Satellite telemetry derived summer movements of Antarctic blue whales

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ABSTRACT

Movements of Antarctic blue whales on their summer foraging grounds have been described using data from the Discovery marking program, photo identification studies and acoustic recordings. However, these techniques are unable to provide a continuous time-series of actual movements, instead inferring movement from two (or more) known locations at two (or more) separate points in time. As such, the detailed large scale and fine scale movements of Antarctic blue whales remains poorly understood. Satellite tags capable of providing detailed, long-term movement data were deployed on two Antarctic blue whales during the first voyage of the Southern Ocean Research Partnership's (SORP) Antarctic Blue Whale Project. The tags collected movement data for 14 and 74 days tracking each whale over 1433 and 5300 kilometres respectively. Both whales performed long scale movements interspersed with patches of searching, often in close association with the ice edge. These satellite tag derived movements are at the upper range of the within season scale of movement suggested by the Discovery marking program and photo identification studies and corroborate movement between IWC Management Areas. Given the valuable data that can be collected by satellite tags, additional satellite tag deployments on future Antarctic Blue Whale Project affiliated voyages will contribute to a better understanding of both the fine scale and large scale movements of Antarctic blue whales.

Introduction

During the twentieth century, the Antarctic blue whale (*Balaenoptera musculus intermedia*) was targeted heavily by the commercial whaling industry with approximately 346,000 whales killed prior to the end of commercial exploitation in the mid 1960s (IWC, 2009). By this time, the Antarctic blue whale population had been reduced to as low as 0.15% (0.10-0.28%) of its original, pre-exploitation size. There is some evidence to suggest that the Antarctic blue whale population is beginning to recover (Branch et al., 2004). However these analyses employ the use of abundance estimates that are imprecise and more than a decade old leading to the inability to draw strong conclusions (Kelly et al., submitted).

Antarctic blue whale movement has been described using static location information such as that derived from the retrieval of discovery-tagged whales (Branch et al. 2007), photo identification (Olson 2012) or acoustic data (Stafford et al., 2004). These techniques have provided valuable information describing Antarctic blue whale movement in a general sense. For example, retrieval of Discovery marks have found that Antarctic blue whales sometimes disperse widely over time however there is no clear relationship between the distance caught from the marking location in relation to the amount of time passed since marking (Branch et al. 2007). Movements inferred from photo identification studies have indicated that some Antarctic blue whales return to the same IWC Management Area in multiple years whilst others forage widely (Olson, 2012). Antarctic blue whale acoustic recordings indicate continuous circumpolar distribution (Širović et al., 2009) with recordings collected in all months but a decrease in detections during the winter (Širović et al., 2004; McKay et al., 2005). However, Discovery marks, photo identification and acoustic recordings are unable to provide a continuous record of actual movements instead inferring movement from two (or more) known locations at two (or more) separate points in time. Actual movements of the whale between these points in time are not known. As such, movements including large scale migration between breeding and feeding grounds or even fine scale movement within a feeding ground remain poorly understood. Satellite-linked tags can provide detailed, long-term movement data that cannot be provided by any other method.

The Antarctic Blue Whale Project is the flagship programme of the Southern Ocean Research Partnership and aims to undertake research focusing on the role of the Antarctic blue whale in the Southern Ocean ecosystem and to gain an understanding of the recovery of the Antarctic blue whale population. The inaugural voyage of the Antarctic Blue Whale Project (January - March 2013) successfully employed acoustic tracking techniques to detect Antarctic blue whales (Double et al., 2013; Miller et al., 2013). Mark-recapture data was then collected in the form of photo and genetic identification with the aim of contributing to a new Antarctic blue whale abundance estimate (Olson et al., 2013). Additionally, satellite tags were deployed to explore the movements of Antarctic blue whales and to characterise behaviour on the feeding grounds.

Methods

Satellite tag deployment

Satellite tags were deployed on two Antarctic blue whales during the Southern Ocean Research Partnership's Antarctic Blue Whale Voyage in the western Ross Sea, January - March 2013 (see Double et al., 2013). The satellite tags employed comprised of a custom-designed, anchor section (see Gales et al., 2009) joined to a stainless steel housing containing the Spot 200 transmitter manufactured by Wildlife Computers (Redmond, Washington, USA). Satellite tags were deployed using a modified version of the Air Rocket Transmitter System (ARTS, Restech - Heide-Jørgensen et al., 2001) at a pressure of 7.5 – 8.5 bar. Retention teeth on a purpose-designed projectile carrier grip a metal ring fitted to the end of the tag allowing the tag to be fired from the air gun. When the tag makes contact with the whale, the rapid deceleration of the tag and the projectile carrier withdraws the retention teeth releasing the projectile carrier (Double et al., 2010). The metal ring then falls off in time to reduce the drag of the tag. The tag is sterilised with ethylene oxide prior to deployment and implants up to a maximum of 290mm into the skin, blubber, interfacial layers and outer muscle mass of the whale. Retention of the tag is maintained through two actively sprung plates, and a circle of passively deployed 'petals.' Once the tag is immersed in salt water, the salt water switch activates and the tag begins to transmit locations via the Argos satellite system. Tags were duty cycled to a three hour on, three hour off transmission period at a 30 second repetition rate. Each tag was deployed from the bow-sprit of a purpose built 6.3 m aluminium Naiad RHIB and was positioned high on the body, approximately in line with the pectoral fins.

Biopsy collection

At tagging, a small amount of skin and blubber were also collected for genetic analyses. These were collected using a biopsy dart fired from a modified .22 Paxarms system (Krutzen et al., 2002). Most samples included sufficient tissue (biopsy plugs averaged ~ 5 cm in length) to divide and preserve in three ways to maximise analysis potential (All Protect Tissue Reagent - Qiagen, 70% ethanol, and freezing in liquid Nitrogen). DNA was subsequently extracted using a Tissue DNA purification kit for the Maxwell 16 DNA extraction robot (Promega Corporation). The sexes of the tagged whales were determined using a 5' exonuclease assay of the polymorphisms in the sex-linked Zinc Finger genes as described by Morin et al. (2005).

Argos data processing

Argos locations were filtered using an algorithm based on swimming speed, distance between successive locations, and turning angles (Freitas et al., 2008) to remove unlikely position estimates (default thresholds – speed of 2 ms^{-1}, spike angles of 15° and 25°, spike lengths of 2500m and 5000m). A state-space modeling approach using the CRAWL package (Johnson et al., 2008) in R (R Core Team 2013) was employed to smooth the Argos locations due to the dominance of low quality positions (91.7% of all locations were classes 0, A and B) and to obtain an additional 6-hourly position estimate. Great circle distances between locations were calculated in R (R Core Team 2013).

Sea ice concentration

Daily AMSR2 sea ice maps (http://www.iup.uni-bremen.de:8084/amsr2/) were imported into ArcMap10 to produce shapefiles representing the ice edge for track visualisation purposes.

Results

Due to the high priority placed on photo identification and the collection of biopsy samples throughout the Antarctic Blue Whale Voyage, satellite tagging was attempted on approximately four occasions. On the two occasions that satellite tagging was successfully attempted, the animals tagged were within a group (tag 123223 – group size of 4; tag 121205 – group size of 6) and not undertaking directed travel (tag 123223 was presumably feeding at the time of tagging; tag 121205 was interacting socially with other members of the group).

Table 1 summarises whale movements and satellite tag performance from the filtered and smoothed tracking data. Tag 123223, deployed on a female, transmitted intermittently providing tracking data for 40 days across its 74 day lifespan. Tag 121205, deployed on male, transmitted locations continually over 14 days before failing. Examination of temperature data collected by each tag suggests that tag failure was due to tag rejection with the temperature recorded gradually decreasing from approximately 20°C to below O°C towards the end of the tracking period.

Whilst both whales travelled at similar speeds (3.90 kmh^{-1} and 5.86 kmh^{-1} respectively; table 1) and covered a similar distance per day (80.13km and 102.37km per day respectively; table 1), their direction of travel was markedly different. Tag 123223 travelled 616km north post tagging and then proceeded to travel in a westerly direction parallel to the polar front until a temporary pause in transmission (fig. 1). 25 days later the tag began transmitting again locating the whale approximately 100km north of the ice edge but a further 1762km to the west. After an additional 8 day break in transmission, the whale continued heading in a westerly direction, parallel to and just north of the

Table 1: Tag performance and movement summaries calculated from filtered (SDA filter – Freitas et al. 2008) and smoothed (CRAWL – Johnson et al. 2008) Argos location data transmitted by two Antarctic blue whales tagged February – March 2013 in the western Ross Sea, Antarctica. All distances are great circle distance.

	PTT 123223 (*"Markus"*)	**PTT 121205 (*"Henry"*)**
Sex	Female	Male
Date deployed	14/2/2013	8/3/2013
Track duration	74 days (locations transmitted on 40 of 74 days)	14 days
Location deployed	62.00°S, 149.01°E	64.04°S, 168.29°E
Photo identification date	14/2/2013	9/2/2013
Photo identification location	62.06°S, 149.01°E	64.97°S, 143.47°E
Locations per day (mean ± se; range)	7.75 ± 0.90; 1 - 20	12.07 ± 1.58; 3 - 25
Track distance	5300km	1433km
Distance per day (mean ± se)	80.13 ± 7.74km	102.37 ± 9.94km
Speed (mean ± se; max)	3.90 ± 0.16 kmh^{-1}; 34.09 kmh^{-1} max	5.86 ± 0.31 kmh^{-1}; 26.04 kmh^{-1} max
Locations per day (mean ± se; range)	7.75 ± 0.90; 1 - 20	12.07 ± 1.58; 3 - 25
Last transmission date	29/4/2013	21/3/2013
Last transmission location	62.96°S, 73.95°E	68.18°S, 175.59°W

ice edge until the tag failed completely. Whilst tracking along the ice edge, this whale also travelled roughly parallel to the Antarctic circumpolar current. Excluding the initial northwards movement, the dominant direction of travel was westerly covering a track line from IWC Management Area V to Area IV.

Tag 121205 travelled in a south easterly direction post tagging, eventually tracking the ice edge closely for the majority of the 14 day tracking period (fig. 2). Interestingly, this animal was photographed 27 days prior and 1184km to the west of the tagging location (see fig. 2). The general trend in movement for this animal from photo identification on February 9 through to tag failure on March 21 was in an easterly direction, presumably remaining in IWC Management Area V for this entire period of time. Whilst specific analyses have not yet been employed to identify area restricted search behaviour, examination of the track transmitted by tag 121205 (fig. 2) demonstrates distinctive directed travel interspersed with restricted movement more indicative of search behaviour.

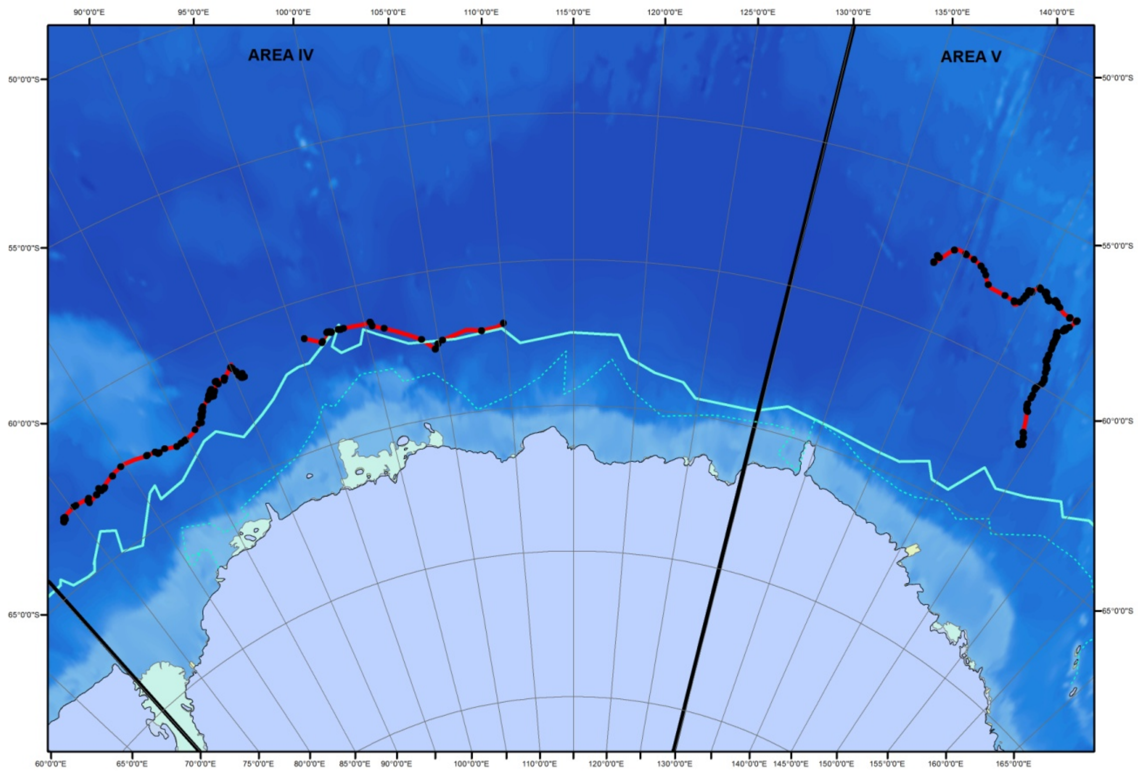

Figure 1. Satellite tag derived movements of Antarctic blue whale: Tag 123223 ("Markus") tagged on the 14/2/2013 at 62.00°S, 149.01°E. The whale proceeded to travel north and then west until a temporary pause in transmissions. 25 days later the tag began transmitting again locating the whale 1762km to the west. After an additional 8 day break in transmission, the whale continued heading in westerly direction until tag failure producing a 74 day track during which locations were received on 40 days. Ice extent at tag deployment (14/2/2013) and tag failure (29/4/2013) is represented by the dashed and solid lines adjacent to the Antarctic coastline. The red line is the smoothed track with an additional location every 6 hours and the black points are the estimates of each smoothed location retained post filtering.

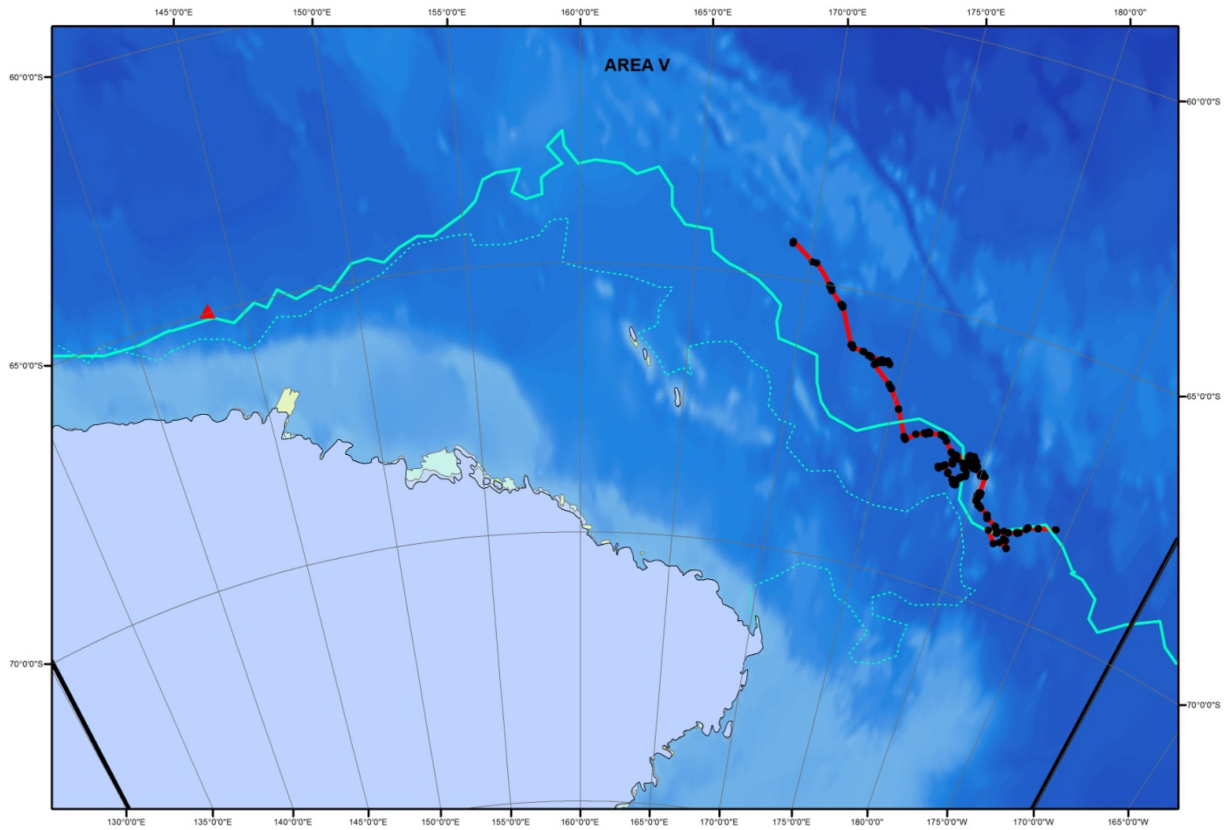

Figure 2. Satellite tag derived movements of Antarctic blue whale: Tag 121205 ("Henry") tagged on the 8/3/2013 at 64.04°S, 168.29°E. The whale proceeded to travel south easterly across the 14 day tracking period. The location at which the whale was photographed on the 9/2/2013 is represented by the red triangle. Ice extent at photo identification (9/2/2013) and tag failure (21/3/2013) is represented by the dashed and solid lines adjacent to the Antarctic coastline. The red line is the smoothed track with an additional location every 6 hours and the black points are the estimates of each smoothed location retained post filtering.

Discussion

Whilst little is known of the large scale or fine scale movements of Antarctic blue whales, discovery marks and photo identification studies have indicated disparate movements with some individuals moving widely whilst others remain close to their marking (Discovery or photographic) location (Branch et al., 2007; Olson, 2012). The satellite telemetry derived movements of Antarctic blue whales described here enable further and detailed description of the summer fine scale and large scale movements of Antarctic blue whales. The scale of Antarctic blue whale movement indicated by this satellite tag data is at the upper range of the within season scale of movement suggested by the Discovery marking program (3 - 100 kilometres per day; see Appendix 4 of Branch et al., 2007) and photo identification studies (10 – 162 kilometres per day; Olson) and corroborates movement between IWC Management Areas.

Similar to their highly studied counterparts in the Northeast Pacific (Mate et al., 1999; Bailey et al., 2009), satellite tagged Antarctic blue whales perform longer scale movements interspersed with patches of searching. For Northeast Pacific blue whales, these patches of searching on feeding grounds were likely related to increased zooplankton biomass (Bailey et al., 2009). For Antarctic blue whales, further study is needed to examine areas of search as related to the physical environment. Of particular interest is productivity associated with the ice edge as both satellite tagged whales interacted closely with the ice edge. Presence along the ice edge as demonstrated by these two tagged whales is in agreement with 30 years of SOWER sightings data where Antarctic blue whale sightings were concentrated at the edge of the pack ice (Branch et al., 2007). However, historical catches of Antarctic blue whales were more broadly distributed, especially in the summer months. Both tagged individuals travelled parallel to the Antarctic circumpolar front however one individual ranged more broadly and travelled parallel to the Antarctic polar front, as the catch data suggests. Considering that both the ice edge and frontal zones play established roles in the foraging of other Antarctic predators (Boyd et al., 2002; Friedlaender et al., 2006; Bost et al., 2009), study of movements relative to frontal systems is also of interest.

To our knowledge, satellite tags have not been deployed on Antarctic blue whales prior to this voyage. As such, the data from these two tags contribute new and valuable information on the small and large scale movements of Antarctic blue whales. The ability to get within tagging range appeared to improve with increasing group size with both tag deployments occurring on individuals within pod sizes of four and five respectively. On both occasions, these pods appeared to be employed in activities that were not related to directed travel (feeding and social interaction). The small boat was able to achieve a range suitable for biopsy collection (within 30m) for individuals employed in directed travel but was not able to achieve the close range (< 10m) needed for satellite tagging.

Considering that Antarctic blue whales are the largest animal to ever have lived, surprisingly little is known of their movements both on feeding grounds and the linkages between feeding and breeding grounds (Branch et al., 2007; Olson, 2012). These satellite tag deployments accomplished by the inaugural voyage of the Southern Ocean Research Partnership's Antarctic Blue Whale Voyage demonstrate the valuable data that can derived from satellite tagging Antarctic blue whales. Further analyses will specifically examine behaviour on the feeding grounds, relate movement to environmental covariates and be used as a first step towards assessment of within and between season capture heterogeneity. As such, this data can contribute to the overall goal of the Antarctic Blue Whale Project to use mark-recapture methods to deliver a new circumpolar abundance estimate for Antarctic blue whales. It is hoped that future Antarctic blue whale voyages can also attempt to satellite tag Antarctic blue whales to build on this preliminary description of movements and fill this large gap in knowledge.

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