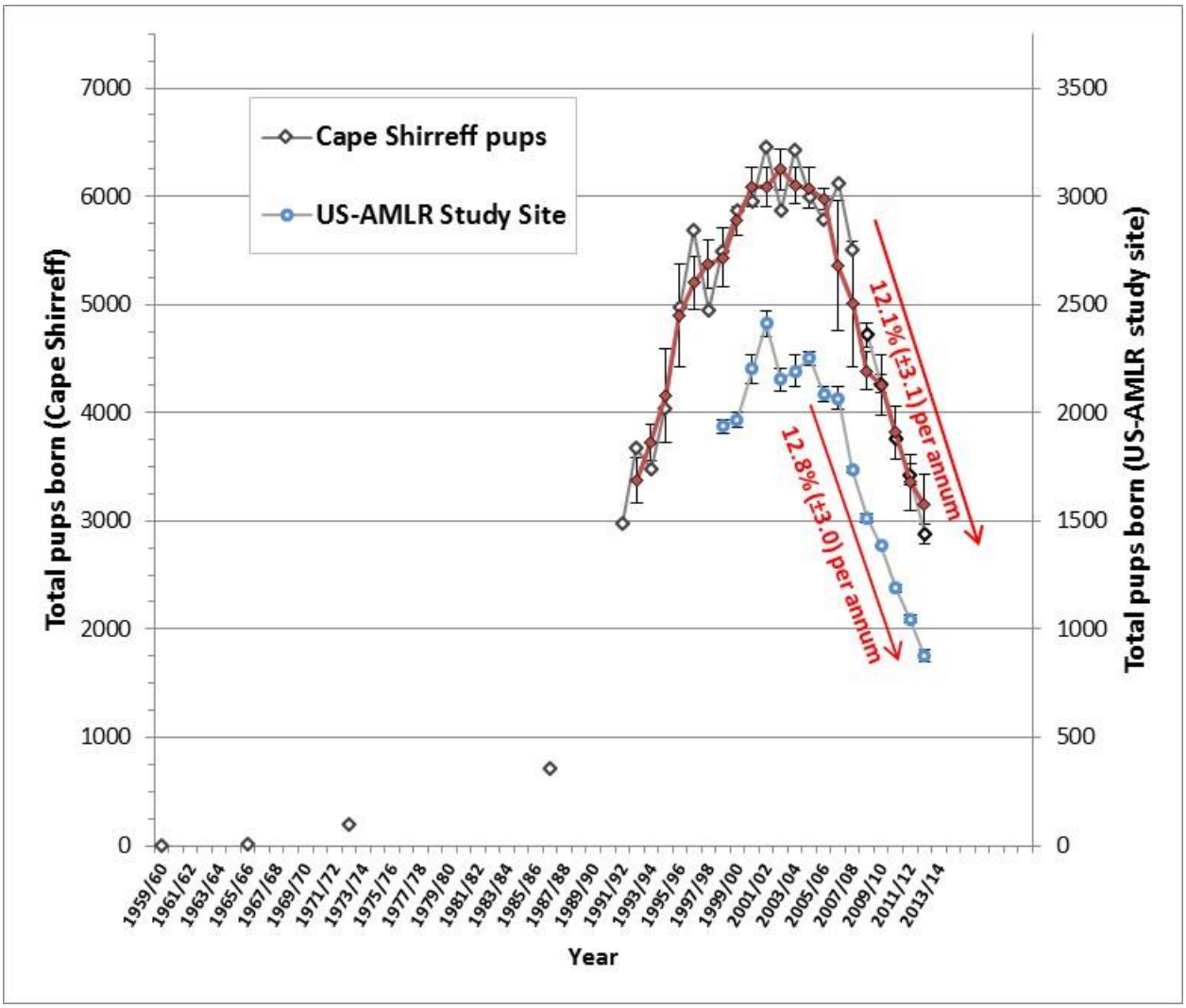

Cape Shirreff pups
US-AMLR Study Site
Total pups born (Cape Shirreff)
Total pups born (US-AMLR study site)
Year
12.1% (±3.1) per annum
12.8% (±3.0) per annum
0
1000
2000
3000
4000
5000
6000
7000
500
1500
2500
3500
1959/60
1961/62
1963/64
1965/66
1967/68
1969/70
1971/72
1973/74
1975/76
1977/78
1979/80
1981/82
1983/84
1985/86
1987/88
1989/90
1991/92
1993/94
1995/96
1997/98
1999/00
2001/02
2003/04
2005/06
2007/08
2009/10
2011/12
2013/14

Figure 2.

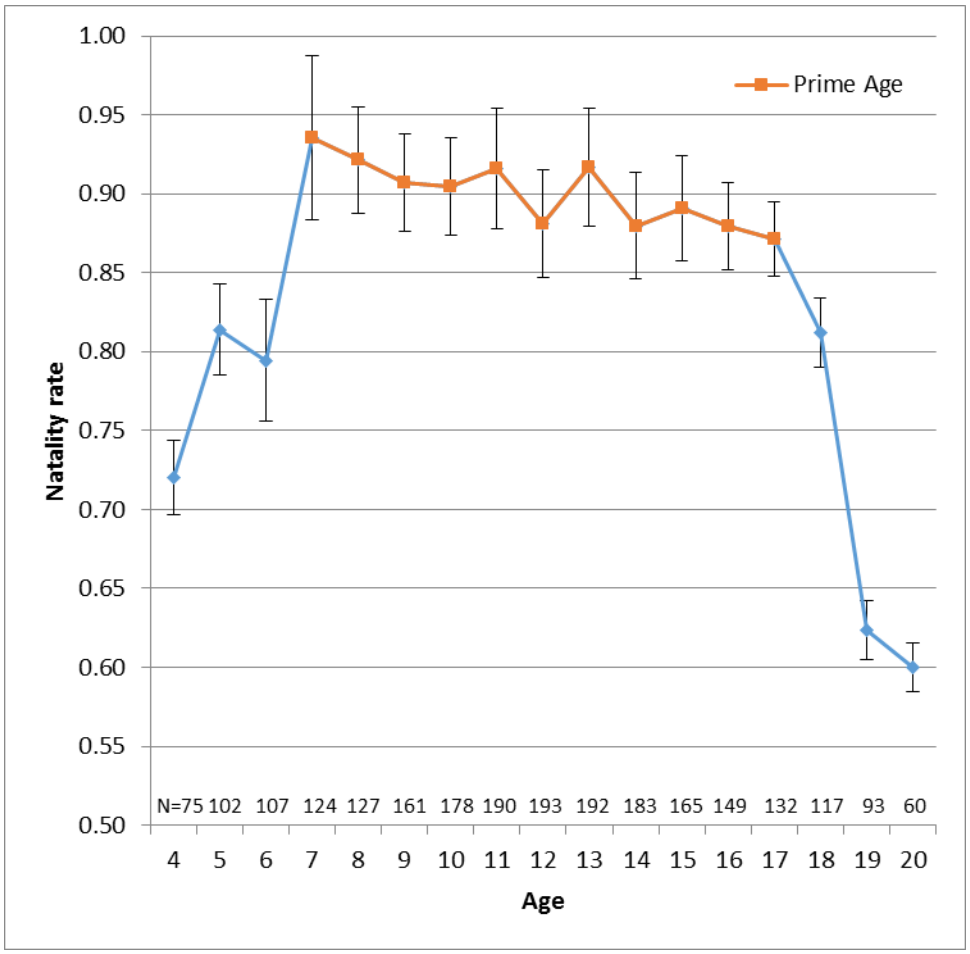

Prime Age
Natality rate
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
N=75 102 107 124 127 161 178 190 193 192 183 165 149 132 117 93 60
4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Age

Figure 3.

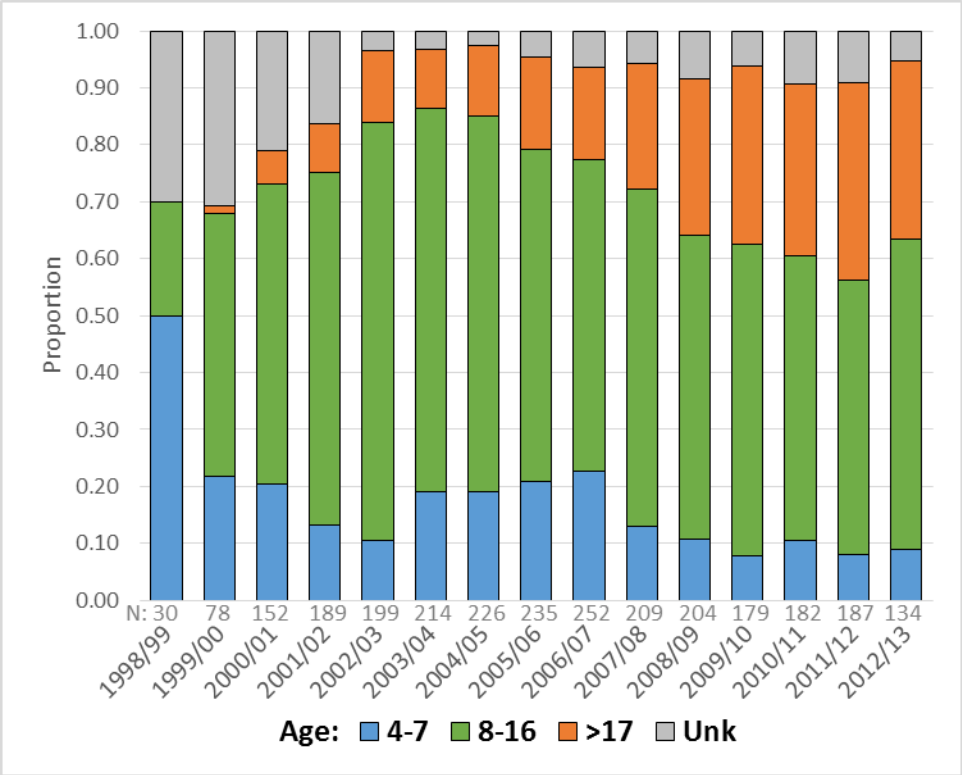

1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Proportion
N: 30 78 152 189 199 214 226 235 252 209 204 179 182 187 134
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
Age: 4-7 8-16 >17 Unk

Figure 4.

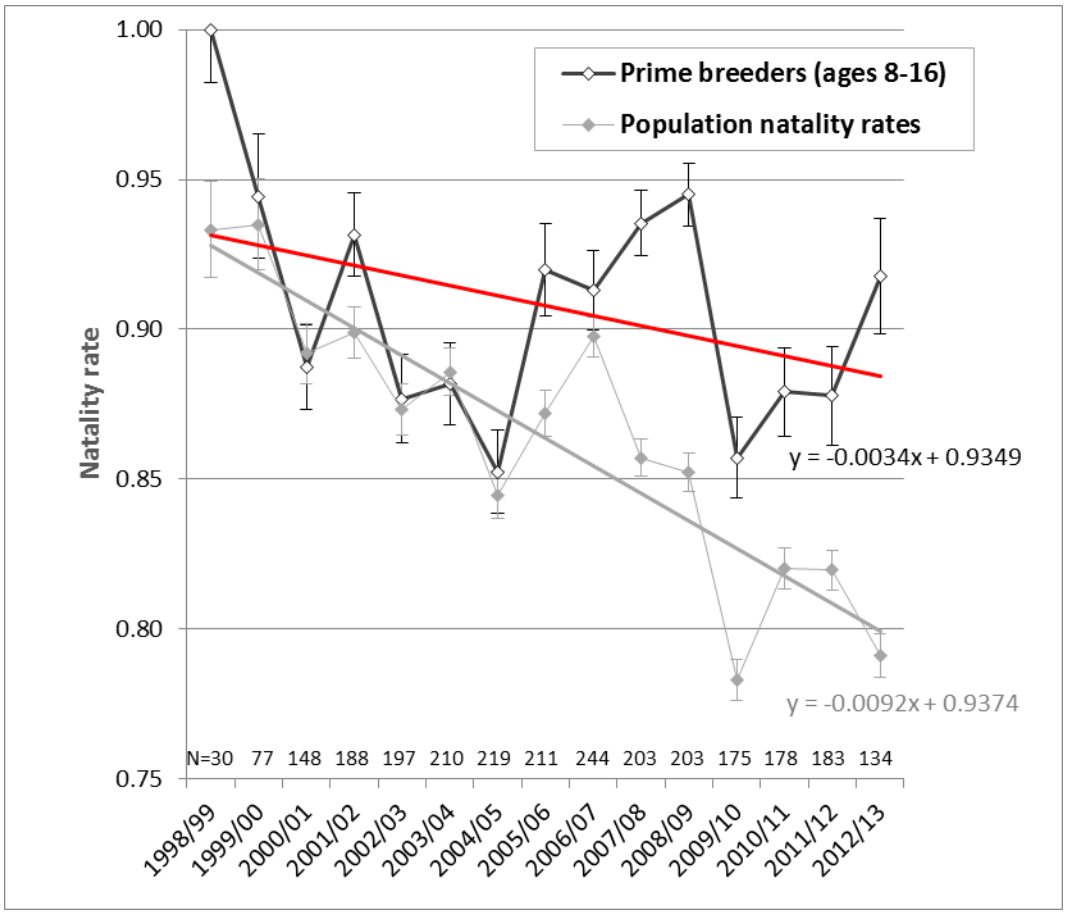

Prime breeders (ages 8-16)
Population natality rates
Natality rate
1.00
0.95
0.90
0.85
0.80
0.75
y = -0.0034x + 0.9349
y = -0.0092x + 0.9374
N=30 77 148 188 197 210 219 211 244 203 203 175 178 183 134
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13

Figure 5.

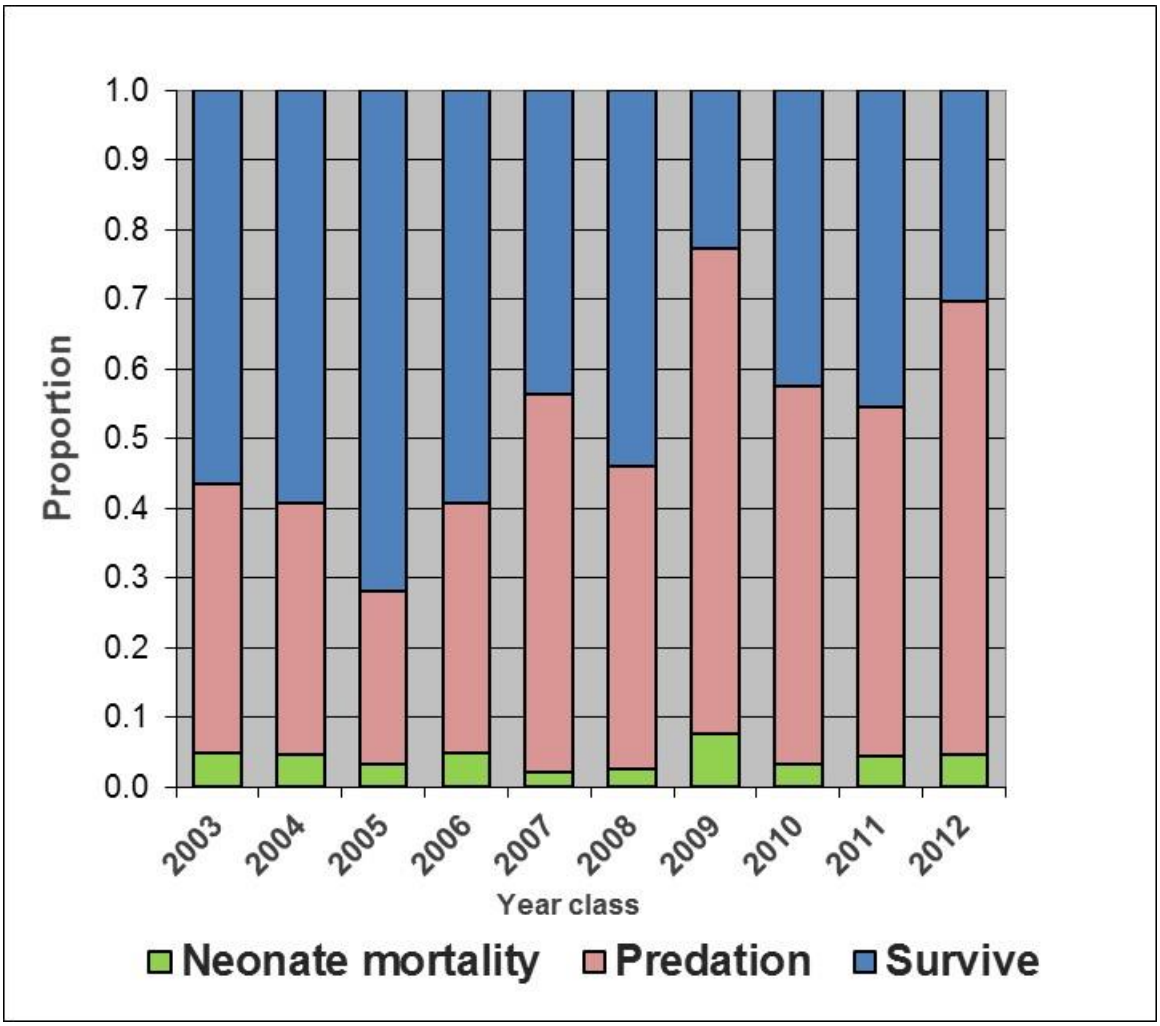

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Proportion
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year class
Neonate mortality
Predation
Survive

Figure 6

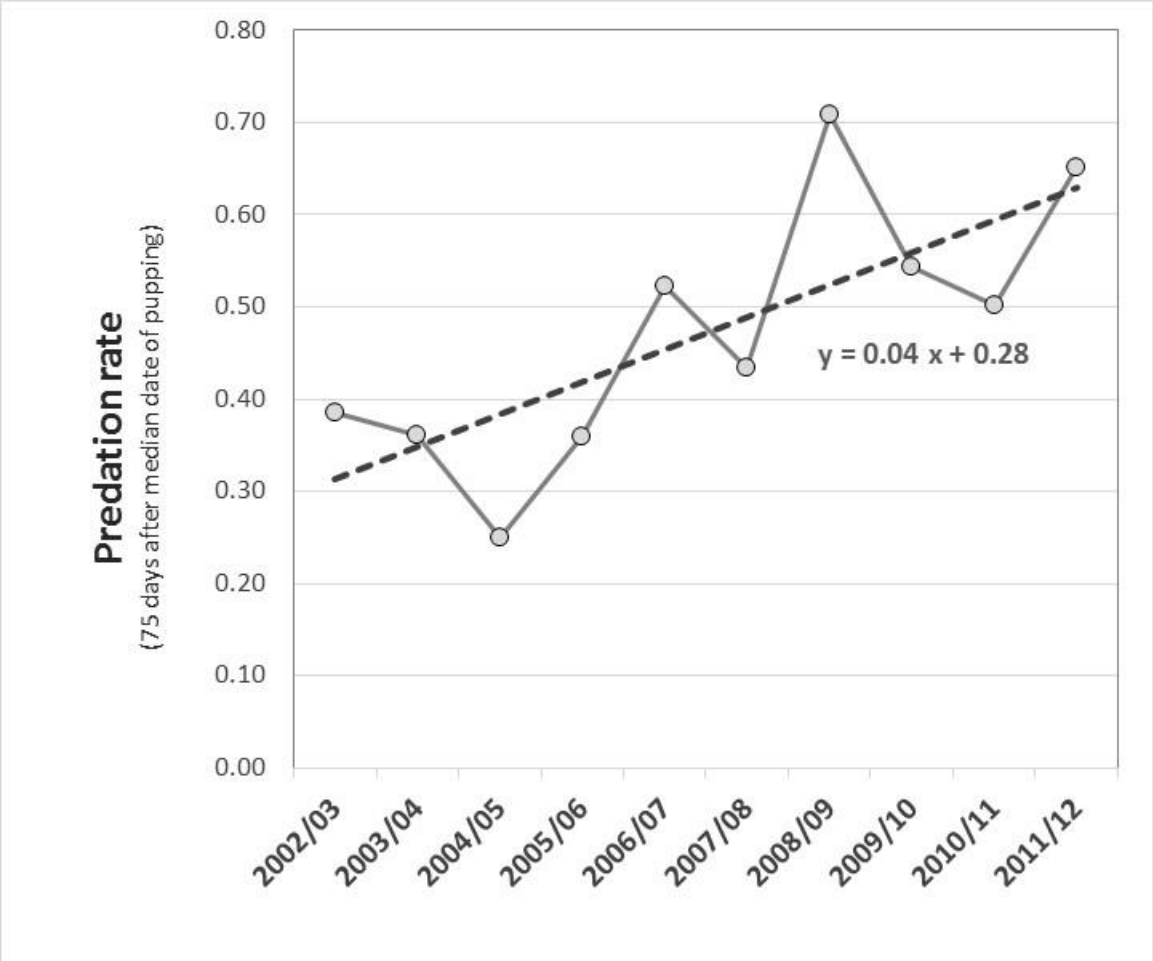
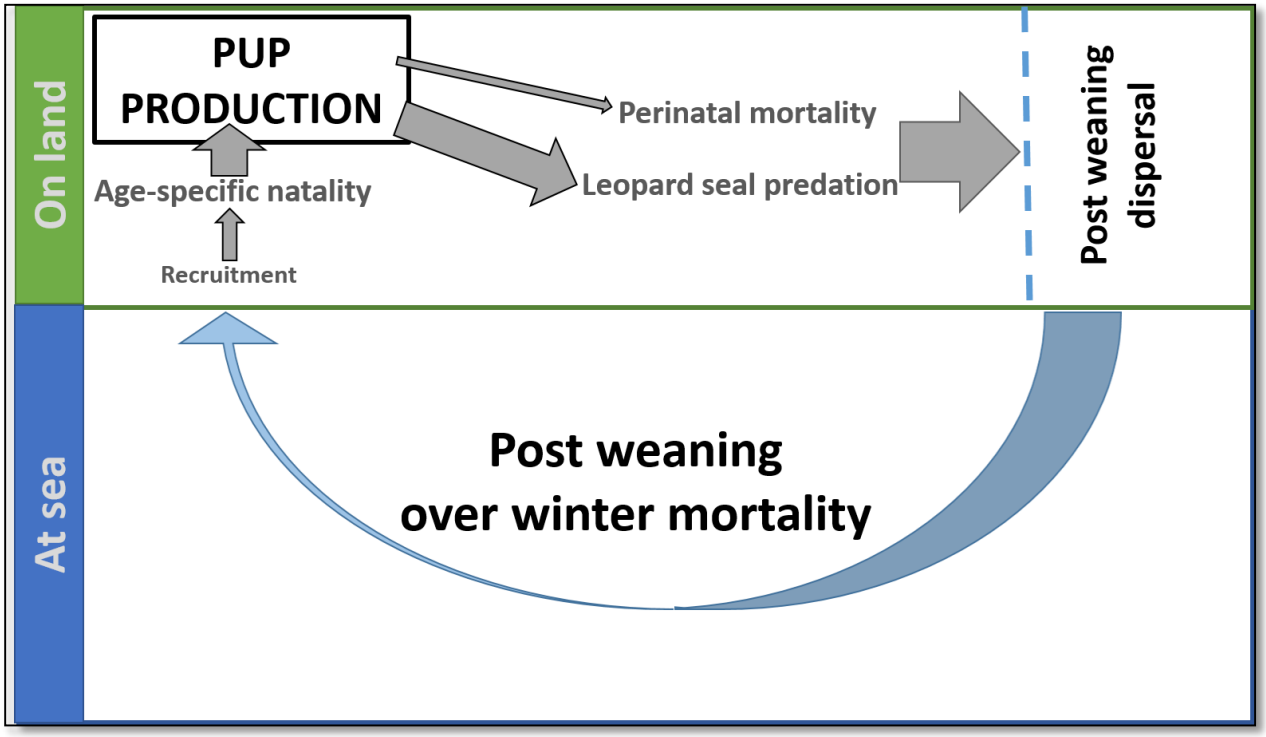

Predation rate
(75 days after median date of pupping)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
y = 0.04 x + 0.28
2002/03
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12

Figure 7.


On land
PUP PRODUCTION
Perinatal mortality
Leopard seal predation
Age-specific natality
Recruitment
Post weaning dispersal
At sea
Post weaning over winter mortality