Advances in non-lethal research on Antarctic minke whales: biotelemetry, photo-identification and biopsy sampling

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Abstract

During the austral summer of 2012-2013 we studied Antarctic minke whales in their sea ice habitat in two regions of the Antarctic: the Ross Sea and the Western Antarctic Peninsula. In less than a month of field work, during which a portion of time was dedicated to minke whale research we deployed 16 satellite-linked data recorders; two short-term archival data recorders; obtained 19 skin and blubber biopsy samples and took a large number of photo-identification images of well-marked individuals. We attached four types of biotelemetry tags using three different attachment techniques: blubber penetrating satellite tags, dorsal fin mounted satellite tags, dorsal fin mounted satellite and dive recording tags, and suction cup mounted multi-sensor acoustic tags. We believe that such dedicated effort offers great promise to gain insight into many aspects of the movement patterns, habitat use, behavior and life history of Antarctic minke whales.

Introduction

Antarctic minke whales (*Balaenoptera bonaerensis*) have been the focus of decades of study by the International Whaling Commission as part of the IDCR/SOWER surveys. A key objective of these surveys was to derive estimates of abundance of Antarctic minke whales by sector and at a circumpolar scale. Estimates derived from these surveys over a decadal time period were not statistically different, but differences were apparent by sector (e.g., Areas I, II and V showed a statistical decrease, Areas III, IV and VI showed no difference). There has been significant discussion regarding the ecological drivers underlying these changes, including possible changes in habitat (particularly ice) in different survey years and concomitant shifts in whale distribution, real changes in the abundance of minke whales at a regional level, or some combination of these.

An understanding of the movements and dive patterns of individual Antarctic minke whales would address some of the uncertainties regarding the abundance of this species in the Antarctic. Biotelemetry is an ideal tool for addressing a range of questions relevant to these uncertainties, including:

- How do Antarctic minke whales utilise sea ice habitat?
- What are the movement patterns of individual whales in relation to the management Areas currently used by the IWC?

Observations of the surfacing behaviour of individual whales generated through biotelemetry can also inform issues of 'availability' for data derived from boat based surveys (particularly IDCR/SOWER) and aerial surveys. Such data can be derived from devices that record dive behaviour and/or surface intervals. The Southern Ocean Research Partnership (SORP, http://www.marinemammals.gov.au/sorp) has also identified the need for biotelemetry data from Antarctic minke whales. One of the objectives of the SORP project 'Foraging ecology and predator-prey interactions between baleen (minke and humpback) whales and krill; a multi-scale comparative study across Antarctic regions' is to obtain biotelemetry data on these two species at a range of spatial and temporal scales. This SORP project is intended to elucidate foraging strategies used by minke and humpback whales in a variety of habitats, including sympatrically.

During the austral summer of 2012-13 a multi-disciplinary team of researchers from Australia and the US studied Antarctic minke whales in the Ross Sea and the Western Antarctic Peninsula (WAP). We dedicated research effort to deploying a variety of biotelemetry devices and obtaining biopsy samples and photo-identification data.

Biotelemetry

We tagged 18 Antarctic minke whales with four different types of biotelemetry devices (Table 1). The devices included blubber penetrating satellite tags (*n*=10, Wildlife Computers, SPOT 177N), dorsal fin mounted satellite tags (e.g. Andrews et al. 2008; Durban and Pitman, 2012) (*n*=3, Wildlife Computers, SPOT 240C), dorsal fin mounted satellite and dive logger tags (*n*=3, Wildlife Computers, SPLASH 292A) and suction cup mounted, multi-sensor biologging tags (*n*=2, Acoustimetrics, Acousonde™). Tags were deployed in the Ross Sea (*n*=3) and on the WAP (*n*=15) using crossbows (both types of dorsal fin tags), an air gun (blubber penetrating satellite tag) and carbon fibre pole (Acousonde™). The whales were tagged from the ice (Ross Sea) and from a small boat (WAP) at distances of about 4-15m. During deployments, the whales occurred in group sizes from 5 to about 50. This is the first time that Antarctic minke whales have been successfully tagged with any form of biotelemetry device.

Collectively, the tags provided data on the movement patterns of the whales at fine and broad scales, detailed dive behaviour and the sounds they made and hear. Some whales remained in relatively small areas for relatively long periods, but others moved large distances over similar time periods (Figures 1 and 2).

Table 1. Biotelemetry devices attached to minke whales during the 2012-13 Antarctic season. Two of the satellite tags are still reporting data.

Tag type	Attachment type	Data type	Deployment date	Minimum transmission/ recording
SPOT 177N	Blubber penetrating	ARGOS location	8-Feb	1 day
SPOT 177N	Blubber penetrating	ARGOS location	8-Feb	13 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	14 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	22 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	42 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	29 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	113+ days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	113+ days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	61 days
SPOT 177N	Blubber penetrating	ARGOS location	9-Feb	113+ days
SPOT 240C	Dorsal fin penetrating	ARGOS location	3-Dec	121 days
SPOT 240C	Dorsal fin penetrating	ARGOS location	4-Dec	32 days
SPOT 240 C	Dorsal fin penetrating	ARGOS location	2-Feb	66 days
SPLASH 292A	Dorsal fin penetrating	ARGOS location+dive	3-Dec	92 days
SPLASH 292A	Dorsal fin penetrating	ARGOS location+dive	6-Feb	51 days
SPLASH 292 A	Dorsal fin penetrating	ARGOS location+dive	11-Feb	31-days
Accusonde	Suction cup	Movement and sound		8 hours
Accusonde	Suction cup	Movement and sound		18 hours

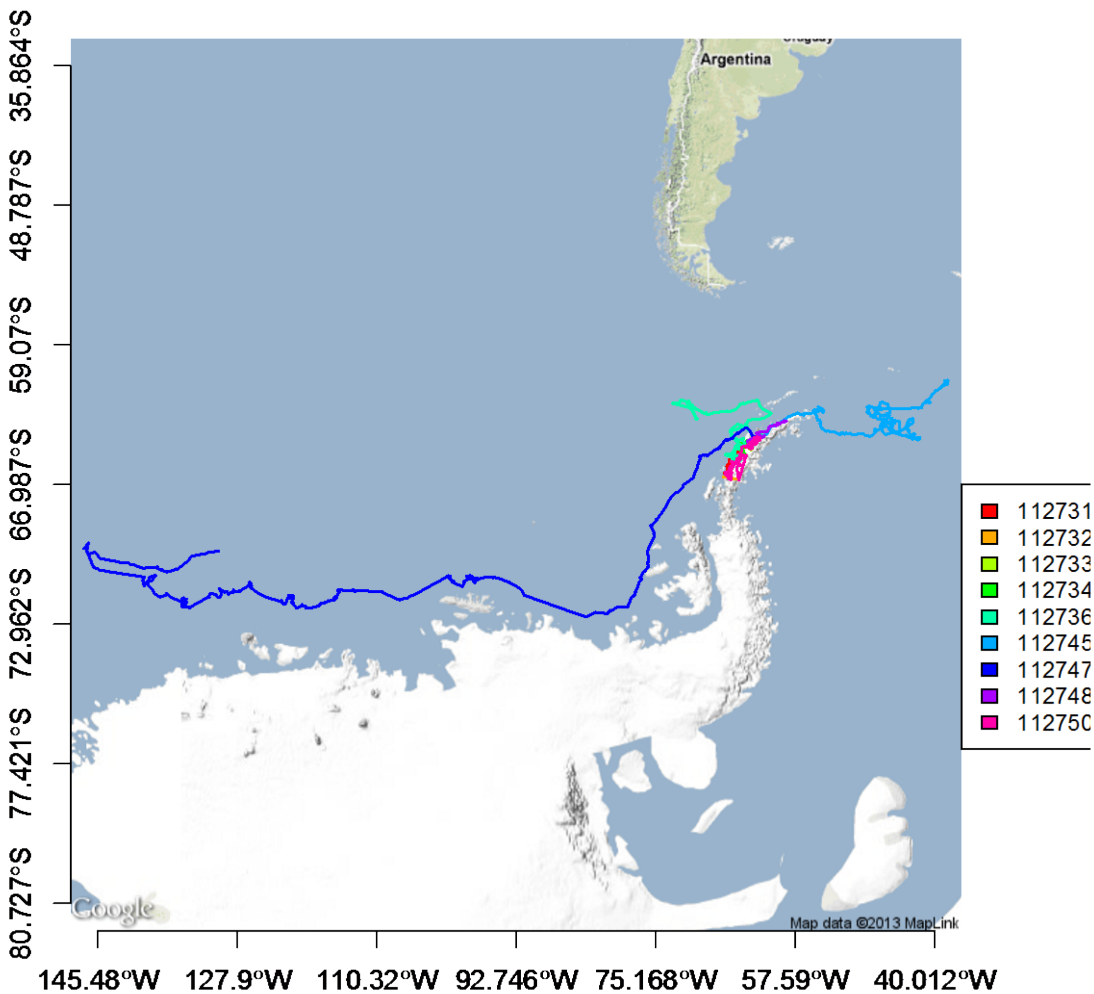

Figure 1. Satellite-derived movements of minke whales tagged with the Wildlife Computers SPOT 177N tags. Deployments are for essentially the same time period as all 10 of these tags were deployed over a period of 2 days, 8-9 February (Table 1). As of the writing of this paper (20 May), 2 of the tags are still active.

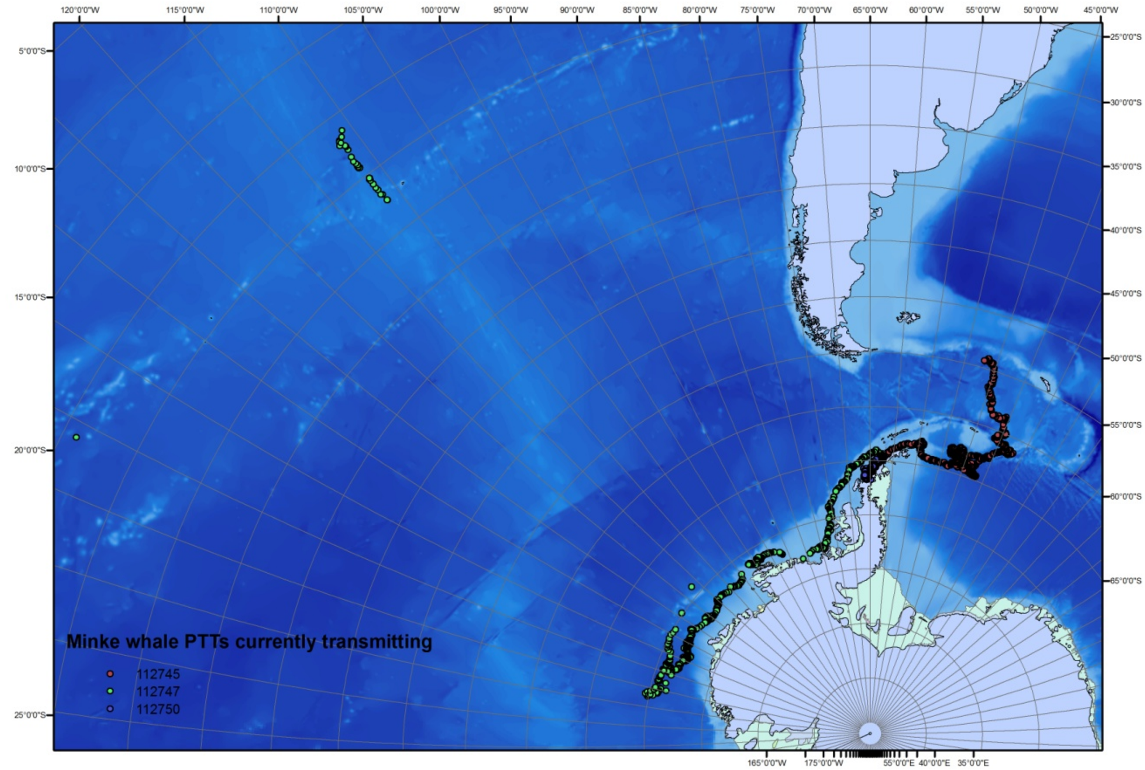

Figure 2(update as of 31 May). 3 tags still transmitting.

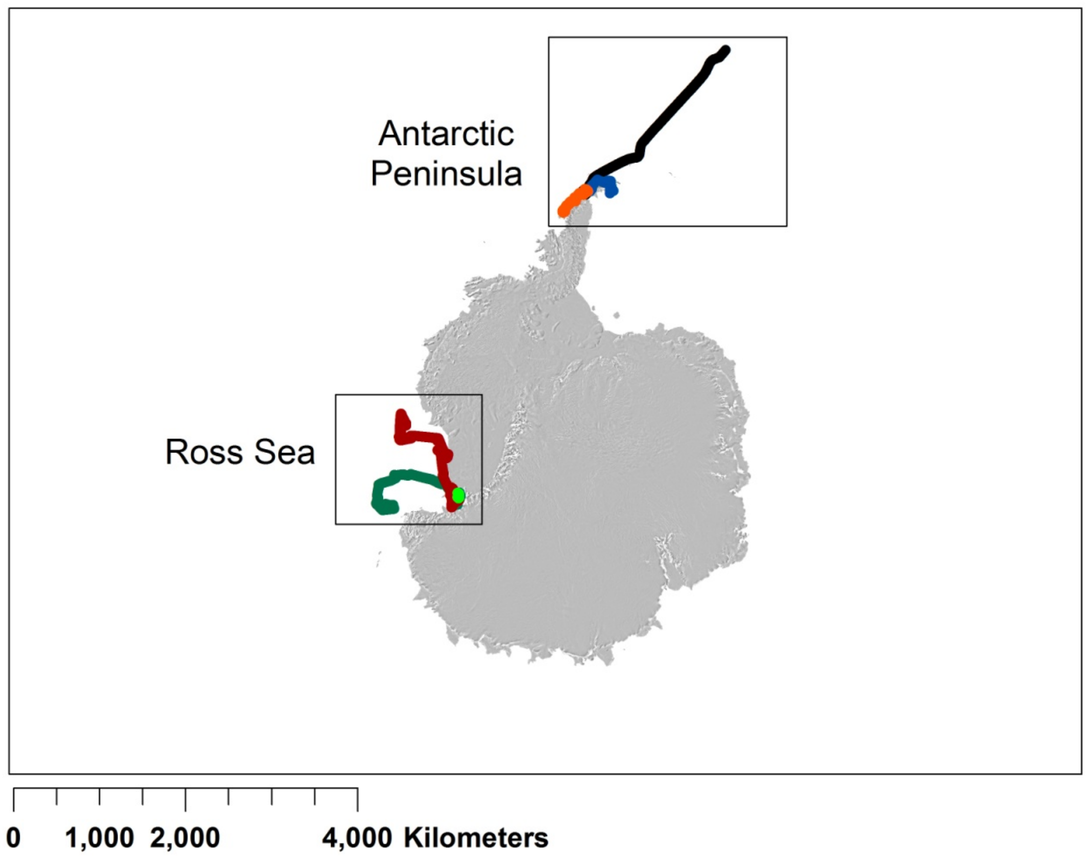

Figure 3a. Maps showing the movement of each of the whales tagged with dorsal fin mounted satellite transmitters over the duration of deployment. The circles represent locations calculated by the Argos satellite system (www.argos-system.org) using a positioning algorithm that employs Kalman filtering of the received frequency measurements (Lopez and Malardé 2011); the size of the circles represents the estimated error radius of each location. The lines are movement tracks estimated by fitting a continuous time correlated random walk model (Johnson et al. 2008) to smooth across the location errors, assuming the estimated error was normally distributed about each calculated location with each standard deviation specified by the associated error radius. Following initial model fitting, the measurement error shock diagnostic of de Jong and Penzer (1998) was used to eliminate significant outliers. The model was then refitted to estimate the complete maximum likelihood track for each animal, which was only partially observed at the time of location estimates. The observed data for each animal was augmented with uniform times on a 1-hour interval. We used the R statistical software (R Development Core Team 2010) to perform all model fitting using the R package crawl (v. 1.3–2), both available from CRAN (http://cran.r-project.org/).

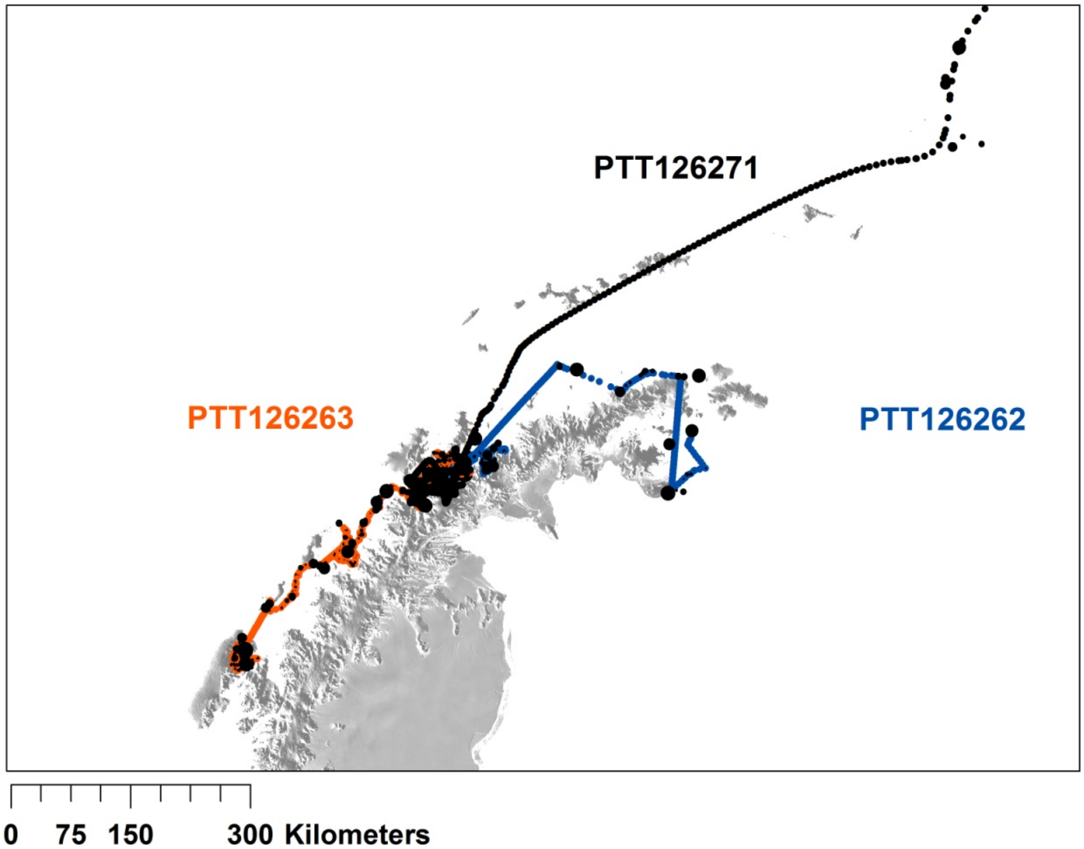

Figure 2b. Detailed satellite derived movement of Antarctic minke whales along the WAP.

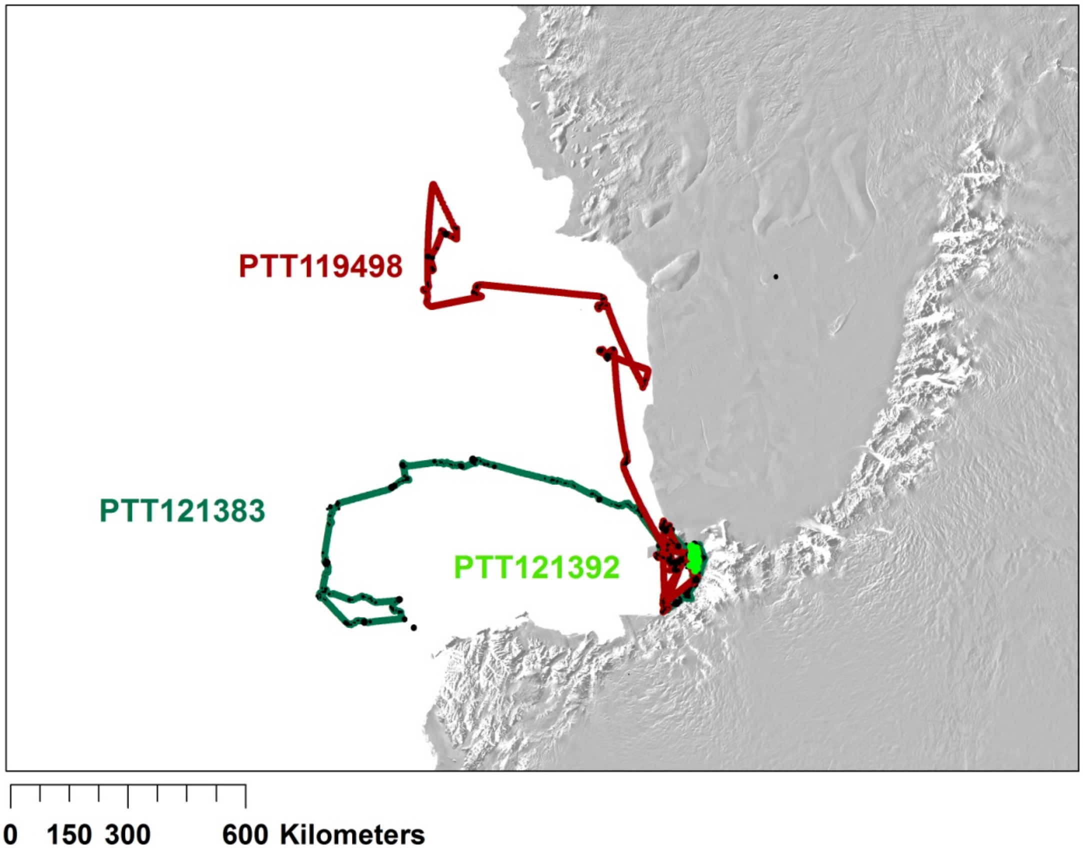

Figure 2c. Detailed satellite derived movements of minke whales tagged in the Ross Sea.

Three of the satellite tags we deployed provided information on diving behavior, which generated additional insight into the movement and habitat use of the tagged whales. The SPLASH 292A satellite and dive-logging tags recorded 5919, 4460 and 1690 dives (Figure 3). In addition, the 27+ hours of data recorded from the two Acousonde™ deployments generated movement patterns and dive behaviour at a very fine scale, including feeding lunges recorded by the accelerometers (Goldbogen et al. 2006). These data can be used to generate feeding rates, which are unknown for minke whales. Finally, these multi-sensor tags also recorded sounds made and heard by the animals. From these data we can generate vocalization rates, which are critical to passive acoustic monitoring (PAM) efforts (see Zimmer 2011). Also, in the appropriate circumstances, good estimates of vocalization rates can be used to generate density estimates of cetaceans (Marques et al. 2009).

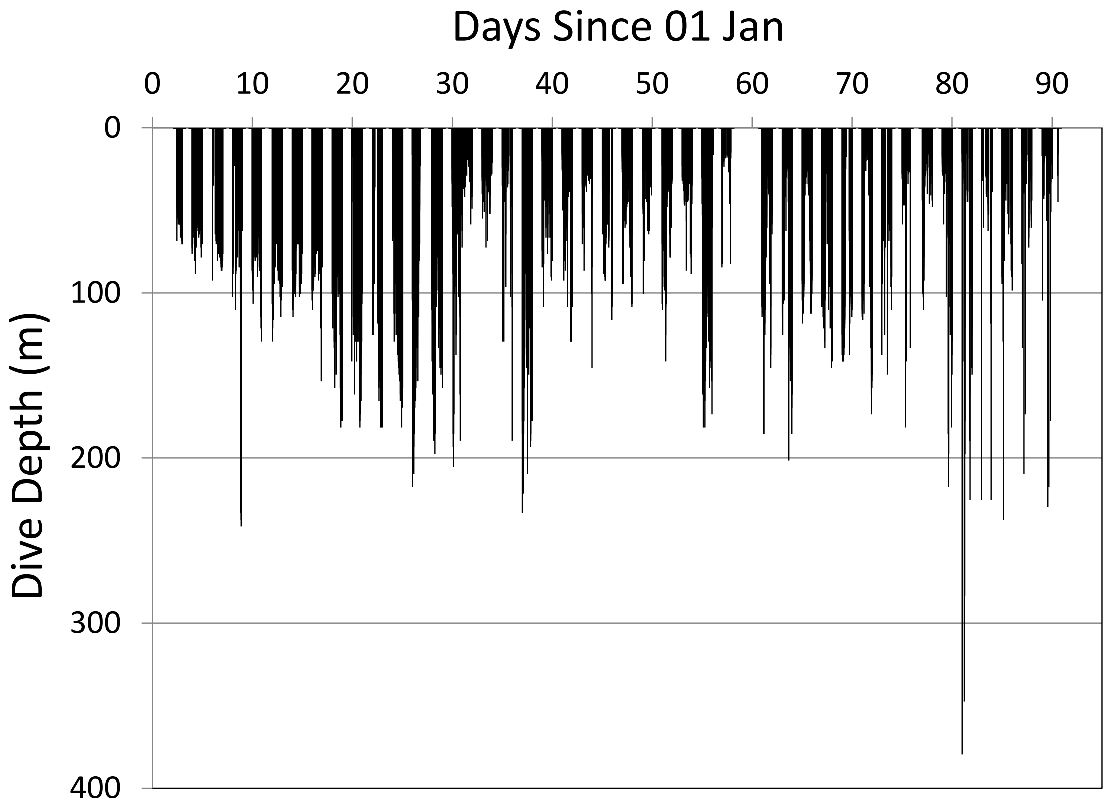

Figure 4. ***Dive-depths for an Antarctic minke whale tagged with a dorsal fin mounted satellite transmitter (SPLASH 292A) in the Ross Sea. The tag was active for 92 days. Gaps in the record reflect the tag's duty cycle: this tag was programmed to record and transmit data every second day to extend battery life.***

Fine-scale diving and kinematic patterns

Two suction-cup multi-sensor archival tags (Acousonde™) were deployed in February 2013 in Wilhelmina Bay (Figure 4). These tags collected 18 and 8 hours of data respectively, and represent the first detailed information on the feeding rates and diving behavior of Antarctic minke whales (Figure 5). Both whales remained in the vicinity of Wilhelmina Bay during their deployments and fed almost continuously. The whales fed at an average depth of 19 meters, reaching a maximum depth of 106 meters. Dives averaged 1.5 minutes, and a maximum of 9.4 minutes. The whales had extremely high lunge rates of up to 112/hour, which is over four times higher than reported for any other baleen whale. As such, the whales filtered water at a rate of approximately 219 m^3/hr, which is 18 times less than for a blue whale in the same period of time at similar depths. In general, a significant positive relationship exists between dive depth and number of lunges as seen in other baleen whales. From our tag data, we find 40 dives containing more than 15 lunges and a maximum number of 24 on a single dive. It appears that minke whale feeding dives can be sorted into several categories based on depth, duration, and lunge counts (Figures 6-7 and Table 2). Two of these dive types do not demonstrate significant positive correlations between depth and lunge count and they warrant further investigation as they may represent alternative feeding strategies heretofore unknown, including under sea ice feeding.

Figure 4. Antarctic minke whale with Acousonde™ multi-sensor suction cup tag, Wilhelmina Bay, Western Antarctic Peninsula.

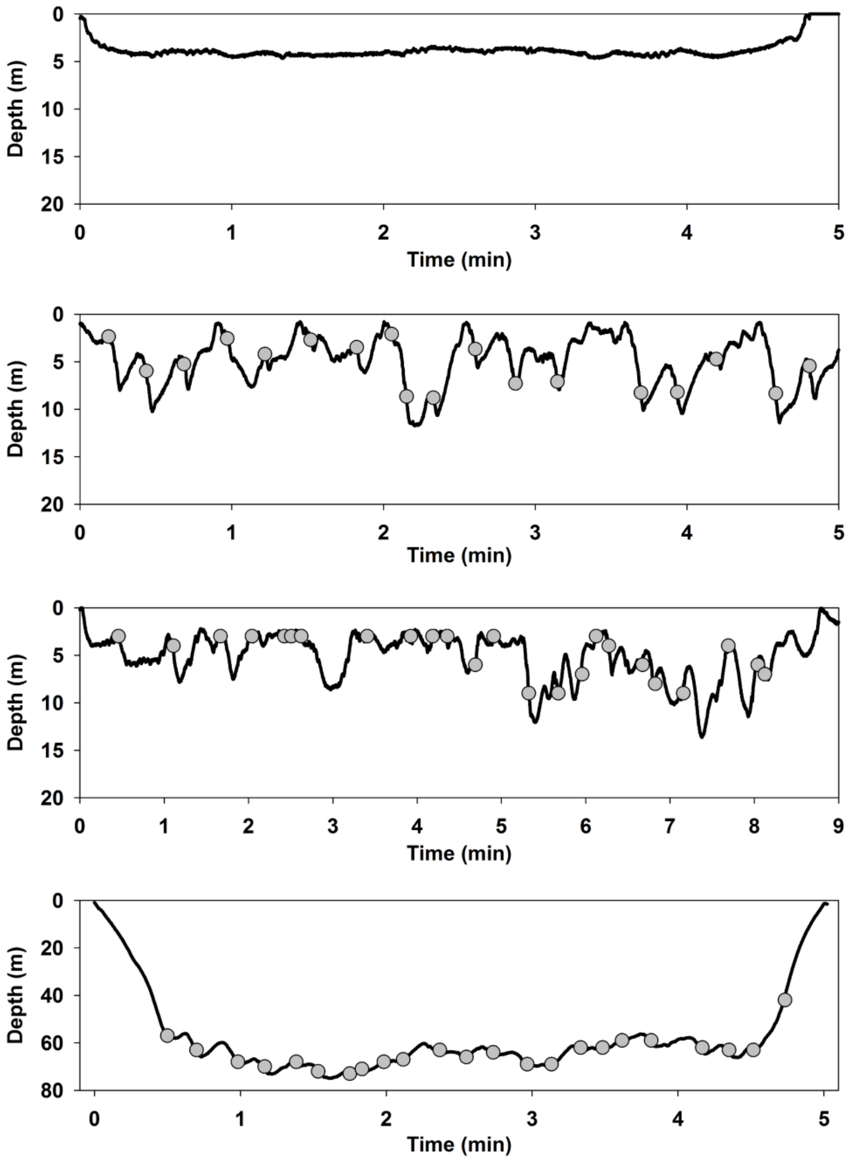

Figure 5. Examples of minke whale dive types (feeding lunges are indicated by grey circles). From the top: a non-feeding dive; a 5-minute series of shallow feeding dives; a 9-minute shallow feeding dive with 24 lunges; a 5-minute deep feeding dive with 23 lunges.

Table 2. *K*-means clustering of minke whale foraging dives determined by dive depth, number of lunges, and dive time.

Dive Cluster	Dive Depth (m)	Lunges/dive	Dive Time (min)
1	24.5	10.4	3.3
2	8.5	2.2	0.8
3	54	14.6	3.9

Distributions Cluster=3

Figure 6. Minke whale dive clusters showing distribution of dive times (left) and number of lunges per dive (right).

Biplot 3D

Figure 7. 3-D biplot of *k*-means clustering of minke whale foraging dives showing three distinct types based on dive time, dive depth, and number of lunges per dive.

Photo-identification

We did not attempt to obtain collect capture-recapture data that would allow us to generate abundance estimates because tagging was our primary aim, but we collected a large sample of photographs of well-marked minke whales. These preliminary data indicate that, with a dedicated effort, it would be possible to use standard photo-identification methods (Urian and Wells 1996) in a capture-recapture framework to generate estimates of abundance, at least on a localized scale (Hammond 1986).

Photo-identification has been used extensively with many species of cetaceans, although rarely with minke whales. Many minke whales had well marked dorsal fins, often with scars from past encounters with lines or fishing gear (Figure 8). We obtained a large number of photos of highly distinctive animals, and are currently estimating *theta*, the proportion of marked animals in the population (Read et al. 2003). As indicated by both the telemetry and photo-identification data sets, the Antarctic minke whale groups were present for multiple days at a time, particularly in the bays and fjords along the WAP, facilitating the planning and execution of a photographic capture-recapture experiment.

Figure 8. Antarcitc minke whale dorsal fin photo-identification photo.

Biopsy sampling

Remote biopsy sampling is a highly effective means of obtaining tissue samples from individual animals, which can be used for analyses of population structure (Baker and Palumbi 1997), diet and life history. We collected 19 biopsy samples from Antarctic minke whales in less than a month of field work, although biopsy sampling was a secondary priority after tag deployments.

Discussion

We devoted a month of research effort to studying humpback and Antarctic minke whales, focusing a subset of that time to working in and around the preferred minke sea ice habitat, and we have demonstrated that detailed non-lethal study of the movements and behavior of this species is feasible. Additionally, even though this was a secondary focus, we collected numerous photo-identification images and 19 skin and blubber biopsy samples with a limited sampling effort. The Ross Sea work was conducted on foot, at the edge of the fast ice in McMurdo Sound, accessed by helicopter; our research in the WAP was conducted from small RHIBs; both platforms were very successful. The presence of large groups of minke whales in the WAP persisted over several weeks extending later in the season (one of our team members, ASF, observed similar behavior one month later in March in the same area). Our experience leads us to conclude that there are excellent opportunities for research with this species in and around a variety of sea ice habitats in the Antarctic. By using modern non-lethal research techniques we can obtain extensive information about the movements, habitat use, abundance and dive and acoustic behavior of this species.

Acknowledgements

We would like to acknowledge support from the National Science Foundation (Award info to ASF, NSF ANT-0944694), the Australian Antarctic Division (Nick?), the National Oceanic and Atmospheric Administration, Lindblad Expeditions and the National Geographic Society. We would like to thank the crew of the *R/V Point Sur* for their impressive efforts in the WAP. This work was conducted under permits (John, Andy, Bob and Nick, insert permit info).

References

Andrews, R., Pitman, R., Ballance, L. 2008 Satellite tracking reveals distinct movement patterns for Type B and Type C killer whales in the southern Ross Sea, Antarctica. Polar Biology 31: 1461-1468.

Baker, C. S. and S. R. Palumbi. 1997. The genetic structure of whale populations: Implications for management. Pages 117-146 *in* A. E. Dizon, S. J. Chivers, and W. F. Perrin, editors. Molecular Genetics of Marine Mammals. Society for Marine Mammalogy.

de Jong, P., and Penzer, J. 1998. Diagnosing Shocks in Time Series. Journal of the American Statistical Association, 93, 796–806.

Durban, J.W., Pitman, R.L. 2012. Antarctic killer whales make rapid, round-trip movements to subtropical waters: evidence for physiological maintenance migrations? Biology Letters 8:274-277.

Goldbogen, J. A., J. Calambokidis, R. E. Shadwick, E. M. Oleson, M. A. McDonald, and J. A. Hildebrand. 2006. Kinematics of foraging dives and lunge-feeding in fin whales. Journal of Experimental Biology **209**:1231-1244.

Johnson, D.S., J.M. London, M.A. Lea, and J.W. Durban. 2008. Continuous-time correlated random walk model for animal telemetry data. Ecology, **89**:1208-1215.

Hammond, P. S. 1986. Estimating the size of naturally marked whale populations using capture-recapture techniques. Reports of the International Whaling Commission **8**:253-282.

Lopez, R., and J.-P. Malardé. 2011. Improving ARGOS Doppler Location Using Kalman Filtering. CLS-DT-MEMO-11-65. www.argos-system.org%2Ffiles%2Fpmedia%2Fpublic%2Fr282_9_technical_paper.pdf

Marques, T. A., L. Thomas, J. Ward, N. DiMarzio, and P. L. Tyack. 2009. Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales. J Acoust Soc Am **125**:1982-1994.

Read, A. J., K. W. Urian, B. Wilson, and D. M. Waples. 2003. Abundance of bottlenose dolphins in the bays, sounds, and estuaries of North Carolina. Mar Mammal Sci **19**:59-073.

Urian, K. W. and R. S. Wells. 1996. Bottlenose dolphin photo-identification workshop. Final report; NOAA technical memorandum Contract No. 40-EUNF-500587, National Marine Fisheries Service, Southeast Fisheries Science Center, Charleston, SC.

Zimmer, W. M. X. 2011. Passive Acoustic Monitoring of Cetaceans. Combridge University Press, Cambridge.