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ABSTRACT

Satellite transmitters were attached to seven southern right whales (*Eubalaena australis*) in their breeding grounds in Golfo Nuevo, Península Valdés, Argentina, to monitor their movements and migration towards feeding destinations. Five fully implanted tags, deployed in two mothers and three juveniles, transmitted for a to-date average of 93 days (range: 23-212 days), with one tag still transmitting by the time this report was completed. The migratory movements of four whales were documented and showed substantial individual variation. These individuals visited the outer Patagonian shelf east of Península Valdés and north of the Falkland/Malvinas Islands, the Scotia Sea near South Georgia/Islas Georgia del Sur and the South Sandwich Islands/Islas Sandwich del Sur, and western South Atlantic basin between 38 and 58°S. State-space models were used to estimate behavioral states and suggested areas of potential foraging importance in the Patagonian shelf, the subtropical convergence and the continental shelf break east of South Georgia/Islas Georgia del Sur.

KEYWORDS: SATELLITE TAGGING, SOUTHERN RIGHT WHALES, WESTERN SOUTH ATLANTIC, MIGRATION, FEEDING GROUNDS

INTRODUCTION

Southern right whales (SRWs) were historically targeted by whaling and were depleted to near extinction by the late 1800s (IWC, 2001; 2013). This species is now fully protected and for more than fifty years has been recovering (Best et al., 1993; Cooke et al., 2001; IWC, 2001; 2013). In 1998, the IWC held a workshop on the Comprehensive Assessment of right whales and agreed to divide the Southern Hemisphere into 11 management units for southern right whales based on the distribution patterns and locations of breeding aggregations (IWC, 2001). One of these units corresponded to breeding grounds off Península Valdés (PV), Argentina, which houses the largest aggregations of southern right whales in the western South Atlantic Ocean. Abundance in this region was estimated at nearly 4,200 individuals in 2009 with an annual growth rate of 6-7% over the past 40 years (Cooke et al., 2001; Crespo et al., 2011; Cooke, 2013; IWC, 2013).

Whales in PV have died in unprecedented numbers over the past decade, primarily impacting calves under 3 months of age and with a significant variation in number from year to year (IWC, 2011; Rowntree et al., 2013). Causes for this high mortality are unknown but there is concern that it is affecting population growth rates (Marón et al., 2015). A workshop led by the International Whaling Commission in 2010 (IWC, 2011) suggested three leading hypothesis to explain the mortality of calves and to focus research efforts: mortality is a consequence of (1) poor nutritional state of the mothers, (2) exposure to harmful algal bloom (HAB) and/or bacteria-associated biotoxins in the feeding or calving grounds, and (3) infectious pathogens. Histology, toxicology, bacteriology, and virology carried out on tissues of dead whales to date have so far produced inconclusive results (McAloose et al., 2011, 2014; Rosas et al., 2012; Torres et al., 2015). Similarly, gull attacks that severely disturb the behavior of these whales, especially calves, causing significant skin wounds have also been assessed although no evidence has yet been found that they are a direct cause of mortality (Marón et al. 2014, Rowntree et al. 1998; Sironi et al. 2009; Thomas et al., 2013). The thinking is that there may be a suite of interacting casual factors, including resource limitation in feeding grounds, and habitat pollution (i.e., harmful algal blooms), and harassment by seagulls at the nursing grounds. In the first workshop in 2010 and as part of the Conservation Management Plan for South Atlantic Right Whales, satellite telemetry to identify feeding areas was identified as a high priority project. Participants in the Second Workshop on Mortality of Southern Right Whales at PV, hosted by the IWC and held in Puerto Madryn, Chubut, Argentina in August 2014 reiterated the recommendation for "increased telemetry work to identify feeding areas" (SC/66a/Rep8).

Because right whales in normal reproductive cycles calve every three years (but they calve every two years if they have lost a calf, Marón et al., 2015), and because mortality differs widely between years (Rowntree et al., 2013) there is still an untested hypothesis of family-associated mortality (e.g., maternal lineage directed fidelity to feeding areas). Nonetheless, it is of important value to have baseline information about migration routes and feeding grounds for this population.

All working hypothesis require thorough knowledge about the location of SRW feeding grounds, and the migratory corridors that connect them to the calving and nursing grounds where the animals have historically been observed and studied. Several feeding grounds have been suggested for these right whales in the Southwest Atlantic, based on historical catch records, with different prey species consumed at different latitudes and regions, but the precise information on the location(s) and utilization of the main feeding grounds for this whale population is still poorly known. As these locations are determined, the scientific community can then focus on characterizing such habitats from an environmental and ecological perspective, providing information on the availability and seasonality of resources, and exposure to toxins, pollution and infectious agents along the entire migratory habitats of this population of southern right whales breeding in southeastern South America. The IWC's South Atlantic Right Whale Conservation Management Plan (SARW CMP) highlights that it is a top priority to determine local movements within the PV calving ground, the location of feeding ground(s) in the South Atlantic Ocean, and the migratory routes between these calving and feeding grounds.

All working hypothesis require thorough knowledge about the location of SRW feeding grounds, and the migratory corridors that connect them to the calving and nursing grounds where the animals have historically been observed and studied. Several feeding grounds have been suggested for these right whales in the west South Atlantic, based on genetic and isotopic evidence (Rowntree et al., 2008; Valenzuela et al., 2009), on sightings of photo identified individuals (Best et al., 1993) and on historical catch records (Tormosov et al., 1998), with different prey species consumed at different latitudes and regions, but the precise information on the location(s) and utilization of the main feeding grounds for this whale population is still poorly known. As these locations are determined, the scientific community can then focus on characterizing such habitats from an environmental and ecological perspective, providing information on the availability and seasonality of resources, and exposure to toxins, pollution, infectious agents and human induced threats (eg, shipping, fishing) along the entire migratory habitats of this population. The IWC's South Atlantic Right Whale Conservation Management Plan (SARW CMP) highlights that it is a top priority to determine local movements within the PV calving ground, the location of feeding ground(s) in the South Atlantic Ocean, and the migratory routes between calving and feeding grounds.

The goals of this work were to investigate the feasibility of tagging southern right whales using transdermal satellite tags near PV and to determine migratory routes and feeding destination of SRWs wintering in this region.

MATERIALS AND METHODS

Transdermal configurations of Wildlife Computers' location-only (SPOT5) and archival (SPLASH10) Argos satellite tags were deployed in SRWs in Golfo Nuevo, PV, Argentina (Fig. 1). The electronic components of these tags were cast in a 290mm in length and 24mm in diameter surgical quality stainless steel housing. Anchoring of the tags was provided by an identical version of the system developed by Gales et al. (2009), except that head of the tag was fixed (as opposed to articulated) and the anchor and transmitter components of the tag were fully integrated as described in Robbins et al. (2013) and Zerbini et al. (2013).

Tag deployment was conducted between 6-20 October 2014 from the bow of rigid-hull inflatable boats or from a fiber-glass speedboat at distances ranging from 3-8 m. Tags were deployed with a custom-modified pneumatic line thrower (Heide-Jørgensen et al., 2001; Gales et al., 2009) set to pressures ranging from 10-20 bar. A projectile carrier was attached to the posterior end of the transmitter by retention teeth. The rapid deceleration of the tag and carrier as they strike the whale leads to the withdrawal of the retention teeth that hold the tag to the carrier and their subsequent disengagement (Gales et al., 2009). In three cases, biopsy skin samples were collected concurrently to tag deployment with a crossbow for genetic characterization, but these samples have not yet been analyzed. Sex of tagged individuals was determined by their role in a social group (e.g. mother with a calf) or, whenever possible, by examination of photographs of the genital area of a tagged whale. Individuals were followed for nearly one hour after tagging to assess their behavior and to obtain photographs of their callosity patterns for photoidentification and of the tag site.

Satellite tags were programmed to maximize data transmission in periods that coincided with Argos satellite overpasses. SPOT5 tags were programed to transmit every day during from 1:00 to 14:00 and from 19:00 to 23:00, for a maximum of 600 transmissions per day during the entire duration of the deployment. SPLASH tags were programed according to the same daily cycle, but the number of transmissions per day was set at 500. These tags were also duty cycled to increase tag longevity. Transmissions were sent every day for the first three months of deployment and every second day for subsequent months. SPLASH tags provide, in addition to location data, temperature at depth, dive at depth, and dive profiles (time series and behavioral log). Only spatial (location) information is presented in this report.

Argos location data presented in this document were filtered using the R package 'argosfilter' (Freitas et al., 2008; R Development Team, 2013), which remove locations considered 'unrealistic' based on speed, distance, and turning angles of successive locations, assuming a maximum swimming speed of 12km/h. Argos locations type 3, 2, 1, 0, A, and B were included in the analysis. A switching state-space model (SSSM) (Jonsen et al., 2005, 2007; Bailey et al., 2009) was applied to the raw Argos data. This model allows for location estimates to be inferred from the observed Argos locations by accounting for measurement errors and from the dynamics of the movement process (Patterson *et al.*, 2008). Two behavioral modes were estimated and were assumed to represent transiting (mode 1) and 'area restricted search' (ARS) behavior (mode 2). The model was fit to the filtered Argos data using package 'bsam' in R (Jonsen et al., 2013; R Development Core Team, 2013) within a Bayesian framework. This package fits the SSSM using Markov Chain Monte Carlo (MCMC) simulations via software JAGS (Plummer, 2003). A time step of six hours was specified to obtain predicted locations. Two MCMC chains were run in parallel, each for a total of 20,000 samples. The first 10,000 were discarded as a burn-in. The posterior distribution of behavioral modes was approximated by retaining every 20^{th} sample in the remaining chain to reduce auto-correlation (thus keeping 500 samples from each chain). While two behavioral modes were estimated for each MCMC simulation, the means of the MCMC samples provided a continuous value from 1 to 2 for each location predicted by the model. We assumed the behavioral state to correspond to ARS if the posterior mean at each location was >1.75, as transiting if the mean was <1.25, and as uncertain otherwise (Jonsen et al., 2007; Bailey et al., 2009). In this document locations estimated as ARS behavior were used to estimate high-use habitats by SRWs.

RESULTS AND DISCUSSION

Seven tags were deployed on three juveniles and four mother right whales in Golfo Nuevo, PV (Table 1, Fig. 1). The two first deployed tags (PTT 111867, 111870) achieved only 10-15% penetration and were shed within a day since tagging. These are not considered further here. Another five tags were fully implanted and one was still providing transmissions by the time this report was finished (PTT 120950/Papillon). Duration of these five tags ranged from 23 to 212 days, with a current average and mean durations of 93 and 71 days, respectively (Table 1). Longer lasting tags were those that achieved a more perpendicular penetration.

One whale (Helena, PTT 120201), a female with a calf at the time of tagging, only transmitted for 23 days while this individual was still in Golfo Nuevo. The four remaining individuals provided information on migratory routes and potential feeding grounds of SRWs wintering near PV (Fig. 1). The three juveniles left Golfo Nuevo earlier than the mothers. Blubber (PTT 87637), a whale of unknown sex, left the PV on 19 October 2014 and moved southward close to the Argentinian coast for another four days, until it began moving offshore. This whale's tag interrupted transmissions due to an unknown cause for 10 days and resumed providing locations when the whale was at the edge of the shelf, nearly 300km north of the Falkland/Malvinas Islands. Blubber moved inshore and spent 8 days at the edge of the Patagonian shelf. The tag stopped transmitting when this individual started to move offshore, 33 days after deployment. Papillon, a juvenile male, followed a similar pattern. He left Golfo Nuevo on 27 October 2014, moved south along the Argentinian coast for nearly 200km and then offshore in a southeast course. This whale reached the shelf break north of the Falkland/Malvinas on 13 November 2015 and circled back towards the outer Patagonian shelf, east of PV, six days later. This individual has remained in this region at depths ranging from 100-200m for the last 6 months and his tag is still transmitting (on 15 May 2015) 212 days after deployment. A third juvenile of unknown sex, Barefluke (PTT 84482) left Golfo Nuevo on 24 October 2014 and moved at a relatively constant rate east and then southeast. This whale spent 20 days navigating across the Patagonian shelf and then moved into the South Atlantic Basin towards South Georgia/Islas Georgia del Sur. On 29 November 2014 it migrated past Shag Rocks/Rocas Cormoran and moved into the Scotia Sea and the South Sandwich Islands/Islas Sandwich del Sur. Barefluke's tag stopped transmitting on 27 December 2014, 71 days after deployment, when this whale was about 600km northeast of South Georgia/Islas Georgia del Sur. During the last 12 days of transmission, this whale navigated through a portion of the southern South Atlantic consistently inhabited by humpback whales at the terminus of their migration from their wintering grounds off the east coast of South America (Zerbini et al., 2006; 2011).

Buena Onda (PTT 84498) was the only female with a calf for which migratory movements were monitored once she departed her nursing grounds near PV on 13 November 2014 (Fig. 1). This whale also moved through the Patagonian shelf and then migrated in an approximately northeast course towards offshore waters nearly 600km southeast of the La Plata River at ~39^{o}S. This was the northernmost latitude reached by any of the whales monitored in this study and corresponds to a region of high biological productivity known as the Subtropical Convergence (Peterson and Stramma, 1991; Odebretch and Castello, 2001). The tag interrupted transmission for unknown reasons on 17 December 2014 and but resumed providing locations 42 days later, when this individual was moving towards South Georgia/Islas Georgia del Sur. Buena Onda circled around South Georgia/Islas Georgia del Sur on the south side approximately following the 1000m isobath. This whale remained at the shelf break, west of the island, for 12 days until the tag stopped transmitting 126 days after deployment.

Behavioral states estimated by the SSSM indicated the predominance of ARS locations in four main areas: 1) Península Valdés, 2) the Patagonian Shelf between 43 and 47^{o}S and the 100m and the 200m isobaths, 3) the South Atlantic Basin off the La Plata River, and 4) the shelf break east of South Georgia/Islas Georgia del Sur (Fig 1). The relatively high use of waters near PV by right whales has been known for at least 40 years (Payne et al., 1990; Cooke et al., 2001, Rowntree et al., 2001). This species use the relatively calm waters of Golfo Nuevo and Golfo San Jose for breeding and nursing their calves. On the other hand, the occurrence of whales in the other three areas, which likely represent a portion of this species foraging grounds, has not been as well documented in recent years. The outer Patagonian shelf has been historically used by right whales (Townsend, 1935) and the area inhabited by some of the tagged whales during the austral summer and fall corresponds to a region where nearly 1,000 whales were illegally killed by Soviet whalers in the 1960s (Tormosov et al., 1998). Satellite tagging revealed that this may presently be an important feeding ground for SRWs wintering near PV. All four migrating whales in this study moved through or remained in this region for significant periods of time. The occurrence of SRWs in South Georgia/Islas Georgia del Sur has also been relatively well documented from early 20th century and the 1960s whaling (Tormosov et al., 1998; IWC, 2001) and sighting data (Moore et al., 1999). In addition, this region has been known as a feeding destination of some SRWs wintering off PV (Best et al., 1993; Rowntree et al., 2001). Interestingly, existing data suggest that whales tend to occur mainly in areas near Shag Rocks/Rocas Cormoran and the northern side of South Georgia/Islas Georgia del Sur (IWC, 2001), but the two whales that migrated near South Georgia/Islas Georgia del Sur moved through the south, remained to the east of the Island, and also occupied areas close and north of the South Sandwich Islands/Islas Sandwich del Sur. Finally, the presence of SRWs near the Subtropical Convergence is also broadly consistent with historical whaling data (Townsend, 1935). However, due to its relatively remote location, the occurrence of SRWs in these offshore areas has been relatively poorly documented in recent years. The use of satellite telemetry may help understanding space use patterns of whales in these far offshore feeding areas.

In general, these whales moved eastwards towards the Patagonian shelf and the South Atlantic basin between 39^{o}S and 57^{o}S, but, in some cases, visited different potential feeding habitats (e.g., Buena Onda visited the subtropical convergence and South Georgia/Islas Georgia del Sur). This movement pattern is largely consistent with that of SRWs in other regions. Childerhouse et al. (2010) showed that whales tagged near the Auckland Islands migrated west and used areas near the vicinity of the subtropical convergence to the south of the Australian continent. In addition, Mate et al. (2011) showed similar westward movement for whales instrumented with satellite tags in coastal waters off South Africa, with some of the whales they tracked also moving through wide latitudinal ranges.

The present study described unprecedented information on the migratory movements of southern right whales from PV. It also provided insights into the current feeding areas used by this population. Results presented here showed substantial variability in the movement patterns of SRWs wintering near PV. The variability detected in direct movement of individual provides specific evidence that is consistent with different isotopic signatures of prey/SARW tissues samples analyzed from this population (Valenzuela et al. 2009; 2011). However, our sample size is small and additional satellite tagging is needed to better understand their seasonal movements towards their feeding destinations and the space-used patterns in their foraging grounds.

The tagging data, when related to biopsy samples over time, may provide insights into whether there is a correlation among animals feeding in certain areas with higher incidences of calf mortality from a component of the population. Specifically, with additional tagging/sampling over the next several years, it will be possible to assess whether there are indications of potential maternal lineage and/or familial bias associated with increased mortalities. Ultimately, genetic and movement data will be integrated to explore relationships between genetic, behavioral, and environmental factors to the unusual mortality events in the SRWs of PV.

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Table 1 – Summary of satellite tracking data for SRWs tagged near Península Valdés, Argentina, in October 2014.

PTT-id (whale name)	Tag type	Sex/Reproductive Stage	Tagging date	Last received location	Tag duration (days since tagging)	Distance travelled (km)
84482/Barefluke	SPLASH 10	? (juvenile)	17 Oct 2014	27 Dec 2014	71	5941
84494/Buena Onda	SPLASH 10	F (mother)	19 Oct 2014	22 Feb 2015	126	6713
87637/Blubber	SPOT5	? (juvenile)	15 Oct 2014	17 Nov 2015	33	2627
111867	SPOT5	F (mother)	8 Oct 2014	-	0	0
111870	SPOT5	F (mother)	14 Oct 2014	15 Oct 2014	1	23
120950/Papillon	SPOT5	M (juvenile)	17 Oct 2014	Still transmitting on 15 May 2015	212	7782
121201/Helena	SPOT5	F (mother)	14 Oct 2014	6 Nov 2014	23	477

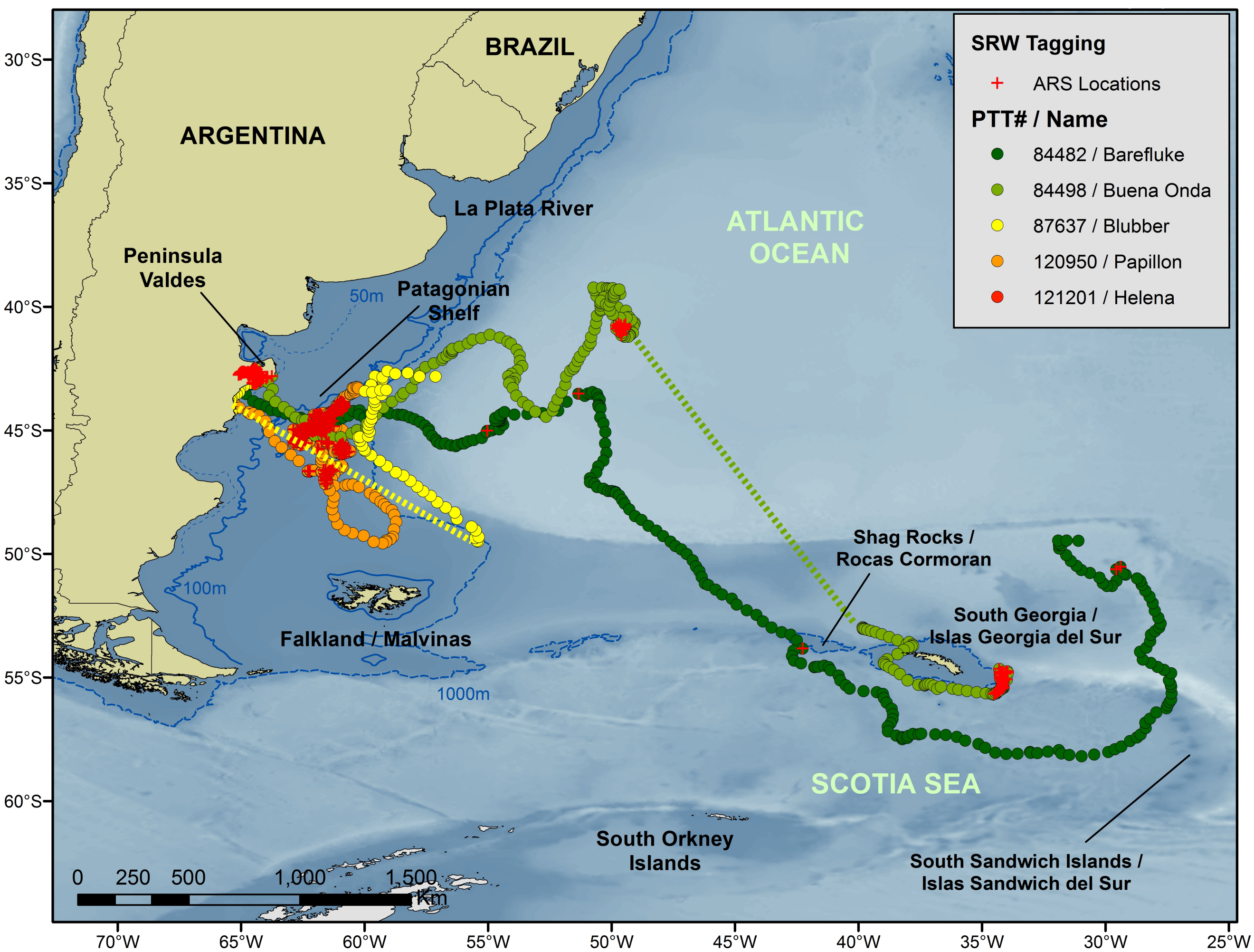

Fig. 1 – SSSM predicted tracks and areas of high use (Area Restricted Search, ARS Locations) of Southern Right Whales tagged in Golfo Nuevo, Península Valdés, Argentina. Dotted lines connect tracks of individual whales in periods without tag transmission.