

Satellite imagery can be used to detect variation in abundance of Weddell seals (*Leptonychotes weddellii*) in Erebus Bay, Antarctica

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Abstract The Weddell seal population in Erebus Bay, Antarctica, represents one of the best-studied marine mammal populations in the world, providing an ideal test for the efficacy of satellite imagery to inform about seal abundance and population trends. Using high-resolution (0.6 m) satellite imagery, we compared counts from imagery to ground counts of adult Weddell seals and determined temporal trends in Erebus Bay during November 2004–2006 and 2009, and December 2007. Seals were counted from QuickBird-2 and WorldView-1 images, and these counts were compared with ground counts at overlapping locations within Erebus Bay during the same time. Counts were compared across years and within individual haul-out locations. We counted a total of 1,000 adult Weddell seals from five images across all years (for a total of 21 satellite-to-ground count comparisons), approximately 72% of the total counted on the ground at overlapping locations. We accurately detected an increase in abundance during 2004–2009. There was a strong, positive correlation ($r = 0.98$, $df = 3$, $P < 0.003$) between ground counts and counts derived from

the imagery. The correlation between counts at individual haul-out locations was also strong ($r = 0.80$, $df = 19$, $P < 0.001$). Detection rates ranged from 30 to 88%. Overall, our results showed the utility of high-resolution imagery to provide an accurate way to detect the presence and variation in abundance of Weddell seals. Our methods may be applied to other species in polar regions, such as walruses or polar bears, particularly in areas where little is known about population status.

Keywords Weddell seal · *Leptonychotes weddellii* · Remote sensing · Satellite imagery · Antarctica · Erebus Bay

Introduction

Weddell seals (*Leptonychotes weddellii*) are found along the coast of Antarctica, where fast ice is present for a significant portion of the year. Females are philopatric (Stirling 1969a; Stirling 1974; Croxall and Hiby 1983; Cameron and Siniff 2004; Cameron et al. 2007; Hadley et al. 2007) and form traditional haul outs for pupping where persistent tide cracks reliably offer access from the ocean to the ice surface (Tedman and Bryden 1979; Siniff et al. 2008). While one of the best-studied marine mammal populations in the world exists in Erebus Bay (Hastings and Testa 1998; Cameron and Siniff 2004), less is known about populations of Weddell seals elsewhere around the Antarctic continent. The paucity of data regarding population status of seals is largely due to the logistical difficulties of accessing potential seal habitat in areas of Antarctica that are not in close proximity to research stations. Knowledge of seal distributions and numbers in other areas would be valuable for a variety of reasons. First, when attempting to

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understand the dynamics of local populations, it would be useful to know the status of nearby populations that may be involved in temporary immigration/emigration exchanges (Cameron and Siniff 2004; Rotella et al. 2009). Further, information on population status from numerous locations around the continent will be important for monitoring the species' overall status and its responses to environmental change (Siniff et al. 2008). Thus, developing methods for attaining knowledge of Weddell seal status throughout Antarctica is important to understand the ecology of sea ice seals and to assess the potential impacts of climate change or other anthropogenic influences on upper top-trophic predators.

Knowledge of Weddell seal abundance at diverse locations will also be useful for more general monitoring of the Antarctic marine system. For example, Weddell seals are an important predator of Antarctic toothfish (*Dissostichus mawsoni*; Ponganis and Stockard 2007), which have become the target of a fishery in the Ross Sea (Ainley and Siniff 2009; Blight et al. 2010). Given the difficulties of using standard methods to monitor toothfish in Antarctic pack-ice conditions, and in keeping with CCAMLR's precautionary and ecosystem management principles (Constable et al. 2000; Croxall and Nicol 2004), it would be desirable to monitor seal numbers along with fish harvest to evaluate fishery impacts on this important top-level predator and its food web.

Traditional monitoring methods for pinnipeds include using aircraft or aerial photography to census populations in the Arctic (McLaren 1966; Burns and Harbo 1972; Lavigne et al. 1982; Gilbert 1989; Johnston et al. 2000; Bester et al. 2002; NMML 2007), and intensive on-the-ground counts on shore-fast ice (Siniff et al. 1977) or ship-based line-transect surveys through pack ice (Gelatt and Siniff 1999; Ackley et al. 2002; Southwell et al. 2004; Flores et al. 2008; Bengston et al. 2011) in the Antarctic. Weddell seals haul out on the surface of shore-fast ice to give birth, suckle young, rest and molt; so employing imaging techniques to obtain population trends along the Victoria Land coast of the Ross Sea is feasible. Aerial surveys have previously been used to count seals in the Ross Sea (Smith 1965; Stirling 1969b). However, technology has advanced such that the use of satellite imagery may now be used to conduct significant research in the Antarctic (Barber-Meyer et al. 2007; Fretwell and Trathan 2009; Fretwell et al. unpublished data), while minimizing the substantial efforts and impact to the Antarctic environment of ground and aerial survey methods (Eberhardt et al. 1979; Green et al. 1995; Southwell 2005a).

Studying Weddell seals in the Ross Sea using satellite imagery has already been suggested in the literature (Barber-Meyer et al. 2007), and distribution and abundance around the continent has only recently been addressed by

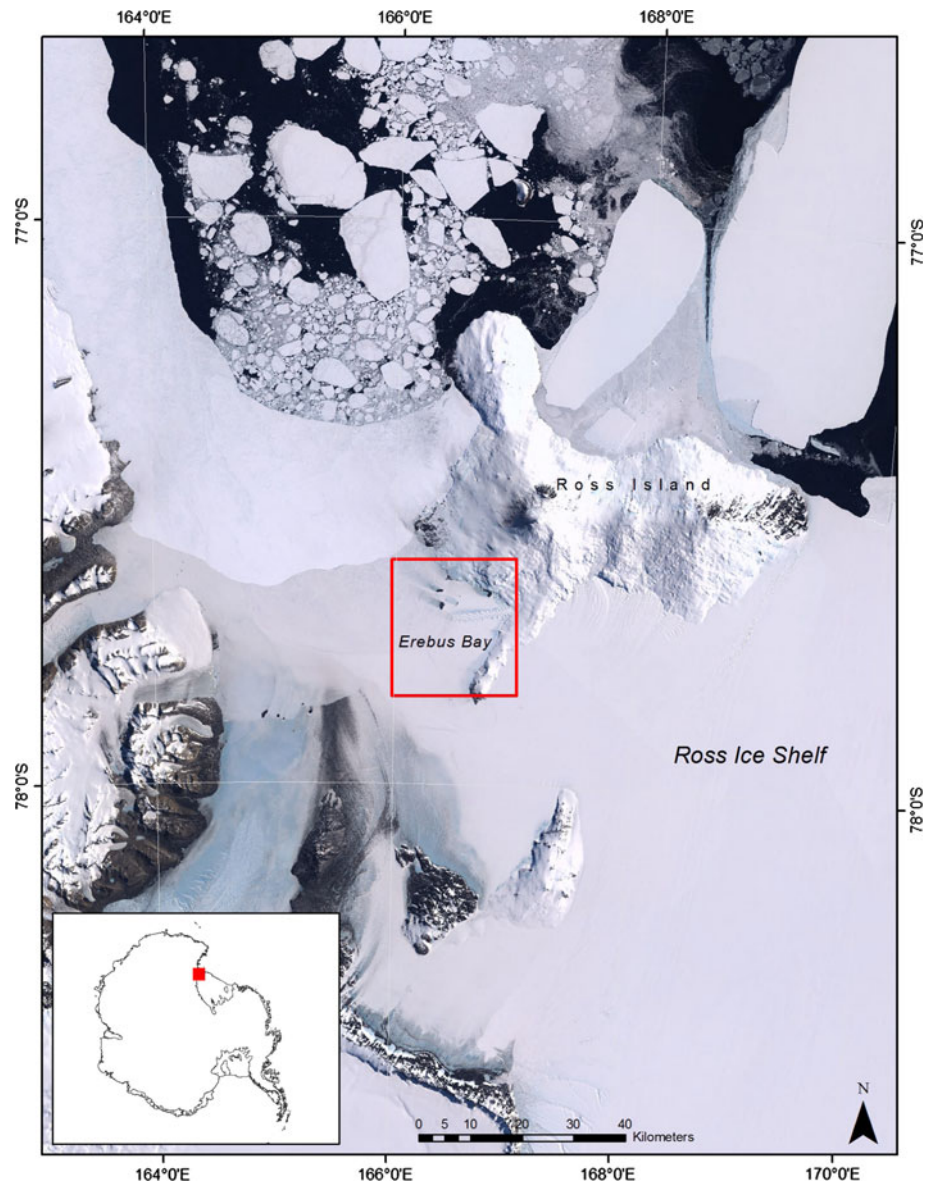
the international research program, Antarctic Pack Ice Seals (Bester et al. 2002; Bester and Stewart 2006; Bengston et al. 2011); United States' efforts took place within the Ross Sea during 1999–2000 (Ackley et al. 2002; Bester and Stewart 2006; Bengston et al. 2011). Thus, we wished to determine whether satellite imagery could be used to reliably identify adult Weddell seals hauled out on the ice and whether counts determined from imagery could provide accurate information about known abundances. Here, we present findings that suggest that high-resolution (0.6 m) satellite imagery can, indeed, be used to identify occurrence and to detect changes in abundance of a Weddell seal population. The cost of high-resolution imagery has made this kind of research difficult in the past, but satellite imagery is becoming more available and costs are declining. Our methodology will likely facilitate similar research in the future and may allow an efficient, cost-effective way to study polar pinnipeds in areas where little is known about distribution and abundance.

Materials and methods

Our study area comprised approximately 420 km² of Erebus Bay (Fig. 1), in southeast McMurdo Sound, Antarctica (lat. 77°12'S, long. 166°35'E). Much of Erebus Bay is covered by fast ice for most of the year, owing to its southerly location, the presence of several small islands, and the entrapment of ice by the Erebus Ice Tongue. Wind and tidal action on fast ice, the presence of small islands, and pressure generated by movements of the Erebus Ice Tongue create reliable perennial haul-out sites where Weddell seals establish reproductive colonies (Stirling 1969a). We focused our search efforts on reliable haul-out locations within Erebus Bay (Wilson 1907; Smith 1965; Fig. 2) where continuous mark-recapture studies were initiated in the 1960s (Smith 1965; Stirling 1969a; Siniff et al. 1977) and where recent ground counts coincided with available satellite imagery.

We gathered high-resolution satellite images of Erebus Bay for dates during November 2004–2006 and 2009, and December 2007. We used WorldView-1 (panchromatic, 0.6 m resolution) and QuickBird-2 (2.4 m multispectral and 0.6 m panchromatic) images, which were identified through the vendor's search tools (<http://www.digitalglobe.com>). Local times of image capture ranged from 1000 to 1300 hours, and these images were the only suitable, cloud-free images of the area as of December 2009. Each image was then analyzed for its utility. To do so, a remote sensing analyst determined, without knowledge of ground count results, which images and haul-out locations within each image to use based on image quality. Criteria for including a haul-out location in our analysis were as follows:

Fig. 1 Study area in Erebus Bay, Antarctica, (420 km²) represented by the *box*, to compare ground counts of Weddell seals to counts derived from high-resolution satellite imagery (0.6 m resolution; QuickBird-2 and WorldView-1 satellite imagery) during November 2004–2006 and 2009, and December 2007. Background image is 15 m Landsat image mosaic of Antarctica (LIMA). Imagery courtesy: NSF, BAS, USGS, and NASA



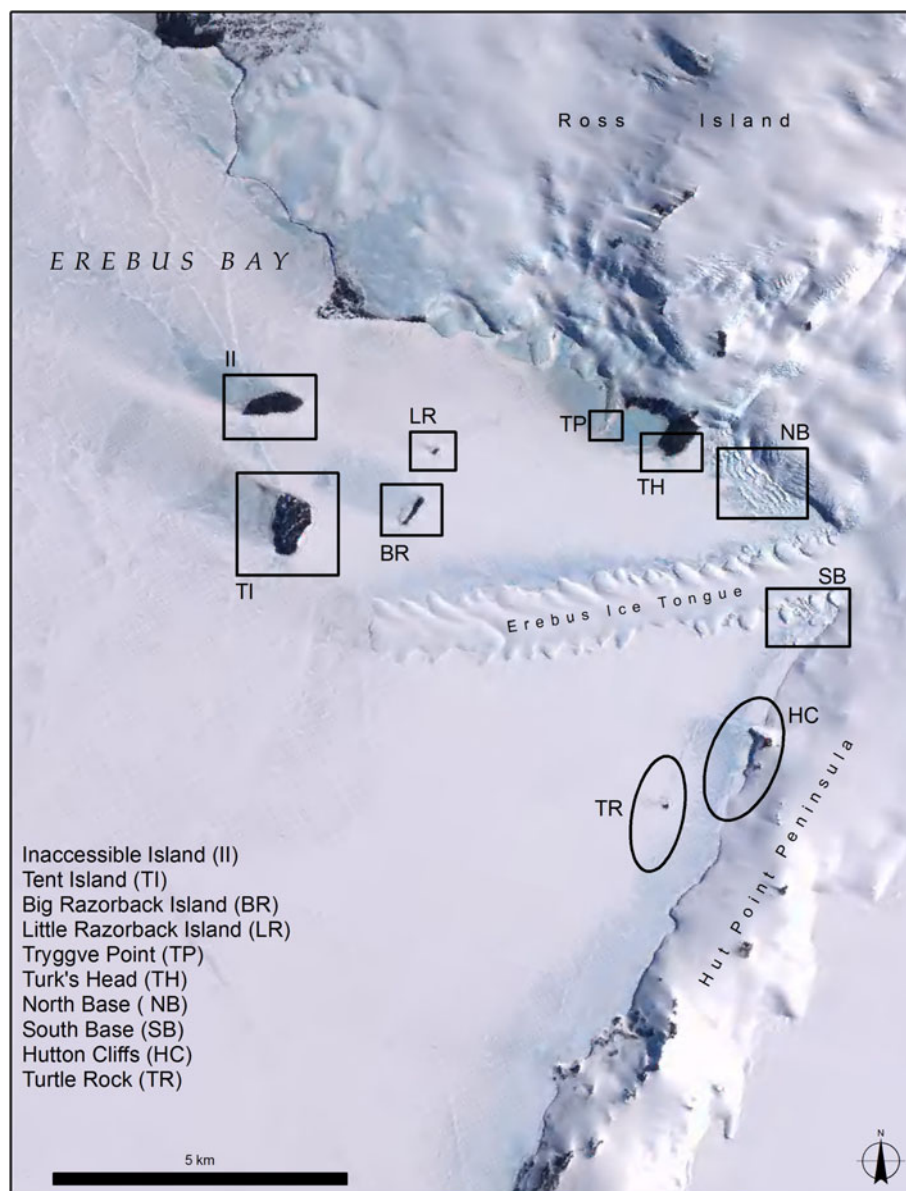
(1) sufficient quality of the image (i.e., low banding, cloud-free, and few shadows); (2) the entirety of a haul-out location was captured within the image; and (3) the dates of ground counts and satellite images were within 7 days of each other. If any haul-out location on any image did not meet all three criteria, it was omitted from analysis.

One observer counted seals from the imagery at each suitable haul-out location on each image. The number of haul-out locations compared per date differed based on image quality and the spatial coverage of each image. For example, Big Razorback Island (Fig. 2) was captured on the image dated November 12, 2006, so we counted the number of seals present and compared those results to ground counts made at that location and on that date. Ground counts at locations that were not represented on a given image were not used for comparison for the image date. We

only made comparisons of seal counts at haul-out locations where the image and ground counts were spatially and temporally comparable (within 7 days).

All QuickBird-2 images were then pansharpended (i.e., increase in image quality by merging lower-resolution multispectral with higher-resolution panchromatic imagery to create one high-resolution, multispectral image) to 0.6 m resolution, and imagery searches were completed in ArcGIS 9.3 (ESRI 2009). We confirmed the presence of seals in our images and then recorded seal counts by overlaying a blank shapefile on the image and placing a single point on each location of a suspected seal. We searched each image at a scale of 1:2,000 (Fig. 3) without prior knowledge of ground count data. The total number of seals at each location per image date was recorded in the GIS shapefiles.

Fig. 2 Specific haul-out locations within the Erebus Bay study area used for direct comparisons of counts of adult Weddell seals derived from satellite images to ground counts conducted during the same time. Background image is 15 m LIMA. Image courtesy: NSF, USGS, NASA, and BAS



Ground counts were conducted in Erebus Bay, Antarctica, from 1000 to 1800 hours at 3- to 6-day intervals from early November until mid-December each year. These counts recorded all individual adult seals, individual pups, and adult-pup pairs. Because Weddell seals that are hauled out are highly detectable (Rotella et al. 2009), we are confident that these ground counts missed very few seals that were present on the ice surface at the time of the count. Thus, our measure of abundance from ground counts was the actual count on the surface on a given day at a given haul-out site. Repeated counts on marked animals can be used with mark-recapture methods (Williams et al. 2002) to estimate actual abundance (Rotella et al. 2009) but that was not our focus in this effort. Here, we were interested in knowing whether counts of seals on the ice made on the ground would strongly correspond with counts of seals via satellite imagery.

For each location and date for which we had associated ground and satellite counts, we calculated the number of seals counted by each method and the proportion of ground-counted adult seals that were detected by satellite across all haul-out locations that could be used across a given year. We excluded pups from all comparisons because we assumed that pups, which even at weaning are generally less than half the size of adults, would be less likely to be detected in 0.6 m resolution imagery. Pearson's correlation coefficient was calculated for annual counts from the two approaches and for counts from the two approaches at individual haul-out locations. We also determined change in abundance through years at three haul-out locations where ≥ 3 satellite-to-ground count comparisons were possible and calculated Pearson's correlation coefficient for each location through time.

Fig. 3 WorldView-1 image (0.6 m resolution) of Weddell seals hauled out east of Inaccessible Island, Erebus Bay, Antarctica, at 1:2,000 scale. This is an example of a suitable satellite image for use in counting seals. Image copyright: DigitalGlobe, Inc. Image provided by National Geospatial-Intelligence Agency (NGA) Commercial Imagery Program



Results

Our results indicate that useful information about seal abundance can be obtained from high-resolution satellite imagery. During 2004–2009, five images of haul-out locations within Erebus Bay were used to compare image counts to ground counts and each haul-out location defined (Fig. 2) was compared at least once. One location was compared four times and two locations had only one satellite-to-ground count comparison (Table 1). A total of 21 satellite-to-ground count comparisons were made across the five images (Table 1). Annual satellite counts summed across multiple haul-out locations had a strong, positive correlation with accompanying ground counts ($r = 0.98$, $df = 3$, $P < 0.003$) and would have been useful for detecting the major changes in annual ground counts (Fig. 4). When

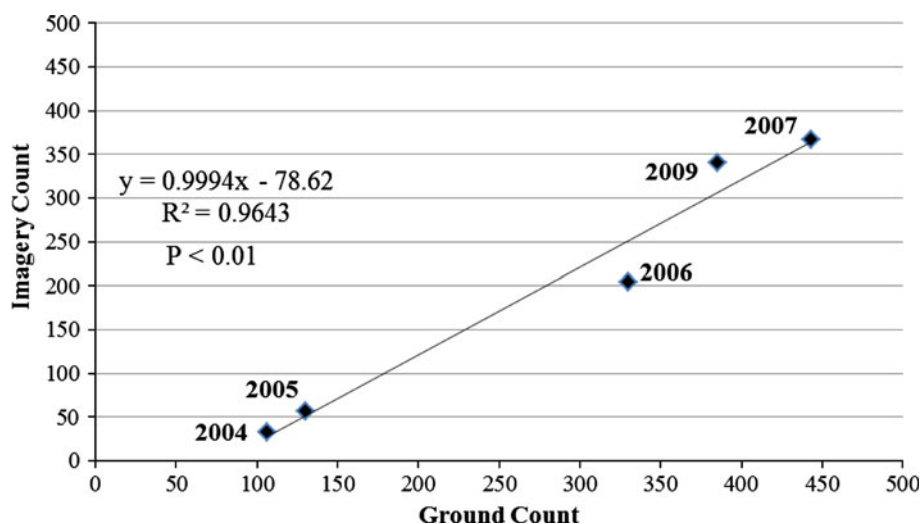
calculated at the individual haul-out level, image counts also had a strong, positive correlation with ground counts ($r = 0.80$, $df = 19$, $P < 0.001$). We further determined strong correlations and detected changes in abundance of seals present on the ice at haul-out locations with ≥ 3 ground-to-satellite comparisons (Fig. 5).

Across the 5 years, 1,000 seals were detected on the five annual images, which represented 71.7% of the 1,394 seals known to be present from ground counts (Table 1). However, satellite counts did not detect a constant proportion of the seals detected in ground counts. In 2004, when the fewest seals were recorded on ground counts, counts from imagery detected only 30% of the seals known to be present. In contrast, during the two most recent years, in which ≥ 385 seals were detected on ground counts, image-based counts detected $\geq 82\%$ of seals known to be present (Table 1).

Table 1 Summary of the comparison of counts of adult Weddell seals derived from high-resolution satellite imagery and ground counts in Erebus Bay, Antarctica

Image type	Image date	Ground count date(s)	Locations compared	Count on images	Ground count of adults	% Detected
WorldView-1	22 Nov. 2009	17, 21, 25 Nov. 2009	TH, TP, NB, TR, HC	340	385	88.3
QuickBird-2	10 Dec. 2007	4 Dec. 2007	TI, BR, II, TR	367	443	82.8
QuickBird-2	12 Nov. 2006	12 Nov. 2006	TI, TP, BR, HC, TR	204	330	61.8
QuickBird-2	9 Nov. 2005	9, 13 Nov. 2005	TH, NB, HC	57	130	43.8
QuickBird-2	19 Nov. 2004	18 Nov. 2004	TH, SB, HC, TR	32	106	30.2
	TOTAL		21	1,000	1,394	71.7

Image type was the satellite platform upon which the image was acquired. The image and ground count dates represent the local date the image was acquired and date(s) that ground counts were conducted at directly comparable locations in Erebus Bay. The locations compared were the haul outs within Erebus Bay, defined in Fig. 2, where ground counts and suitable images overlapped entirely. The percentage detected was the number of seals identified in the imagery divided by the number of adult Weddell seals counted on the ground in each of the overlapping areas for comparable date(s)

Fig. 4 Count of seals on the sea ice from satellite imagery versus ground counts of adult Weddell seals on the sea ice in Erebus Bay, Antarctica, conducted during the same time

Discussion

Our work provides an important step forward in polar ecology by demonstrating that remote sensing data can be used effectively to identify presence and determine abundance of the Weddell seal population within Erebus Bay, Antarctica. This study combined a few important factors that contributed to our strong results. First, the Weddell seal population of the Erebus Bay area was an ideal test population because of its accessibility and proximity to McMurdo Station and because of how much is known about the current and historical population abundance of adult seals there (Smith 1965; Stirling 1969a; Siniff et al. 1977; Testa and Siniff 1987; Hastings and Testa 1998; Cameron and Siniff 2004; Hadley et al. 2007). Long-term population datasets are rare for large, long-lived animals (Fossey and Harcourt 1977; Croxall and Kirkwood 1979; Garrott and Taylor 1990; Micol and Jouventin 2000), and the population of seals in Erebus Bay provided a unique opportunity for the count

comparisons needed to establish strong correlations between ground and satellite counts.

Secondly, because it is nearly impossible to count all animals present in a population (Williams et al. 2002), it is important to conduct surveys during a peak in the population to minimize the number of missing individuals (Eberhardt et al. 1979; Green et al. 1995; Boyd et al. 2010). Ideally, such counts of seals should occur after birthing when adult females are more likely to be on the surface and available for detection (Eberhardt et al. 1979). Thus, the time of year we compared our images to ground counts was important because the population peaks in October–December (Stirling 1969a; Tedman and Bryden 1979; Siniff 1981), when pregnant Weddell seals haul out in groups in Erebus Bay and remain on the ice for several weeks after pups are born (Lindsey 1937; Stirling 1969a). This is also the season when annual ground counts are conducted (Rotella et al. 2009; D.B Siniff, J.J. Rotella, R.A. Garrott, personal communication). Our comparisons were

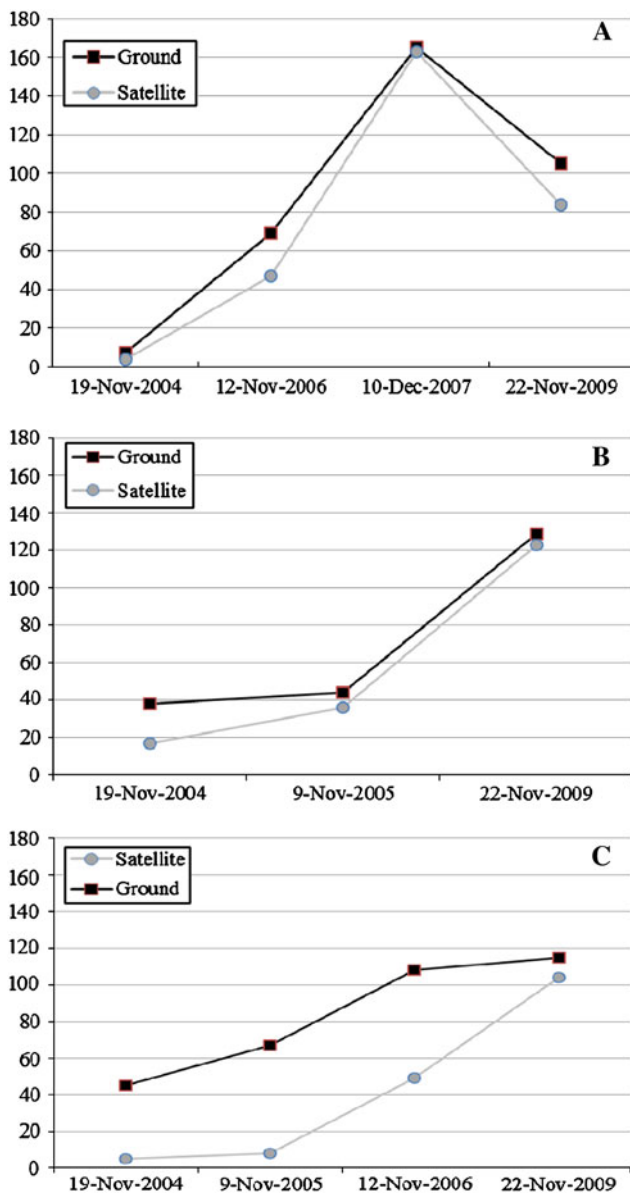


Fig. 5 Abundance of adult Weddell seals present on the sea ice counted on the ground and from satellite imagery per image date at three haul-out locations within Erebus Bay: **a** Turtle Rock ($r = 0.98$, $df = 2$, $P < 0.01$); **b** Turks Head ($r = 0.99$, $df = 1$, $P < 0.05$); and **c** Hutton Cliffs ($r = 0.89$, $df = 2$, $P < 0.05$)

made during an ideal time, when the population was at its peak and when a relatively large proportion of individuals were visible on the ice. It is, however, worth noting that the counts here do not represent the actual abundance of seals present in the study area because on any given survey a large proportion of adult seals, especially males (Stirling 1969a; Gelatt et al. 2000; Gelatt 2001), may be in the water and undetectable with ground or satellite counts. Regardless, mark-recapture estimates of population abundance from repeated surveys within a year do indicate that counts from any single survey are positively correlated with abundance

estimates that do take failed detections into account (J.J. Rotella, R. A. Garrott, and D. B. Siniff unpublished data).

Marine mammal populations are generally difficult to census, and direct observations in particular are often hindered by inaccessibility and difficult logistics (Eberhardt et al. 1979; Green et al. 1995; Gelatt and Siniff 1999; Boyd et al. 2010; Bengston et al. 2011). Our approach minimizes several disadvantages of traditional census methods. First and quite importantly, high-resolution satellite imagery eliminates any effects of observer presence on the individuals in the population that would normally occur by walking near, sailing by, or flying over the area (Buckland et al. 2001; Southwell 2005a). Although such effects are not problematic for Weddell seals, human presence can cause major disturbance in breeding colonies of some pinniped species. Use of satellite imagery provides a passive way of viewing a truly undisturbed population. Second, the imagery we used has a wide swath, which provided us with an image of $\geq 400\text{-km}^2$ for each comparison date. The possible area covered by several satellite images per day ($>5,000\text{ km}^2$) would potentially allow the observation of a much larger region than would be logistically possible to cover on foot, by plane, or by ship in 1 day. Third, satellite-based survey methods would allow us to readily obtain replicate counts and would provide the potential to develop rigorous sampling schemes across large areas. For example, coastal areas already known to be breeding sites for Weddell seals could be repeatedly surveyed during the peak of pupping in November to evaluate changes through space and time. Analyses of data across multiple years could then be used to learn about how similar or dis-similar population changes might be across large areas. The technique described here could also be used to identify other large aggregations of seals, if images for coastal areas were repeatedly surveyed when many seals are hauled out (e.g., November pupping season or January when adult seals stay near breeding colonies during the annual molt [Burns and Kooyman 2001]). Surveys in pack-ice areas that have been shown to support large numbers of other seals (Bengston et al. 2011) can be also used to monitor other species and non-breeding aggregations of Weddell seals. As the methods here did not evaluate the performance of the survey technique in pack ice, it would be ideal to initially pair satellite surveys with information from traditional methods to facilitate comparisons. If correlations between counts from traditional and satellite methods are strong, it could be possible in the future to obtain more information remotely.

Another disadvantage of conducting such rigorous sampling by ship or aircraft-based platforms is that such methods are typically limited by high cost and logistical difficulties, and some areas of Antarctica are impossible to reach. Our methods that used satellite imagery, which was provided through federal licensing agreements, GIS software,

and 1–2 observers would cost a fraction of what would be spent gathering the same data on the ground, especially when scaled to cover large or inaccessible areas. Finally, optical satellite imagery can be combined with remotely sensed sea ice data to correlate patterns of abundance and distribution of seals, providing a broader-scale understanding of the effects of sea ice on seal ecology.

We recognize that counts from satellite imagery were consistently lower than the ground counts of adult Weddell seals. However, we accurately captured changes in abundance across years at three haul-out locations (Fig. 5). But the disparity between the ground counts and the satellite counts may be due to the time of day images were acquired. Because the QuickBird-2 and WorldView-1 satellites have polar orbits, the time of day when our images were on-nadir (i.e., directly vertical over the study area) was always between 1000 and 1300 hours. It is well-known that Weddell seals have a diurnal haul-out pattern (Smith 1965; Stirling 1969a, b; Siniff et al. 1971; Lake et al. 1997), with the largest proportion on the ice between 1200 and 1900 hours (Siniff et al. 1971; Lake et al. 1997). Satellite images were collected just before the most inactive portion of the day, and the seals counted were only a proportion of what would likely be hauled out later during the day. It seems likely that part of the discrepancy between counts was due to the time satellite images were collected during the day.

Further, we noticed that detection rates of seals from the imagery were not consistent, ranging from a low of 30% in 2004 to a high of 88% in 2009. Annual variation in total ground counts and in ice surface conditions was high, which provided a useful dataset for evaluating the utility of counts from satellite images. During the study period, ice conditions and seal numbers were strongly influenced by a massive iceberg that blocked the usual advection of sea ice from the area during 2004–2006 (Arrigo et al. 2002; Siniff et al. 2008). During the first several years of the study, the ice was unusually thick with larger and more extensive pressure ridges than are typically experienced in the area. These large pressure ridges and jumbled ice within Erebus Bay made the detection of seals on the ice more difficult, leading to lower detection rates from the satellite imagery. After the iceberg broke up in 2006, pressure ridges gradually diminished in size and extent and the smoothness of the ice surface increased. Our data succeeded in capturing seal response to these conditions (Fig. 5).

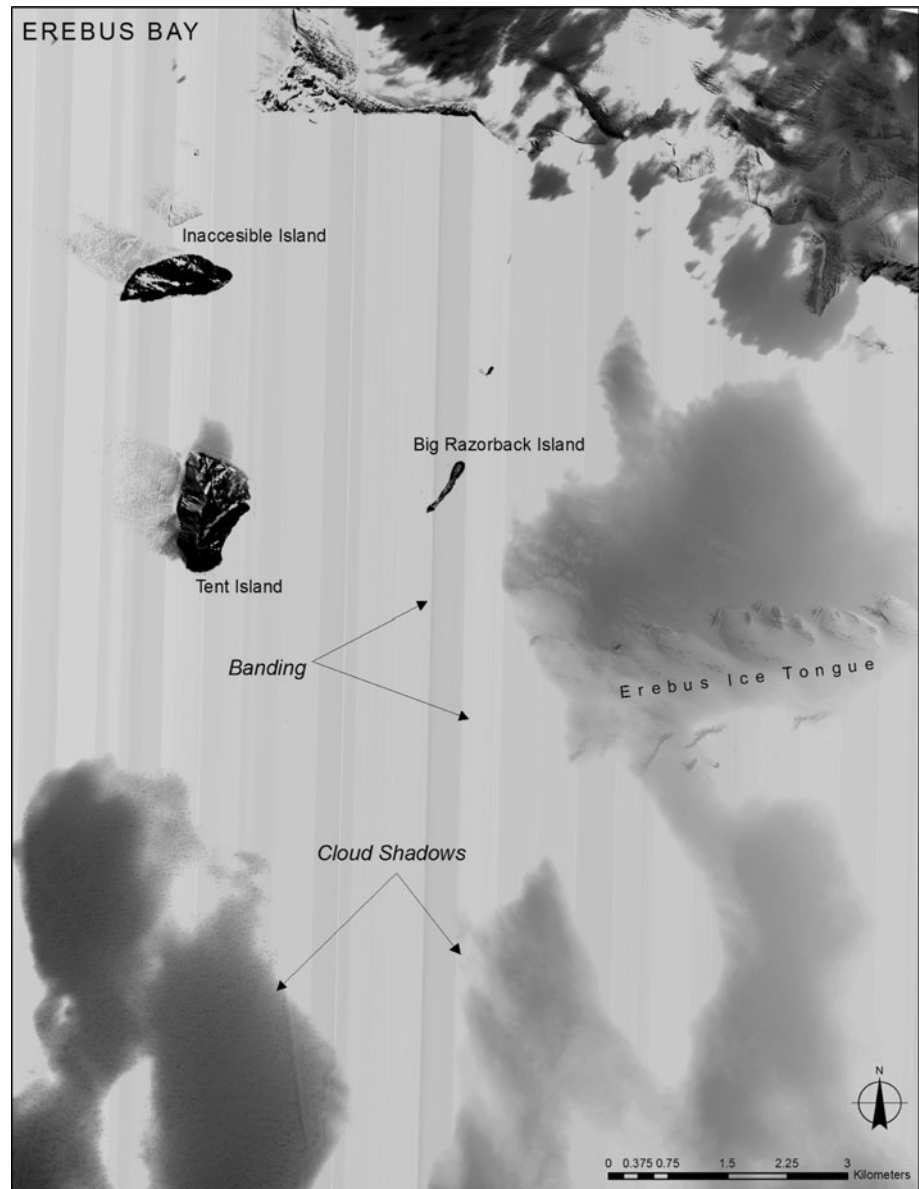
However, the consistent under-identification of seals from satellite imagery suggests that for future work, applying some kind of correction factor may be warranted (Eberhardt et al. 1979; Erickson et al. 1989; Bengston and Stewart 1992; Lake et al. 1997; Southwell 2005b; Boyd et al. 2010; Bengston et al. 2011), should the objective be to determine exact population densities of Weddell seals. We did not include a correction factor for this study

because this was simply beyond the scope of our initial investigation. Our goal here was to demonstrate the utility of high-resolution satellite imagery for identifying and enumerating seals on the sea ice surface, which could potentially be used for providing an index of abundance, and further as a trend indicator for seal populations in the Antarctic.

High-resolution satellite imagery is a powerful tool for remotely evaluating both the biotic and abiotic components of ecosystems (Boyd et al. 2010). Antarctic ecology is particularly intriguing, because photograph identification of ice-dependent, marine species can be fairly straightforward (Barber-Meyer et al. 2007; Fretwell and Trathan 2009; Fretwell et al. unpublished data), as animals are easily detected and identifiable. Further, as satellite technology enhances and resolution of images increases, improvements in the utility of this method will also likely increase. However, we found that weather conditions were one of the most constraining factors to the success of our study. Should these methods be applied in other polar locations or to other species (such as walruses, polar bears, or even large cetaceans), one must realize an almost sole dependence upon cloud-free imagery devoid of shadows, in order to gain any knowledge about animal presence. Short, temporally dependent studies (on the order of days or weeks) may not utilize such high-resolution imagery, as sustained cloud cover or excessive banding could render an entire study useless (Fig. 6). The optical nature of QuickBird-2 and WorldView-1 satellites further dictates a dependence on daylight conditions. During the winter in polar regions, the use of QuickBird-2 or WorldView-1 imagery to answer ecological questions is simply not possible. So, while the use of optical imagery in polar regions has several advantages, it also provides some constraints that must be considered prior to conducting similar studies.

Remote sensing of Weddell seals in Erebus Bay indicated a strong, positive correlation ($r=0.98$) between counts of adult Weddell seals from satellite imagery and actual ground counts collected during the same time. Given our indications here that satellite counts can provide information about relative abundance and, more importantly, changes in relative abundance, we feel confident that our technique can be applied to search for seals in larger areas where abundance is unknown and where general population trends have never been observed. For example, across broad areas one could examine which populations grow, shrink, or remain unchanged as sea ice conditions change, as fish harvesting practices vary, or as other environmental conditions change through time. One could also investigate possible spatial structuring of population units by monitoring populations separated by varying degrees of distance and occupying locations with different environmental attributes.

Fig. 6 Panchromatic Quick-Bird-2 image (0.6 m resolution) of a portion of Erebus Bay, Antarctica, acquired December 1, 2009. This image demonstrates some potential problems (e.g., banding, cloud cover, over-exposure) that could interfere with accurately counting Weddell seals using high-resolution satellite imagery. Image copyright DigitalGlobe, Inc., provided by National Geospatial-Intelligence Agency (NGA) Commercial Imagery Program



It would be useful to conduct further work in Erebus Bay using repeated counts of colonies, assessment of diurnal haul-out patterns, and comparisons of rigorous mark-recapture estimates of absolute abundance (Rotella et al. 2009) with estimates obtained from satellite imagery to determine how well counts from imagery represent absolute abundance. Regardless of the results of such work, our current results indicate that much can be learned about relative abundance. Given that, it is clear that the method presented here can readily identify which sites along the Antarctic coast are or are not occupied by seals under various environmental conditions. Although presence/absence data do not contain as much information on population state as what is provided by data on absolute abundance, recent work has demonstrated the great utility of having occupancy

data, especially at broad spatial scales and over a broad range of conditions (MacKenzie et al. 2005; Fretwell and Trathan 2009). Moreover, Weddell seals are disappearing fast enough in some areas of the Antarctic Peninsula (Siniff et al. 2008) that quantitative, relative abundance may provide a useful indication of ecosystem change.

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