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ABSTRACT

Whether the population structure of Antarctic blue whales consists of one or multiple populations is unresolved. A dataset combining Discovery tag (45) and photo-ID (17) inter-seasonal recaptures was examined for ocean basin fidelity and evidence of separate populations. The majority of Antarctic blue whales were recaptured within the ocean basin where they were marked (50-79%) except for the eastern Indian Ocean sector where only 20% of marked whales were recaptured. Six of seven whales with locations north of 60°S were marked and recaptured in the same ocean basin. Four of seven whales with both intra- and inter-seasonal recaptures were always recaptured within the same ocean basin as the original mark. The Antarctic Peninsula may represent a barrier of some sort in the movement patterns of blue whales south of 60°S, based on the shortest distance between mark and recapture points. The mark-recapture distances for individual Antarctic blue whales on the summer feeding grounds were highly variable. Both short and long distances between locations were exhibited by intra-seasonal recaptures. Two satellite tagged whales moved extensively during the summer season, despite periods of area-restricted search behavior assumed to be foraging. Overall, while there was a trend for ocean basin fidelity, due to small sample size these results do not discriminate between a single or multiple population structure for Antarctic blue whales.

KEYWORDS: ANTARCTIC, BLUE WHALE, MARK-RECAPTURE, MOVEMENTS

INTRODUCTION

It is unknown if Antarctic blue whales (*Balaenoptera musculus intermedia*) are comprised of a single population or multiple populations that are separated by ocean basins. Breeding grounds have not been unidentified, although they are assumed to be at low latitude locations, similar to other baleen whales. Likewise it has been assumed that Antarctic blue whales undertake seasonal migrations to these low latitude locations. Antarctic blue whales produce a single song type (Rankin et al. 2005; McDonald et al. 2006), lending support to the hypothesis of a single population. It is detected throughout the Southern Ocean during the summer season (Branch et al. 2007). It has also been detected in the lower latitudes of the Atlantic, Indian, and Pacific Oceans during the winter months (Širović et al. 2018; Samaran et al. 2019).

Genetic studies provide an inconclusive picture. Attard et al. (2016) identified three populations, but when assigning individuals to populations found that the majority of the whales were assigned to a mixture of all three populations. Sremba et al. (2012) did find significant differentiation among the six IWC Management Areas, but at the same time was unable to assign individuals to particular populations. Sample sizes for these studies were small.

To date, mark-recapture data has not yielded a clear picture regarding feeding area site fidelity, with both small and large inter-annual distances between marks and recaptures represented (Branch et al. 2007; Olson et al. 2020). Distances recaptures ranged from 19km to over 5,000km. Data have been available from two sources: Discovery tags (reported by Branch et al. 2007) and photo-ID (reported by Olson et al. 2020). The Discovery marking program and the International Marking Scheme spanned the years 1934-1964, during which marks (a metal tube stamped with a unique number) were fired into Antarctic blue whales and then recovered during whaling efforts. Photo-ID data were collected from multiple research surveys and platforms of opportunity, 1980-2020, and compiled into the Antarctic Blue Whale Catalogue.

In a new study, Rand et al. (2022) used Discovery tag data in Bayesian mark recovery models to estimate inter-seasonal movement rates among three ocean basins (Atlantic, Indian, and Pacific). They found that the majority of whales were recaptured in the same ocean basin (Atlantic 59%, Indian 58%, and Pacific 65%). But the high probabilities of inter-season movement in almost all directions (median 0.08 to 0.28 yr^{-1}) suggested to the authors that there was little evidence for population structure.

Two Antarctic blue whales were satellite tagged in 2013 during a research voyage conducted by the Australian Antarctic Division (Double et al, 2013). These are the only individuals tagged thus far, revealing specific intra-seasonal movement on the feeding grounds. The whales moved >1433km and 5300 km over 14 days and 74 days, respectively, exhibiting speeds associated with both foraging and transiting (Andrews-Goff et al. 2013).

In this study, we combined Discovery tag, photo-ID, and satellite tag data with the goal of determining which hypotheses of population structure and movement is most consistent with the available data. The data are sparse. The objective here is to illustrate patterns in the data rather than establish statistical significance.

METHODS

Two sources of recapture data were used in this study: Discovery tag data and photo-ID data. The Discovery tag data were available from the IWC Secretariat and are also given in Branch et al. (2007, Appendix 4). Photo-ID data were obtained from the Antarctic Blue Whale Catalogue, spanning the years 1980-2020 (Olson et al. 2020; Olson et al. 2021). In all years research was conducted during the austral summer. Both data sources contained inter- and intra-seasonal recaptures.

We investigated the combined data of Discovery tag (45) and photo-ID (17) inter-seasonal recaptures (total 62). The proportion of whales recaptured inter-seasonally relative to the number marked is compared between the Discovery tag data and the photo-ID data. Distances between mark and recapture locations were calculated as the shortest great-circle distance between the two points. Ocean boundaries were separated by the longitudinal meridians 67.16W of 20°E, 146.49°E, and 67.1667.16W (IHO 1953). Over half of the samples came from the Indian Ocean sector, so for this exercise the Indian Ocean was subdivided into western and eastern portions at the 70°E meridian (an accepted division based on the Mid-Indian Ocean Ridge, e.g. Saji et al. (1999)). Data were plotted using GIS and examined for evident patterns of ocean basin fidelity and migratory movement.

Subsets of recapture data were selected by season and by geographic region. These were explored by identifying: 1) locations of whales marked and recaptured inter-seasonally north of 60°S; and 2) whales with long (>2,500km), intermediate (500-2500km), or short (<500km) distances between inter-seasonal mark and recapture locations. The first was to see if these data provide information about possible seasonal (winter) fidelity to locations further north. The second was to explore mark-recapture patterns by ocean basin. The movements of individual whales with both inter- and intra-seasonal recaptures were identified. Examining the movements of individual whales can be useful for insights into population level patterns (Rock et al. 2006; Calambokidis et al. 2009; Kennedy et al. 2012; Galletti et al. 2014).

An additional source of migratory movement data is the potential photo-ID recapture of blue whales from lower latitude locations to the Antarctic. Recent identification photographs made available from researchers in Brazil (n=4) and Uruguay (n=1) were compared to the Antarctic Blue Whale Catalogue (n=552) following methods outlined in Sears et al. (1990).

Satellite tag derived movement data was filtered to remove erroneous locations (argosfilter in R; Freitas et al. 2008) and then a state space model was applied to estimate locations at regular time intervals, while taking into account Argos location error (foieGras in R; Jonsen et al. 2019). A move persistence model was fit to the state-space location estimates of each track separately) (foieGras in R; Jonsen et al. 2019). The move persistence model estimates the time-varying autocorrelation in speed and directionality along the track generating a move persistence value (gamma) at each location. Move persistence ranges along a continuum between 0 and 1 - move persistence values approaching 1 indicated directed travel (transit) and move persistence values approaching 0 represent slower, tortuous movements (area restricted search; Jonsen et al. 2019).

RESULTS

Mark-recapture data

In the Discovery tag data 2,295 Antarctic blue whales were marked and 45 were recaptured inter-seasonally for a percentage of 2%. In the photo-ID data, 410 whales were marked (photographically captured) on the left side and 404 on the right side. Inter-seasonal recaptures, 11 and 14 respectively, resulted in a 3% recapture percentage for both left and right sides.

The majority of the blue whales were recaptured within the ocean basin where the individual was marked. Only in the eastern Indian Ocean was the proportion of whales marked and recaptured within that basin less than 0.5 (Table 1). The high proportion of within-basin recaptures in the Atlantic Ocean sector is due in part to the recaptures at South Georgia. One whale marked in the Atlantic was recaptured in the Pacific, just beyond the Indian Ocean-Pacific Ocean boundary. Other than this individual there were no other whales linked between the Atlantic and Pacific Oceans.

The distances between inter-seasonal marks and recaptures were highly variable, ranging from 19km to 5,579km (great-circle distances). Whales marked in the Atlantic sector had the fewest long distance (>2,500km) recaptures (n=2) and whales marked in the Pacific had the most (n=7) (Table 2). The inverse was true for whales with short distance (<500km) recaptures, with 6 marked in the Atlantic and 2 marked in the Pacific. The majority of whales had recaptures of intermediate distances (500-2,500km).

Table 1. Numbers of individual whales recaptured inter-seasonally (Discovery tags and photo-ID) in each ocean basin.

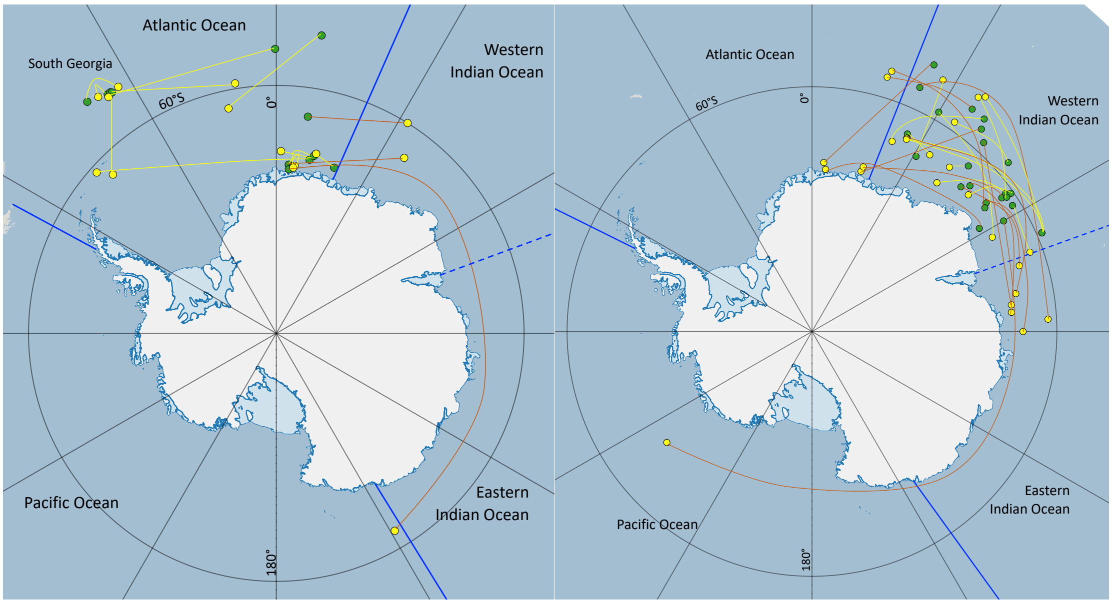
Ocean basin marked	No. of whales marked	Recaptured Atlantic Ocean	Recaptured Western Indian Ocean	Recaptured Eastern Indian Ocean	Recaptured Pacific Ocean	Proportion recaptured in same ocean basin
Atlantic	14	11	2	0	1	0.7857
Western Indian	26	6	13	6	1	0.5
Eastern Indian	10	2	2	2	4	0.2
Pacific	12	0	1	4	7	0.5833

Table 2. Number of whales marked (Discovery tags and photo-ID) in each ocean basin with long (>2,500km), intermediate (500-2,500km), and short (<500km) distances between mark and inter-seasonal recapture location.

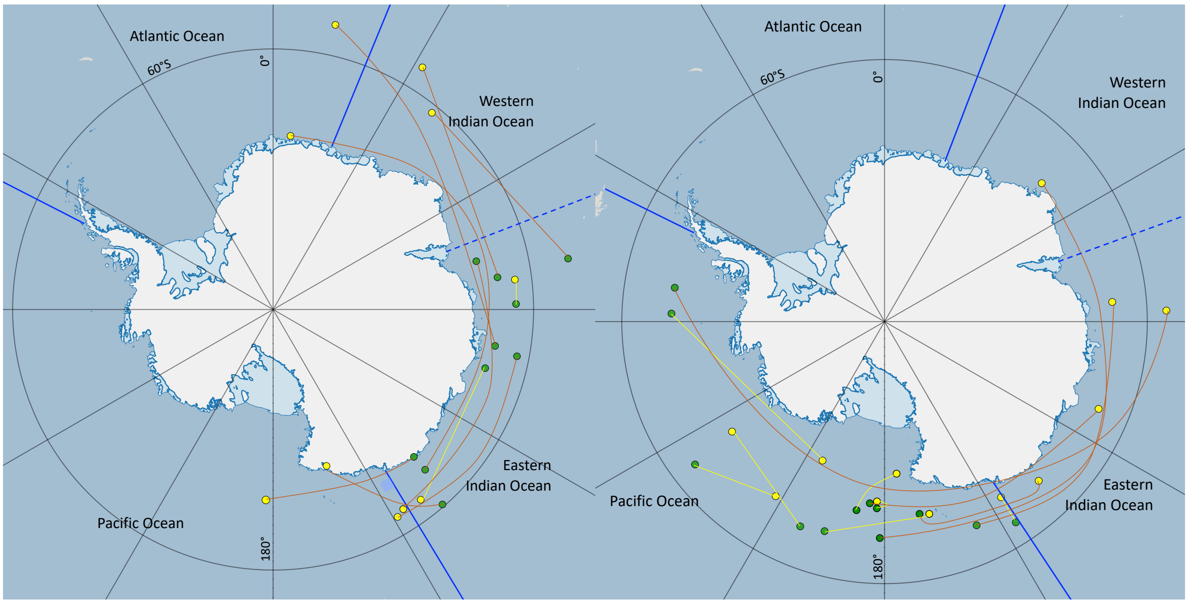
	No. of whales		
Ocean basin marked	Long distances between locations	Intermediate distances between locations	Short distances between locations
Atlantic	2	6	6
Western Indian	3	21	2
Eastern Indian	4	5	1
Pacific	7	3	2

Within the Atlantic, the mean distance between mark and recapture was 1,338km (SD=1,361); within the western Indian 1,726km (SD=1,066); within the eastern Indian 2,481km (SD=1,309); and within the Pacific 2,687km (SD=1,784).

The locations of whales marked in each ocean basin and their respective inter-seasonal recapture locations are shown in Figures 1a-d. Lines connect the mark (green circle) and recapture (yellow circle) points and do not represent whale movement. Yellow lines connect points recaptured within the same basin as marked, and orange lines connect points recaptured in different ocean basins. Blue lines demarcate the longitudinal boundaries between the basins.



Figures 1a and 1b. Locations of Antarctic blue whales marked (Discovery tags and photo-ID) in the Atlantic Ocean sector (left) and marked in the western Indian Ocean sector (right) and their respective inter-seasonal recapture locations.



Figures 1c and d. Locations of Antarctic blue whales marked (Discovery tags and photo-ID) in the eastern Indian Ocean sector (left) and Pacific Ocean sector (right) and their respective inter-seasonal recapture locations.

The vast majority of the inter-seasonal marks and recaptures were south of 60°S. But seven whales were marked and recaptured north of 60°S (all with Discovery tags; Figure 2). Six whales were recaptured in the same ocean basin where they were marked; one whale marked in the western Indian Ocean was recaptured in the Atlantic.

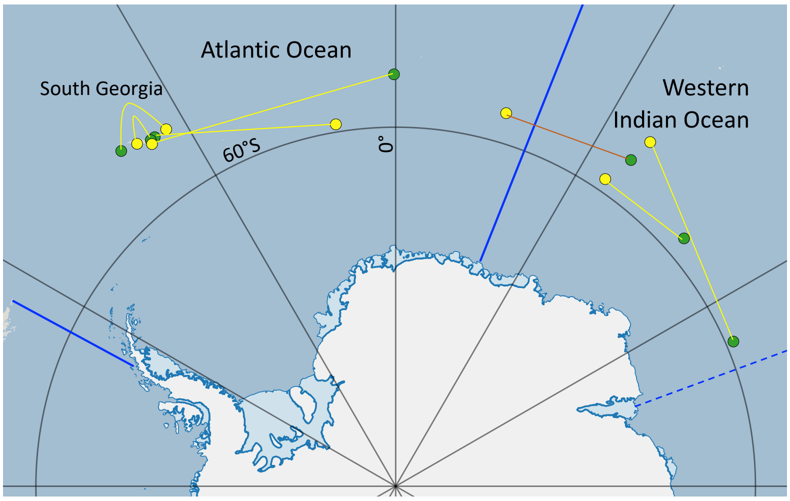


Figure 2. Locations of Antarctic blue whales marked and recaptured (Discovery tags) inter-seasonally north of 60°S. (Symbols and lines are colored as in Figure 1.)

In the photo-ID data, seven whales had both inter- and intra-seasonal recaptures. The inter- and intra-recapture locations of six of the whales were generally in the same regions as their initial capture Figures 3a and 3b). One whale was recaptured 144 longitudinal degrees from its location six years prior (Figure 3c).

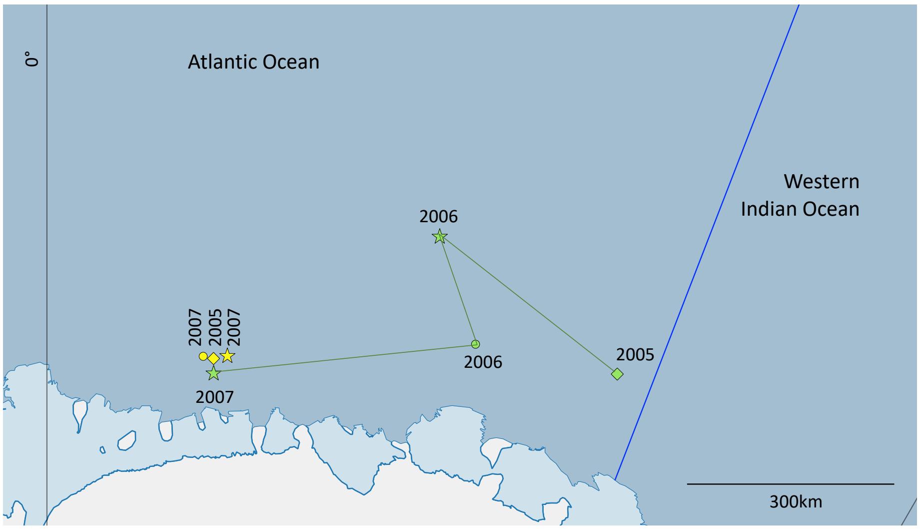


Figure 3a. Locations of two individual Antarctic blue whales marked and recaptured (photo-ID) intra- and inter-seasonally (represented by green or yellow). A diamond shape indicates the initial mark, a circle represents an intra-seasonal recapture, and a star indicates an inter-seasonal recapture.

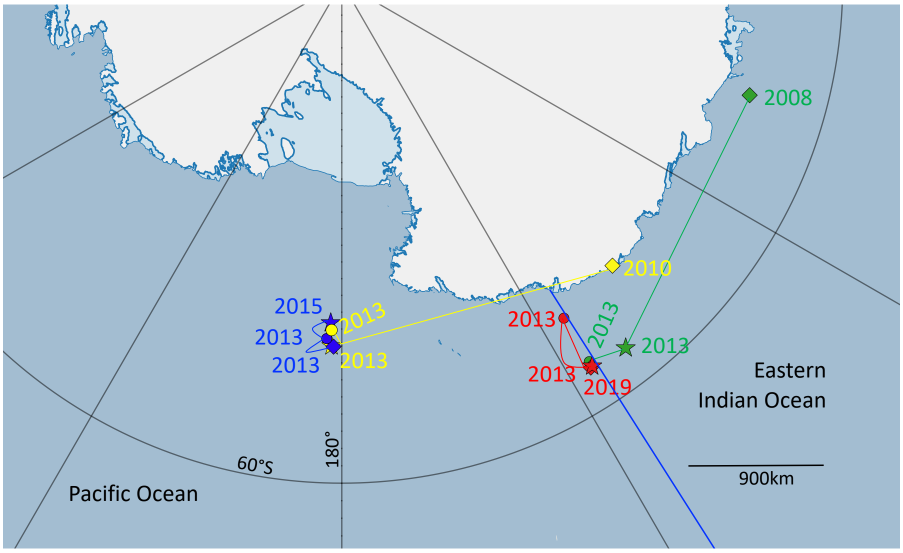


Figure 3b. Locations of four individual Antarctic blue whales marked and recaptured (photo-ID) intra- and inter-seasonally (represented by blue, yellow, red, or green). (Symbol shapes are the same as Figure 3a.)

Figure 3c. Locations of an individual Antarctic blue whale marked and recaptured (photo-ID) intra- and inter-seasonally. (Symbol shapes are the same as Figure 3a.)

No matches were found from the comparisons of identification photographs between Brazil (n=4), Uruguay (n=1), and the Antarctic Blue Whale Catalogue (n=552).

Satellite tag data
The application of the move persistence model to the two satellite tracks shows where the whales were likely feeding vs. transiting (Figures 4 and 5).

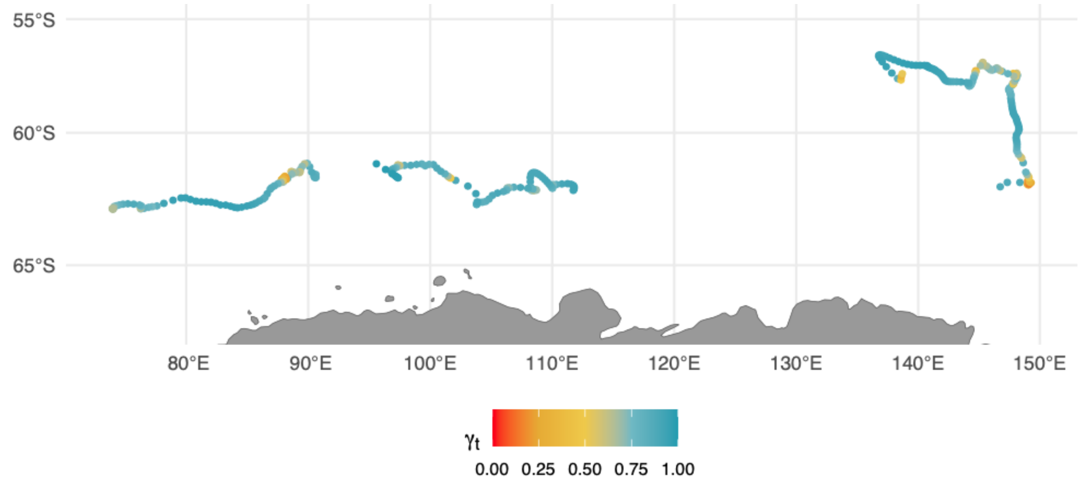


Figure 4. Satellite tag derived movements of Markus - PTT 123223, color coded by move persistence. Values approaching zero (warm colors) indicate area-restricted search (possible feeding areas), while values approaching 1 (cool colors) indicate periods of transit from one region to another.

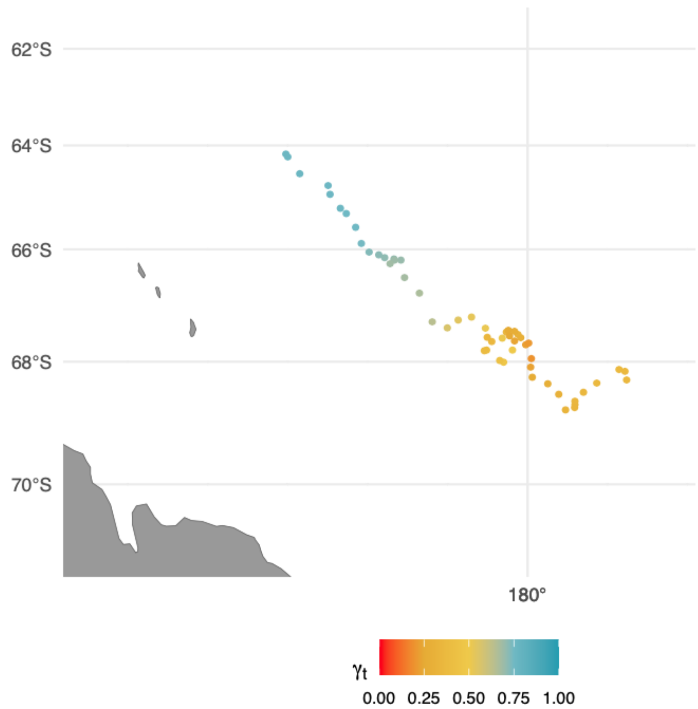


Figure 5. Satellite tag derived movements of Henry - PTT 121205, color coded by move persistence. Values approaching zero (warm colors) indicate area-restricted search (possible feeding areas), while values approaching 1 (cool colors) indicate periods of transit from one region to another.

Analysis of the satellite tag data suggest that Antarctic blue whales move directionally along the ice edge, covering extensive distances. One whale, PTT 123223 (tagged 320 km from the ice edge), initially travelled north and then west for a minimum of 6107km across 74 days. The other whale, PTT 121205 (tagged 200km from the ice edge), covered 1287km in a south easterly direction over 13 days. Average travel speed also differed with PTT 123223 travelling at a lower speed (2.2 ± 0.8 kmh^{-1} - mostly due to the northward leg of the track) than PTT 121205 (4.0 ± 0.3 kmh^{-1}). Excluding the initial northwards movement by PTT 123223, the dominant direction of travel covered a track line westward, remaining around 130km from the ice edge and through an area bordered to the north by the polar front and to the south by the Antarctic circumpolar current. PTT 121205 tracked the ice edge closely (62.95 ± 60.75 km) for the majority of the 14 day tracking period.

Additionally, the two satellite tagged whales had photographic recaptures that added location data to their movement tracks (Figure 6).

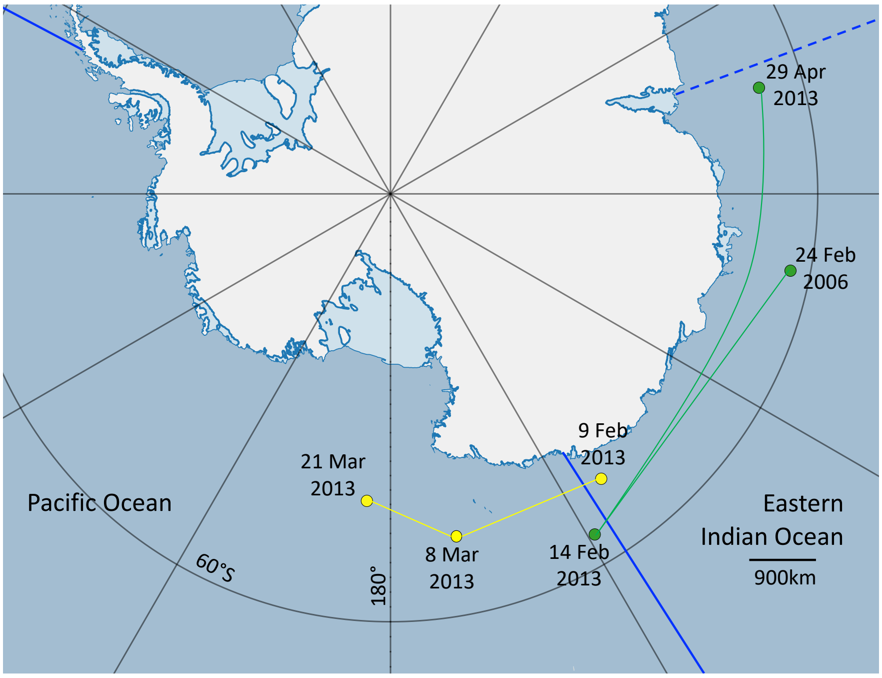


Figure 6. Locations of two individual Antarctic blue whales that were satellite tagged and were also marked and recaptured either intra- or inter-seasonally . The whale represented in yellow (121205) was marked on 9 February 2013 prior to being recaptured and tagged on 8 March. The last tag transmission occurred on 21 March. The whale represented in green (PTT 123223) was marked in 2006, then recaptured and tagged on 14 February 2013. The last tag transmission occurred on 29 April 2013. Lines connect the points and do not represent whale movement.

DISCUSSION

Most of the recaptured blue whales were marked and recaptured in the same ocean basin. Three of four basins had recapture proportions ≥ 0.50. This is comparable to the proportions found in by Rand et al. (2022) (and not surprising since both studies used Discovery tag data). Basin fidelity north of 60°S was more evident, where six of seven whales with marks and recaptures north of 60°S were recaptured within the same ocean basin. Of the seven whales with both intra- and inter-seasonal recaptures, four were always recaptured within the same ocean basin as the original mark. Although there was a trend for ocean basin fidelity, due to small sample size these results do not discriminate between a single or multiple population structure for Antarctic blue whales.

The smaller percentage of inter-seasonal recaptures in the Discovery data (2%), would be expected if the population was larger during whaling years than during the later photo-ID years. Left and right side recaptures in the photo-ID data yielded 3%.

In contrast to the Atlantic basin, where 79% of the marked whales were recaptured in the same basin, in the eastern Indian Ocean only 20% were recaptured in the same basin. The eastern Indian appears to be a region through which most blue whales are transiting. Presumably these whales were moving toward more productive feeding areas further east or west. This is exemplified by the individual whale with satellite tag PTT123233

(Figures 4 and 6) that spent the majority of its time transiting. The location of the initial photo-ID capture, in 2006, is 2,481km across the eastern Indian Ocean from where the whale was recaptured (and tagged) in 2013.

Fidelity to specific feeding grounds south of 60°S by individual whales was not evident in these data. The movement patterns of individual Antarctic blue whales on the summer feeding grounds were highly variable, with both short and long distances between recapture locations exhibited by intra-seasonal recaptures. Both of the satellite tagged whales moved extensively during the summer season, despite having time periods of area-restricted search assumed to be spent feeding. Variability is notably demonstrated by the whale that was recaptured multiple times in 2007 in almost the same location, and then recaptured in 2013 at a location 144 longitudinal degrees and over 5,000km distant (Figure 3c).

Long-range movements by Antarctic blue whales on the feeding grounds does not preclude whales from maintaining fidelity to low-latitude wintering grounds, especially within the same ocean basin. Other populations of blue whales, such as those in the northeast Pacific, the northwest Atlantic, and the Great Australian Bight, move long distances well over 2,000km in their summer feeding areas (Calambokidis et al. 2009; Ramp and Sears 2013; Möller et al. 2020). It is plausible for Antarctic whales to forage widely south of 60°S, for thousands of kilometers, and then return northward into the same ocean basin from which they originated earlier in the season.

The Antarctic Peninsula may represent a barrier of some sort in the movement patterns of blue whales south of 60°S. Based on the shortest distance between inter-seasonal mark and recapture locations, only one whale marked in the Pacific and recaptured in the eastern Indian Ocean, could arguably have moved either direction around the Antarctic continent, thus crossing the Antarctic Peninsula. Furthermore, no whales marked in the Pacific were recaptured in the Atlantic, and only one whale marked in the Atlantic was recaptured in the Pacific, although just over the boundary into the Pacific sector (Figure 3c).

The data are sparse and speculation is based on observations of the data currently available. Future research will reinforce or refute these assessments.

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