Weddell Seal Pup Production in relation to harvesting pressure and the B-15 iceberg

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PCAS 13

Abstract

The Ross Sea, one of two large embayments on the Antarctic continent, provides scientific opportunity to study marine ecosystem processes. The Weddell Seal *Leptonychotes weddelli* resides in the Ross Sea, with breeding colonies in Erebus Bay, McMurdo Sound. The Weddell Seal's life-history is well documented in the literature; females congregate in 'pupping colonies' along cracks in the sea ice and give birth to their pups in October. Since the austral summer of 1968/69 every pup born into the Erebus Bay population has been tagged and the tag number, sex, year of tagging, location, and age at tagging recorded, creating a database containing datum for over 20,000 individual seals.

Weddell Seals produce one pup per year. The age at which first reproduction occurs is an important life-history decision, mediated by several trade-offs. Age at first reproduction also has potential impacts for fitness and reproductive output/pup production – a fact also well documented in the literature. The Ross Sea has a history of exploitation; when permanent research stations were established in McMurdo Sound, adult Weddell Seals in Erebus Bay were harvested to feed resident dog teams. Additionally, in the year 2000 a large tabular (~10,000km^2) iceberg named B-15, calved off the Ross Sea Ice Shelf, blocking the usual advection of sea ice from McMurdo Sound until the winter of 2006.

Several earlier studies have documented the large scale effects that both harvesting and iceberg calving had on the size of the Erebus Bay population of Weddell Seals, and the effects on age at first reproduction, however, no studies have focused on pup production. This study investigated pup production in the Erebus Bay population of Weddell Seals to determine if harvesting pressure and iceberg calving affected the number of pups produced in Erebus Bay from 1969 to 2009. The results of the current study illustrate that both harvesting pressure and environmental disturbances (iceberg calving) affected pup production in Erebus Bay. Pup production reached very low levels in the years that harvesting occurred but increased following the cessation of harvesting in 1985. A similar trend was witnessed from 2000 to 2006 when the B-15 iceberg was blocking McMurdo Sound. Pup production decreased between 2000 and 2006 inclusive, but rapidly increased once the effects of B-15 were removed. While harvesting of Weddell Seals no longer occurs in the Ross Sea, iceberg calving still does. If this was to continue in the future, it is likely that Weddell Seal pup production in Erebus Bay will be somewhat negatively impacted. Other Antarctic seal species such as the Crabeater seal may be negatively affected also.

Introduction

The Ross Sea, Antarctica (Figure 1a) extends from Cape Colbeck to Cape Adare and is one of two large embayments on the Antarctic continent (Waterhouse 2001, Garrot & Rotella 2005). The Ross Sea's special features include a range of natural and physical characteristics, a diverse biota, and an extremely high level of species endemism (Eastman 2005, Smith *et al*. 2007). The Ross Sea also provides scientific opportunity to study marine ecosystem processes (Garrot & Rotella 2005).

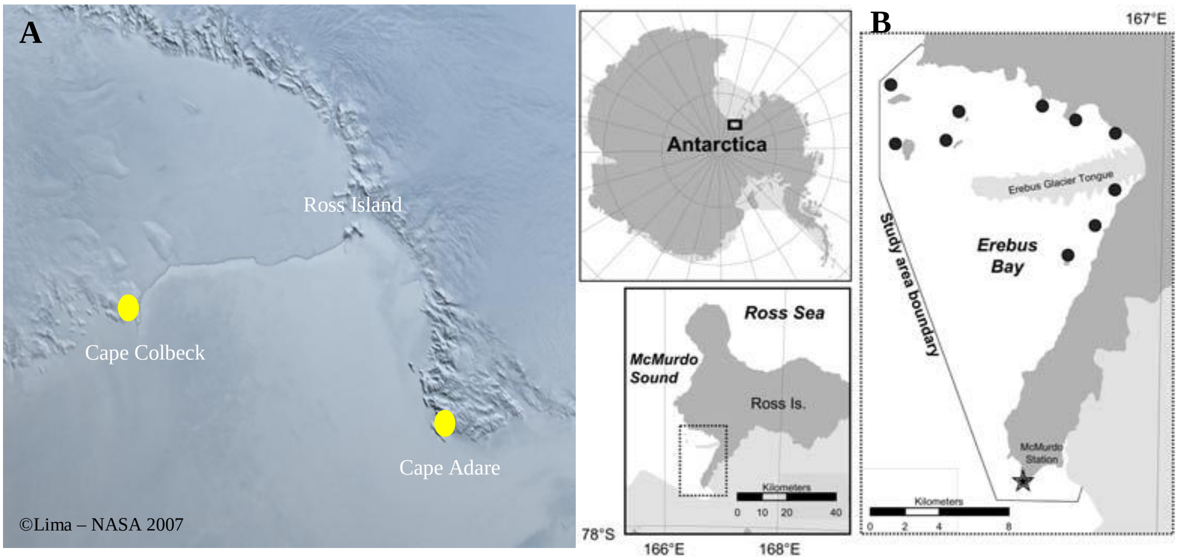

Figure 1. (**A**) A satellite image of the Ross Sea showing Ross Island, Cape Colbeck, and Cape Adare and (**B**) a map of the Erebus Bay study area. The black dots indicate major breeding colonies (taken from Cameron *et al*. 2007).

The Weddell Seal

Antarctic seals constitute a fraction of the few remaining large mammal populations not yet significantly affected or exploited by human activities (Siniff *et al*. 1977). An intensive study of a Weddell Seal breeding colony in Erebus Bay (Figure 1b), at the southern end of the Ross Sea began in the summer of 1968/69 and continues today, representing one of the longest continuous field studies of a long-lived mammal in existence (Garrott & Rotella 2005).

The Weddell Seal *Leptonychotes weddelli* is one of the large Antarctic phocid seals. At around 3m in length and weighing around 400-500kg, Weddell Seals have small, appealing faces with slightly upturned mouths, dark brown eyes and whiskers (Figure 2) (Trewby, 2002). Weddell Seals are the southernmost naturally occurring mammals on Earth (Trewby 2002), have a circumpolar distribution, and are most commonly associated with the fast ice of the Antarctic continent but are occasionally seen in the pack ice (Stirling 1969, Siniff *et al*. 1977). During both winter and summer their movements are largely governed by the presence of sea ice and the availability of suitable breathing and exit holes (Stirling 1969). *L. weddelli* feeds primarily on fish species, particularly the Antarctic toothfish *Dissosticaus mawsoni* and the Antarctic silverfish *Pleuragramma antarcticum* (Siniff 1991).

The life-history of the Weddell Seal is well documented in the literature. In spring, following foraging in the outer pack ice, Weddell Seals return to inshore fast ice locations to breed and give birth (Cameron *et al*. 2007). Males occupy underwater territories beneath the sea ice cracks which allow easy access to the surface (Testa & Siniff 1987, Siniff 1991). In the latitude of McMurdo Sound, the adult members of the population begin to congregate in ‘pupping colonies’ in early October (Siniff *et al*. 1977). The location of “pupping colonies” is dependent on several physical factors, including tidal action, wind, and glacial movements (Stirling 1969, Cameron *et al*. 2007) which cause fissures or cracks in the sea ice, along which these colonies form (Siniff *et al*. 1977, Testa & Siniff 1987). As many as 250 individuals can assemble in these colonies (Cameron *et al*. 2007). Pups are born on the sea ice in late October and November (Siniff 1991), although this changes with latitude (Stirling 1969). Females remain on the ice with their young to nurse (Cameron *et al*. 2007) and commonly have one pup per year, although twins have been recorded *in utero* three times but never documented live. When born, pups in the Ross Sea weigh 29kg and reach a weight of 110kg at the age of six weeks when weaning occurs (Stirling 1969). Pups are introduced to the water at 7-10 days (Cameron & Siniff 2004). Weddell Seals will leave Erebus Bay and disperse throughout the southern Ross Sea in late summer (Cameron *et al*. 2007). Adult Weddell Seals display a high level of philopatry, returning annually to the same pupping colony, however, juvenile members of this species disperse from the pupping colonies where they are born and occupy pack-ice regions until they reach maturity (Siniff 1991) at around 3 – 6 years of age (De Master 1982).

Figure 2. Photograph of an adult Weddell Seal near a sea ice crack in the Erebus Bay region (South side of the Erebus Ice Tongue).

Pup Production

Large mammal populations are typically characterised by long life expectancies, delayed sexual maturity, and low reproductive rates (Boyd *et al*. 1995). For many mammals it is thought that there is considerable variation in the age at which first reproduction occurs. When to begin reproduction is a very important life-history decision for several species and can potentially impact individual fitness and reproductive output (Hadley *et al*. 2006). Trade-offs between current and future reproduction and lifetime reproductive output are thought to be factors constraining variation in the age at first reproduction in large mammal populations (Hadley *et al*. 2006). The evolutionary success of an individual is determined by its lifetime reproductive output. As reproductive output is determined by the outcomes of multiple breeding attempts, surviving to reproduce again is imperative, particularly for long-lived species (Hadley *et al*. 2007). An individual's reproductive performance/output can be influenced by several factors or changes within their environment. In order to effectively study how mammals translate these changes into reproductive output, more data is required (Wheatley *et al*. 2006).

The Weddell Seal is a long-lived, upper trophic level organism (Wheatley *et al*. 2006) which is known to vary in the age at which it first reproduces (Hadley *et al*. 2006). Age at first reproduction has been studied extensively in the Erebus Bay population of Weddell Seals (Hadley *et al*. 2006, Hadley *et al*. 2007), however, our knowledge of reproductive output, or pup production, in relation to harvesting pressure and iceberg calving (environmental disturbances) appears rudimentary at best.

Harvesting Pressure

Permanent human occupation of McMurdo Sound began in 1956 with the establishment of research stations by the United States and New Zealand (Testa & Siniff 1987). Both research stations harvested local Weddell Seal populations in order to provide food for their resident dog teams (De Master 1982, Testa & Siniff 1987, Siniff 1991), however, the Weddell Seal has not been harvested commercially (De Master 1982). At Scott Base in McMurdo Sound, Weddell Seals were killed annually from 1956 to 1985 (Stirling & Greenwood 1971, Crawley 1978, Cameron & Siniff 2004, Ainley 2010). Although numbers taken are thought to have dropped after initial heavy harvest rates, between 1970 and 1976 a total of 399 seals were killed by personnel of the Antarctic division, DSIR (Crawley 1978). The United States discontinued its harvest after the first few years, but New Zealand continued the practice (Testa & Siniff 1987).The New Zealand Antarctic Programme is thought to have killed 50-100 Weddell Seals annually, eventually totalling 2000 seals (Ainley 2010). Some studies have shown population recovery or stability, it is believed that population numbers never returned to pre-harvesting levels (Crawley 1978, Testa & Siniff 1987, Ainley 2010). Seals were killed in late January or early February when the majority of the adult population (>3 years) was concentrated on the sea ice in front of Scott Base. In the 1950s and early 1960s datum on the physical characteristics of the dead animals was recorded and collected rather haphazardly, however, since 1966 the jaws and female reproductive organs were collected and information was recorded more systematically (Crawley 1978). The United States research programme also killed a small but unknown number of animals for scientific purposes (Ainley 2010).

In marine mammals, only small changes in adult survival are necessary to influence population growth (Testa & Siniff 1987). Therefore, one can speculate that only small harvesting levels of adult Weddell Seals is likely to have had large effects on the number of pups produced. Crawley (1978) noted that between 1972 and1975 the overall mean age of Weddell Seals harvested for dog food in Erebus Bay was 10.4 years for males and 9.87 years for females. Both averages are beyond the 3 to 6 years at which Weddell Seals reach maturity (De Master 1982) so it can be assumed that no pups were killed for dog food. Several studies have investigated the population dynamics of the Weddell Seal in relation to harvesting pressure (Stirling 1971, Crawley 1978, Testa & Siniff 1987) and some have incorporated pup production into their studies (Stirling 1971, Testa & Siniff 1987), however, there have been no studies which have examined the effects of harvesting pressure on Weddell Seal pup production over a long time scale. This study will look at pup production from 1969 (12 years into harvesting) to 2009 (present).

Environmental Disturbances

Climatic variation affects both physical and biological components of an ecosystem (Proffitt *et al*. 2007). It is now well known that on average the earth's climate and oceans are warming, and the results of a warming climate are somewhat amplified in Polar Regions (Proffitt *et al*. 2007, Siniff *et al*. 2008). In the Southern Ocean, sea ice is a major factor which determines the distribution of birds and mammals. For many species, sea ice provides a nursery platform, a foraging ground, and a resting site (Flores *et al*. 2008). The sensitivity of marine ecosystems and top-level predators (e.g. seals) to climate change has been documented in several recent studies (Bester & Hofmeyr 2007, Hadley *et al*. 2007, Siniff *et al*. 2008). There are four species of Antarctic pinnipeds (seals), including the Weddell Seal, which relies on the sea ice for critical portions of its life-history and has, in the past, demonstrated sensitivity to even the smallest of changes in the physical and biological environment of the sea ice (Bester & Hofmeyr 2007, Siniff *et al*. 2008).

Polar ice sheets and related ice shelves have become important indicators of climate change, responding in a variety of ways, ranging from increased melt to increased iceberg calving (Arrigo *et al*. 2002). Little is known about the effects of calving events on the marine ecosystem, however, the B-15 iceberg (numbered by the National Ice Centre, Suitland, MD, USA) which carved off the Ross Sea Ice Shelf is providing some insights (Arrigo *et al*. 2002). In March 2000, the iceberg B-15 calved off the eastern portion of the Ross Sea Ice Shelf and almost immediately began to fragment. At the last count there were nine fragments labelled B-15A through to B-15I (Figure 3). Nine months later, in November 2000, the fragmented pieces of the 295km (~10,000km^2) iceberg were still situated in the southwestern Ross Sea, creating a barrier and restricting the usual drift pattern of the pack ice. As a direct result there were unusually heavy concentrations of the sea ice throughout November and December 2000 – the time when the Ross Sea is predominantly ice-free (Arrigo *et al*. 2002). The B-15 iceberg continued to block the usual advection of sea ice from McMurdo Sound until the winter of 2006. Throughout this time, the fast ice increased in thickness, extent, and seasonal persistence and the extensive fast ice along the Victoria Land coast, Ross Sea exceeded typical coverage by a factor of five (Brunt *et al*. 2006, Siniff *et al*. 2008).

Among other animals, the Weddell Seal was directly affected (Siniff *et al*. 2008). Sea ice conditions within Erebus Bay determine the abundance of food resources and access to breeding sites (Hadley *et al*. 2006). As the Weddell Seal displays strong site fidelity in adults, and the B-15 iceberg prevented the usual breakup of the sea ice in Erebus Bay, access to Erebus Bay breeding areas was restricted, and the ice conditions drastically altered, making it difficult for returning animals to reach their usual breeding site in Erebus Bay (Figure 3) (Cameron *et al*. 2007). Therefore, fewer adults showed up for breeding (Siniff *et al*. 2008) and population numbers dropped between 2001 and 2005 inclusive (Cameron *et al*. 2007). Using 40 years of mark-recapture of Weddell Seals in Erebus Bay, this paper investigates the effect of the B-15 iceberg calving on pup production in Erebus Bay.

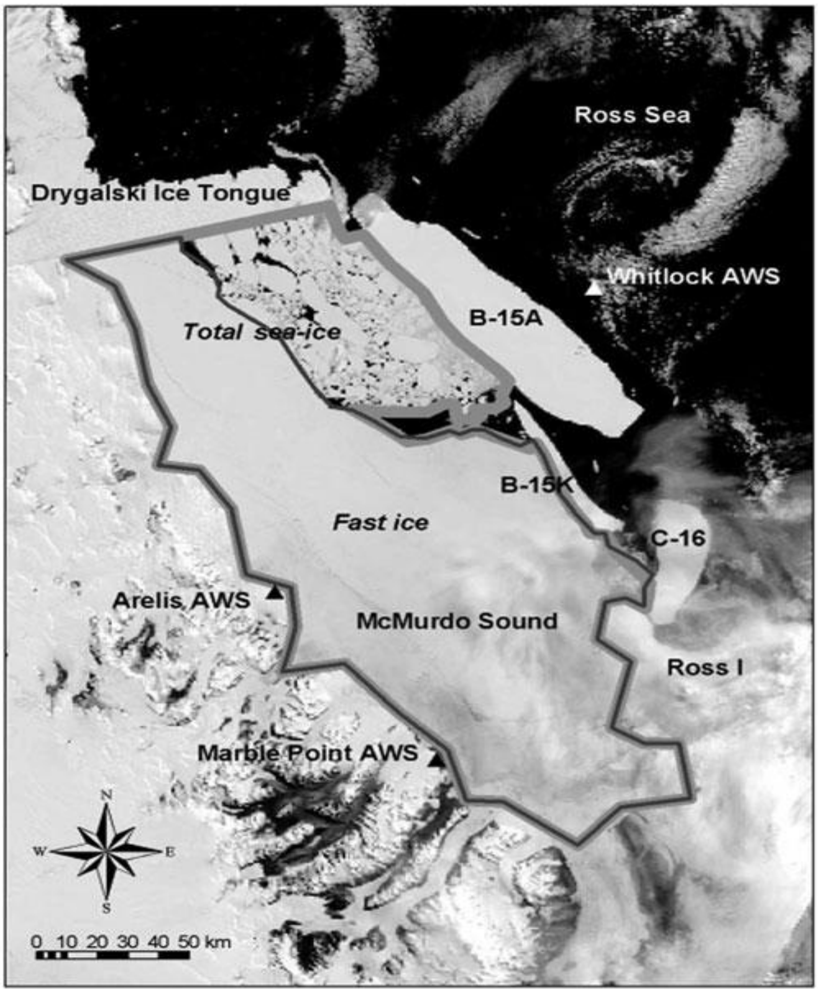

Figure 3. A MODUS (moderate resolution imaging spectroradiometer) image displaying the B-15 iceberg blockade of McMurdo Sound in January 2005, five years after B-15 first appeared. It was at this point that the blockade was at its strongest (image taken from Brunt *et al*. 2006).

Aims and Objectives

The aim of this project is to analyse pup production of the Weddell Seal breeding colony in Erebus Bay in relation to harvesting pressure and iceberg calving.

Based on prior knowledge, this study predicts that:

- pup production in Erebus Bay will be low in the years that harvesting occurred as seals of breeding age were harvested
- pup production will have decreased in response to the B-15 iceberg which made it difficult for adult Weddell Seals to return to their breeding grounds.

Methods

In the summer season of 1969 a mark-recapture project began in Erebus Bay and has continued until the present day. Since then over 20,000 individual Weddell Seals have been captured and tagged (Garrott & Rotella 2005). Pups born within Erebus Bay are tagged with plastic livestock tags which are attached to the interdigital webbing of each rear flipper (Hadley *et al*. 2006). Tags are coloured and numbered (Figure 4).

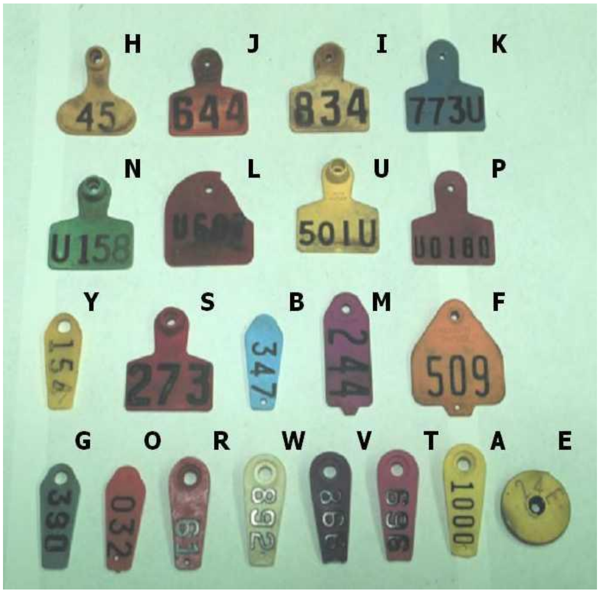

Figure 4. Examples of tag numbers and colours used to tag seal pups in Erebus Bay (image from Garrott & Rotella (2005)).

Since 1969, the mark-recapture information has been recorded and collaborated into one dataset which is available online:

www.homepage.montana.edu/~rgarrott/antarctica/project_description.htm

and contains the following information for each animal captured and recaptured:

- Year Tagged
- Age at Tagging

- Sex
- Location
- Year last sighted

As seal pups have been tagged from 1969 to 2009, this dataset forms the perfect platform from which to study pup production. Harvesting and iceberg calving occurred between 1969 and 2009, and therefore this dataset can be used to investigate the effects of these two factors on the number of pups produced in Erebus Bay. For the purposes of this study, the dataset was downloaded into an Excel spreadsheet from

www.homepage.montana.edu/~rgarrott/antarctica/project_description.htm.

For this study, only the pups and the year each pup was tagged were of interest. A total of 19,822 individual seal and adult pups were in the dataset at the time it was downloaded.

Each 'pup' in the dataset was given the number 1. Using the COUNT function in Excel, the number of pups produced each year (from 1969 to 2009) was calculated. These data were entered into a new spreadsheet (Appendix One) and analysed.

The annual average of pups produced was calculated as was the average per decade. Comparisons were made between pup production and years. Where available, the number of animals killed each year for dog food and the number of days it took an icebreaker to carve a channel to McMurdo Station (indicates the increase in thickness, extent and seasonal persistence of the sea ice) was also added to the graph.

Results

From 1969 to 2009, Weddell Seal pup production in Erebus Bay fluctuated (Figure 5).

For the first four years of tagging (1969-1972 inclusive) pup production was very low (<100), however, it rose to 458 pups in 1973. Pup production steadily decreased again from 1974 until 1985 when harvesting stopped. The average number of pups produced for the 1970s was 261, which is significantly lower than the annual average of 370 pups (Table 1). In the decade following the cessation of harvesting in Erebus Bay, pup production reached an average of 442 pups (Table 1) and the greatest number of pups born in 1997 (556 pups). From 1986 (the year after harvesting stopped) to 1996, pup production appears stable with only minor fluctuations. A large increase was witnessed in 1997 and again 10 years later in 2007 (Figure 5). For each decade after harvesting concluded, the average per decade is higher than the annual average (Table 1).

In the years that the B-15 iceberg was present (2000-2006 inclusive), the mean number of pups was 399 which is greater than the annual average, however, it is evident that pup production declined between 2000 and 2006, dropping as low as 201 pups in 2004 (Figure 5). Between 1969 and 2009, 2007 was the year in which the greatest number of pups was produced. A total of 597 Weddell Seal pups were produced in 2007, the year after the B-15 iceberg finally disappeared from McMurdo Sound (Figure 5).

The number of seals killed in Erebus Bay by Antarctic research programme personnel is recorded on figure 5. The number of seals killed for dog food was low, however, in some years the numbers killed exceeded the number of pups produced (1970 and 1972). Siniff and colleagues' study in 2008 used the number of days it took an icebreaker boat to carve a channel to McMurdo Sound as an indicator of increasing sea ice extent, thickness, and seasonal persistence (Figure 5). The number of days rose from 2 days to 10 days immediately after the B-15 iceberg calved off the Ross Sea Ice shelf. In 2005, the number of days reached a high of 12 days but declined to 4 days in 2006; the final year that B-15 was present in McMurdo Sound (Figure 5).

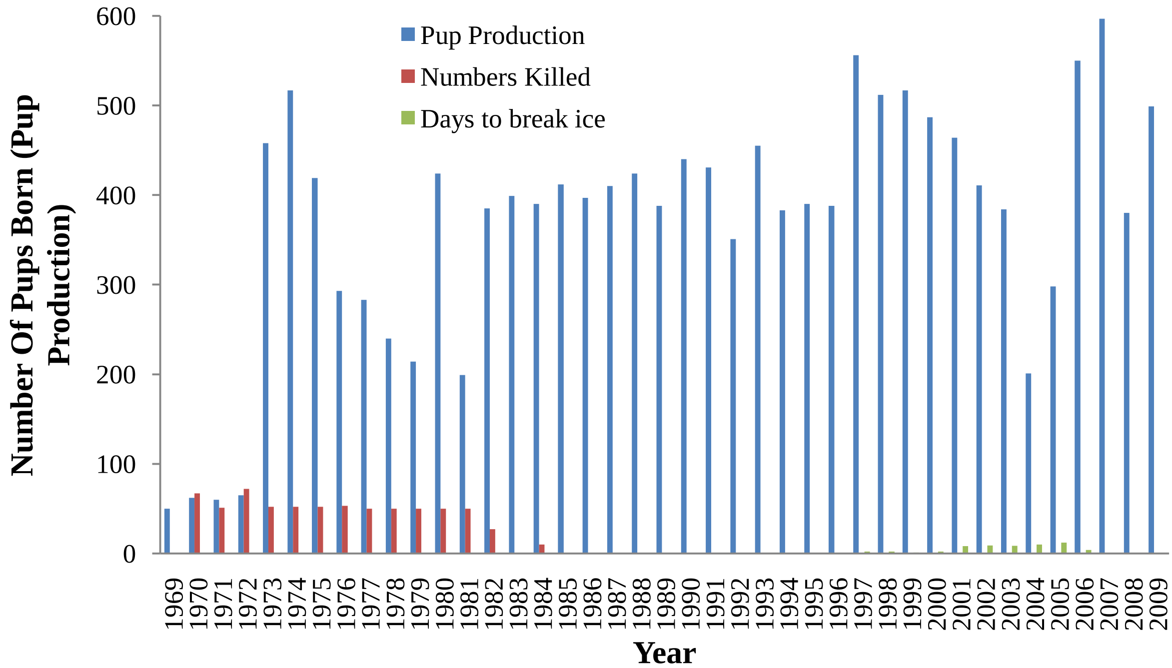

Figure 5. Pup production, number of seals killed, and sea ice extent in Erebus Bay from 1969 to 2009 (seals n = 15183, harvesting n = 686, days to break ice n = 57). Datum for the number of seals killed was collaborated from Crawley (1978), Testa & Siniff (1987), and Stirling (1971). Datum points for the number of days it took an icebreaker to make a channel to McMurdo Sound was sourced from Siniff *et al* (2008) (see also Brunt *et al*. 2006).

Table 1. The average number of pups produced annually, in each decade, andin the years that the B-15 iceberg was present. Note: The final decade is only 2000-2009 and therefore is not a complete decade.

Averages	
Annual	370
Decades	
70-80	261
80-90	383
90-00	442
00-09	427
Iceberg Years	399

Discussion

It is evident that both harvesting pressure and a single environmental disturbance (the B-15 iceberg) effected pup production in the Erebus Bay population of Weddell Seals. Weddell Seal pup production declined throughout the 1970s as a result of harvesting pressure from Antarctic research personnel, and declined again from the year 2000 as a result of a large iceberg (B-15) which carved off the Ross Sea Ice Shelf in March 2000 (Arrigo *et al*. 2002).

Pup production was exceptionally low (<100) for the first four years of the mark-recapture study in Erebus Bay. The low numbers of pups may be due to sampling errors, however, Crawley (1978) noted that when harvesting began in 1956, initial harvesting rates of Weddell Seals in Erebus Bay were very high and therefore the low number pups produced between 1969 and 1971 may be the tail end of a decline in the Weddell Seal population brought about by heavy harvesting rates in earlier years. Crawley (1978) also concluded that between 1970 and 1976 the Weddell Seal population of eastern McMurdo Sound was fluctuating around a stable level below the environmental carrying capacity with no evidence of fewer young being produced. However, the results of the current study show that the population began to steadily decline in 1975 and did so until 1981 when the population appeared to become stable for a number of years. A further study by Testa & Siniff (1987) collaborated three decades of pup production records for eastern McMurdo Sound. This record illustrated that pup production peaked in 1967 but was followed by a variable decline in the 1970s and relative stability from 1979 to 1984 (Testa & Siniff 1987). The results of this study illustrate a similar trend and the increases and decreases in pup production from 1969 to 1981 can be attributed to the heavy harvests of the resident adult Weddell Seals in McMurdo Sound (Testa & Siniff 1987). Interestingly, the mean number of pups produced in Erebus Bay in each decade following the discontinuation of harvesting is higher than the annual average. Additionally, B-15 played a significant role in the last decade (2000-2009) and yet the decade average for 2000-2009 was the highest overall. Possibly, and this is pure speculation, pup production may be higher now than it has been in the past as a way of compensating for population loses caused by harvesting pressure.

The B-15 iceberg caused problems in McMurdo Sound from 2000 to 2006 (Arrigo *et al*. 2002, Siniff *et al*. 2008) and it is obvious that pup production was affected by the presence of B-15. The results of the present study indicate that there was a noticeable decrease in pup production between 2000 and 2006, followed by a rapid increase in 2007 when the effects of the iceberg were removed. This suggests that adult Weddell Seals were in the region but may have been "choosing" not to breed as a result of the decreased productivity and sea ice conditions (Siniff *et al*. 2008). Earlier studies have produced similar results to this study; Stirling & Greenwood (1972) monitored sea ice crack numbers for several years and found that a decline in the number of available sea ice cracks was also partially mirrored by a decrease in pup production and Cameron *et al* (2007) documented a decline in total population size of the Weddell Seals in Erebus Bay in the years that the B-15 iceberg influenced the advection and breakup of the sea ice in McMurdo Sound. Testa *et al* (1991) also found a relationship to the El Niño-Southern Oscillation (ENSO) weather pattern which is likely mediated by changes in sea ice concentration and extent, and Hadley *et al* (2007) recorded a lower pup incidence among females when the sea ice had been more extensive during the previous year. Finally, the relative difficulty for an icebreaker ship to create a channel to McMurdo Sound while B-15 was present is indicative of an increase in extent, thickness and seasonal persistence of the sea ice (Siniff *et al*. 2008). Siniff *et al* (2008) showed that the Weddell Seal was directly affected by B-15 because the increase in ice thickness closed off sea ice cracks which had been predictably present for a number of years. Consequently, fewer adults showed up to breed and fewer pups were produced in Erebus Bay (Siniff *et al*. 2008), a conclusion reflected in the current study.

Regionally, Antarctic climate change does not follow uniform trends. In depth studies have shown rapid warming and retreat of the ice shelves on the Antarctic Peninsula, however, the Ross Sea region of Antarctica has experienced cooling temperatures, a lengthened sea ice season, and increases in sea ice extent (Proffitt *et al*. 2007, Siniff *et al*. 2008). Using the length of an icebreaker channel and the number of days to create channel, both Brunt *et al* (2006) and Siniff *et al* (2008) showed clear increases in the sea ice extent throughout the Ross Sea in the years immediately following the appearance of B-15. Siniff *et al* (2008) also showed that the increase in sea ice extent in the Ross Sea affected access to breeding sites. Climatic variations which influence an individual's access to a preferred breeding site or influence the physical characteristics of a breeding site may have drastic effects on breeding patterns and population dynamics, especially in animals which demonstrate site fidelity or philopatry (Cameron *et al*. 2007). The Weddell Seal demonstrates relatively strong site fidelity (Cameron & Siniff 2004). Siniff *et al* (2008) has already documented a decrease in the number of pups born in Erebus Bay during the B-15 blockade and therefore, it seems obvious that if iceberg calving was to continue in the future, Weddell Seals may not be able to reach their usual breeding grounds thus affecting pup production further. Additionally, sea ice extent and other environmental variation influences food abundance and availability. For a top-predator like the Weddell Seal, producing a pup is a huge energetic drain on female body reserves. Body reserves are affected by food abundance and availability and foraging, which in turn, effects current and future reproduction (Wheatley *et al*. 2006). Overall, if sea ice extent continues to increase as temperatures within the Ross Sea continue to cool, foraging success and pup production may be directly affected (Testa & Siniff 1987, Arrigo *et al*. 2002). However, Hadley *et al* (2006) results suggested that the Weddell Seal displays flexibility in the age at which they first reproduce in order to maximise reproductive output/pup production during times of environmental uncertainty. Based on this, it would be beneficial to monitor age at first reproduction in the Erebus Bay population of Weddell Seals in the face of possible future environmental variability to determine if this is the case. This could also explain the why the average the number of pups produced during the B-15 blockade was higher than the annual average.

Comparisons with other seals

On the whole, the Antarctic pinnipeds have escaped most human exploitation due to their habitat in ice-filled seas, and Antarctic treaty measures (Convention for the Conservation of Antarctic Seals 1978) have ensured that any future seal harvests are regulated closely in order to protect Antarctic seal stocks (Testa & Siniff 1987). However, in comparison with Weddell

Seal harvesting in McMurdo Sound, sustained harvesting of the southern elephant seal *Mirounga leonina* at South Georgia and the harp seal *Pagophilus groenlandicus* off Newfoundland, caused a decrease in the age of first reproduction of these species (Testa & Siniff 1987). If possible, it would be interesting to explore age of first reproduction in Weddell Seals throughout the years that sustained harvesting occurred in Erebus Bay.

In terms of iceberg calving, several other Antarctic seal species stand to be affected. The Crabeater seal *Lobodon carcinophagus*, the most abundant seal species in the world, feeds almost exclusively on Antarctic krill *Euphausia superba* and crystal krill *E. crystallorophias*. Any environmental changes similar to those brought about by the calving of B-15, will affect the availability of Antarctic krill, which in turn, will affect the abundance of the Crabeater seal, albeit indirectly (Siniff *et al*. 2008). Furthermore, *L. carcinophagus* females give birth to their pups on ice floes which must be large enough to ensure that it does not break up until weaning occurs. The ice floe also provides visual protection from Leopard seals *Hydruga leptonyx* and Killer Whales *Orcinus orca* – major predators of the Crabeater seal (Siniff & Bengston 1977, Siniff *et al*. 2008). The B-15 iceberg caused changes in sea ice extent, thickness, and seasonal persistence (Arrigo *et al*. 2002, Siniff *et al*. 2008). These types of alterations to the sea ice, if they continue, will cause changes in Crabeater seal abundance as a result of direct (pupping platform and predator protection) influences (Siniff *et al*. 2008). However, environmental variability is not likely to exhibit a large effect on Leopard seals as they occupy a diverse range of ice floes for pupping and maintain a diverse diet (Siniff *et al*. 2008).

Conclusions

The Weddell Seal population in Erebus Bay, Ross Island, Antarctica is the focus of one of the longest continuous field studies of a long-lived mammal in existence (Garrott & Rottella 2005). Every pup born into this population since 1969 has been tagged (Siniff *et al*. 2008). Using this dataset, pup production in the Erebus Bay population of Weddell Seals was examined from 1969 to 2009 in order to determine how harvesting pressure and the B-15 iceberg affected pup production. It was predicted that pup production would decline in response to both pressures. The results showed steady declines in pup production during the years where harvesting occurred and the years that the B-15 iceberg blocked McMurdo Sound. In between these two events, pup production appears to have been stable with only minor fluctuations. Crawley (1978) and Testa & Siniff (1987) reached similar conclusions in their investigations of population dynamics of the Weddell Seal in Erebus Bay. Harvesting ceased in 1985 (Ainley 2010) but iceberg calving, and the consequences of such environmental disturbances are still a threat to the Erebus Bay population of Weddell Seals (Siniff *et al*. 2008). When the B-15 iceberg calved off the Ross Sea Ice Shelf in March 2000, it caused large scale increases in sea ice thickness, extent, persistence, and prevented the usual advection of sea ice from McMurdo Sound until the winter of 2006 (Arrigo *et al*. 2002, Siniff *et al*. 2008). As a result of these changes in sea ice conditions, adult Weddell Seals were unable to reach their breeding grounds and thus fewer pups were born (Siniff *et al*. 2008). B-15 also caused changes to primary productivity and food abundance and availability

(Arrigo *et al*. 2002). If iceberg calving was to continue, or increase in frequency, the consequences would be the same, once again influencing Weddell Seal pup production. Other Antarctic seal species such as the Crabeater seal are likely to be affected also (Siniff *et al*. 2008).

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Appendix One

Year	Pups Produced	Numbers Killed	Icebreaker Days
1969	50	0	0
1970	62	67	0
1971	60	51	0
1972	65	72	0
1973	458	52	0
1974	517	52	0
1975	419	52	0
1976	293	53	0
1977	283	50	0
1978	240	50	0
1979	214	50	0
1980	424	50	0
1981	199	50	0
1982	385	27	0
1983	399	0	0
1984	390	10	0
1985	412	0	0
1986	397	0	0
1987	410	0	0
1988	424	0	0
1989	388	0	0
1990	440	0	0
1991	431	0	0
1992	351	0	0
1993	455	0	0
1994	383	0	0
1995	390	0	0
1996	388	0	0
1997	556	0	2
1998	512	0	2
1999	517	0	1
2000	487	0	2
2001	464	0	8
2002	411	0	9
2003	384	0	8.5
2004	201	0	10
2005	298	0	12
2006	550	0	4
2007	597	0	0
2008	380	0	0
2009	499	0	0
Total (n)	**15183**	**686**	**59**