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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. Fifteen integrated transdermal implanted tags were deployed in juvenile and adult whales. Tag duration varied between 10 and 237 days (average of 90 days). Movement patterns showed substantial individual and yearly variation. Tagged whales 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 the 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. A preliminary investigation of movement patterns relative to oceanographic features indicated that SRWs may be using anti-cyclonic cold eddies in the Subtropical Convergence for foraging. In addition, dive profiles suggest potential differences in how juvenile and adult whales explore the water column.

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). Península Valdés (PV), Argentina, houses one of the largest southern right whale breeding aggregation in the Southern Hemisphere. 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; SC/66b/BRG02). 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., 2016; 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; SC/66b/BRG02). 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 (CMP) 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.

The goals of our program are to determine migratory routes and feeding destination of SRWs wintering in this region. Following on successful tagging efforts in 2014 (reported to the IWC SC in 2015 in Zerbini et al. 2015), we conducted a second year of tagging of SRWs in PV in 2015.

MATERIALS AND METHODS

For completion and comparability, data from the 2014 and 2015 seasons are included here. Integrated transdermal configurations of Wildlife Computers' location-only (SPOT5) and archival (SPLASH10) Argos satellite tags were deployed in SRWs in Golfo Nuevo, PV, Argentina using the tags and deployment methods described in Zerbini et al. (2015). Tag deployment was conducted from the bow of a rigid-hull inflatable boat 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) and biopsy skin samples were collected concurrently to tag deployment with a crossbow or a pole for genetic characterization. Whenever possible, sex of tagged individuals was determined by their role in a social group (e.g. mother with a calf) or by examination of photographs of the genital area of a tagged whale.

Argos data processing and analysis followed the methods described in Zerbini et al. (2015). Briefly, Argos location were filtered using the R package 'argosfilter' (Freitas et al., 2008; R Development Team, 2013) and modeled using a switching state-space model (SSSM) (Jonsen et al., 2005, 2007; Bailey et al., 2009). 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 20th 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

A total of 15 tags were deployed (including 8 archival tags) on SRWs in Golfo Nuevo, PV in 2014 and 2015 (Table 1, Fig. 1). The first two tags deployed in 2014 (PTT 111867, 111870) achieved only 10-15% penetration and were shed within a day since tagging. One of the tags deployed in 2015 (PTT 112700) was low on the whale and did not provide transmission. These tags are not considered further here.

Table 1 – Southern Right Whales tagged in Península Valdés in 2014 and 2015

PTT	Name	Tag Type	Tagging Date/Time	Tag Duration	Sex	Class	Distance Travelled (km)
84482	Barefluke	Archival	10/17/14 11:42	71.04	?	Solitary Juvenile	5520
84498	Buena Onda	Archival	10/19/14 14:25	125.60	F	Mother	6028
87637	Blubber	Location	10/15/14 15:35	32.61	?	Solitary Juvenile	2562
111867	-	Location	10/8/14 16:50	0	F	Mother	-
111870	-	Location	10/14/14 11:17	0	F	Mother	-
120950	Papillon	Location	10/17/14 14:55	236.75	M	Solitary Juvenile	5675
121201	Helena	Location	10/14/14 13:45	22.85	F	Mother	260
112700	Angeles	Location	9/20/15 15:54	0	F	Mother	-
112728	Eclipse	Archival	9/25/15 13:15	94.64	?	Solitary	3715
112730	Atrevida	Location	9/24/15 11:28	118.60	F	Female in a mating group	6828
120942	Zarpazo	Archival	9/25/15 9:50	96.18	F	Mother	1970
120947	Antenita	Archival	9/21/15 15:53	86.43	F	Mother	1761
121191	Seductora	Archival	9/24/15 9:50	88.67	F	Mother	3198
121197	Borboleta	Location	9/20/15 10:01	97.66	?	Solitary	3446
121198	Primavera	Location	9/21/15 12:54	10.57	F	Solitary Juvenile	633

Tag duration ranged from 10-236 days, with an average of 90 days. Mean tag duration was greater for juveniles (106 days) than for adult females (84 days. Mean distance and total distance travelled by animals tagged in 2014 was 4009 km and 20,045 km, respectively. This translates into an average rate of movement of 47.9km/day. For 2015, mean and total distance traveled was 3079 km and 21,551km (average travel rate of 38.42 km/day).

Medium/Short Range Movements

Telemetry data revealed that whales travel throughout Golfo Nuevo, but habitat use is greater in the northern and western part of the Golfo (Fig. 1). None of the tagged whales moved towards Golfo San José, another region around PV known to have high concentrations of SRWs.   One individual, PTT 121197, a solitary animal of unknown sex, left Golfo Nuevo and moved to inshore waters in northern Golfo San Matias (Fig. 2), suggesting that whales from PV may visit other habitats along the coast of Argentina during the breeding season. This individual spent 5 days outside Golfo Nuevo, but returned to the area before it migrated offshore.

Migration and Feeding Destinations

Behavioral states estimated by the SSM 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 between 40 and 58^{o}S and 45 and 60^{o}W and 4) the region of the Scotia Sea/South Georgia and the South Sandwich Islands (Fig. 3). 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) as the species inhabit the relatively calm waters of Golfo Nuevo and Golfo San Jose for breeding and nursing their calves. 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).

Based on the 2015 tag data, it is quite apparent that the animals did not undertake the same type of extensive oceanic migrations across the South Atlantic that we were detected in 2014 (Fig 4). However, considering both 2014 and 2015 tag data and SSM, SRWs tended to congregate and move between high-use habitat areas likely for foraging in the areas of #2, 3, and 4 above.

Contrasting tagged animals by month in the tagging years 2014 and 2015, some notable inter-annual patterns emerge (Fig 5 and 6). Broadly speaking, animals that migrated to areas off the Patagonian Shelf and the South Atlantic Basin, and did so in the months of November and December and remained in these areas for as long as the tags continued to transmit. The animals that migrated to Scotia Sea/South Georgia region in 2014 migrated through these areas until switching behavioral states consistent with foraging in December 2014 and January-February 2015. While the sample sizes are still small, these data are providing some initial insights into feeding ground preferences and differences among PV SRWs.

Even with some broad patterns emerging, the 2014-2015 data continue to show substantial individual variability in the movement patterns of animals from different age, sex and reproductive classes. Nonetheless, the movements by these individual to different foraging areas provides specific evidence that is consistent with different isotopic signatures of prey/SARW tissues samples analyzed from this population (Valenzuela et al. 2009; 2011) and with the movement patterns of SRWs in other regions (Childerhouse et al., 2009; Mate et al., 2011). And of note and stated previously, 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 more than 1,000 whales were illegally killed by Soviet whalers in the 1960s (Tormosov et al., 1998). Satellite tagging revealed that this seemingly remains an important feeding ground for SRWs wintering near PV.

A preliminary investigation revealed that whales moving through the South Atlantic Basin appear be associated to oceanographic features in latitudes consistent with the highly productive sub-tropical convergence (Peterson and Stramma, 1991; Odebretch and Castello, 2001). One individual tagged in 2014 (PTT 84498), a mother with a calf at the time of tagging, moved towards middle latitudes of the Basin before migrating south, towards South Georgia. The track of this whale indicated that it appeared to be transiting around (avoiding) anti-cyclonic, warm eddies (Fig. 7), but that it associated with cyclonic, cold eddies which are characterized by upwelling and high productivity (Fig 8) (Odebretch and Castello, 2001). Movement patterns of this individual were consistent with other whales migrating through or to the basin and provide evidence of potentially important feeding habitats along the migration in middle latitudes of the South Atlantic.

Dive profiles revealed unprecedented information on the diving behavior of SRWs, providing new insights into how SRWs are exploring the water column during the migration and in the feeding grounds. Fig. 9 shows the profiles of a juvenile (PTT 84482) and an adult (mother, PTT 84498) thought the time they were tracked. Dive depths for the juvenile whale were typically around 100m, but deeper dives (up to 450m) were observed for short periods of time (2-3 days) in two occasions (early November and mid December) for one of the whales that migrated to the Scotian Sea/South Georgia area. In contrast, the dive profile of the mother revealed that this individual typically dove to depths of less than 100m with a few occasional dives near 150m of depth. The dive patterns of this whale were similar to that of other adult individuals once they leave the breeding grounds around PV. While preliminary, these data suggest possible differences in dive behavior of individuals of different age classes.

Conclusions

While our sample size may still be small, there are novel insights into current feeding areas and provide the first direct assessment of inter-annual variability for habitat-use outside of PV. Clearly, additional satellite tagging is needed to better understand how representative and consistent the 2014 and 2015 seasonal movements towards their feeding destinations will be in the coming years. This will be important to examine, particularly if different cohorts of animals (especially females and mothers) exhibit some fidelity or inter-annual variation, while taking into account animals of different age, sex and reproductive classes. With this information, we believe that more consistent patterns in movements and high habitat-use areas for foraging will emerge. Provided some additional funding can be secured to compliment likely or secured resources, we intend to continue and hopefully increase the tagging efforts in 2016 and beyond.

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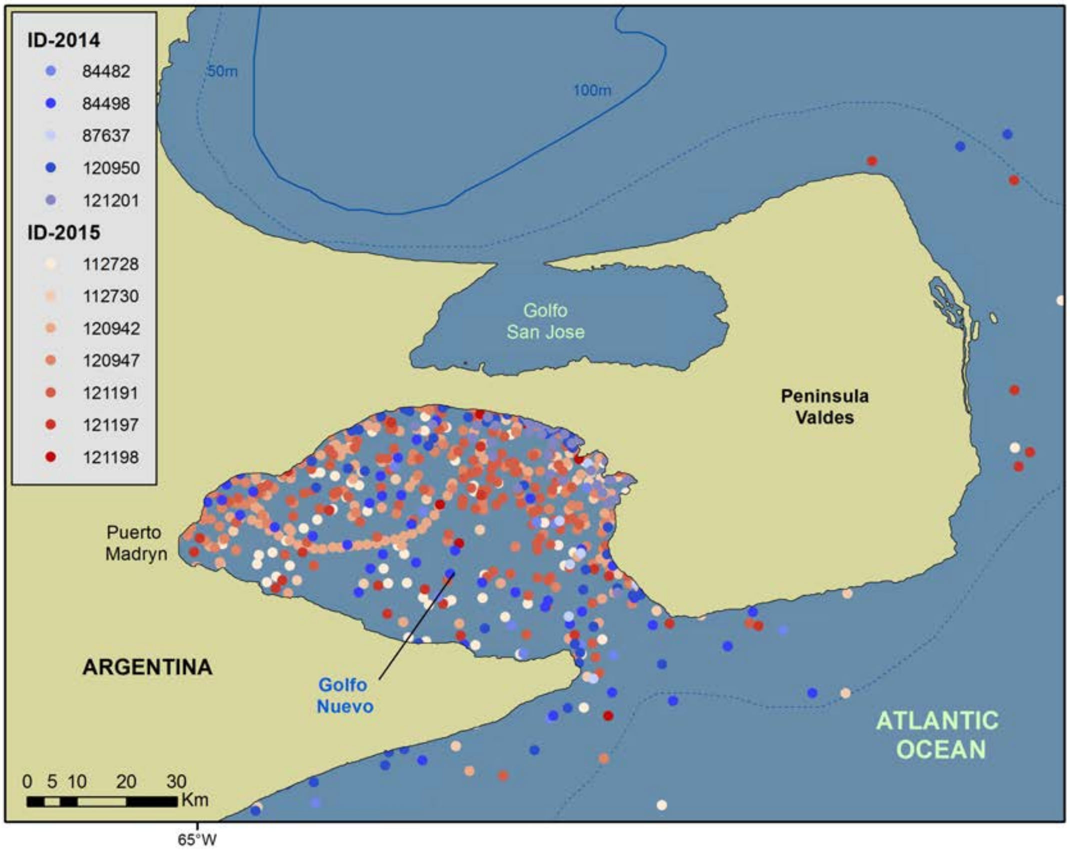


Fig. 1 – Habitat use of southern right whales in Golfo Nuevo, Península Valdés, Argentina. Note that while tagged whales visited the whole Golfo, higher concentration of locations was observed in the northern and western part of the Golfo.

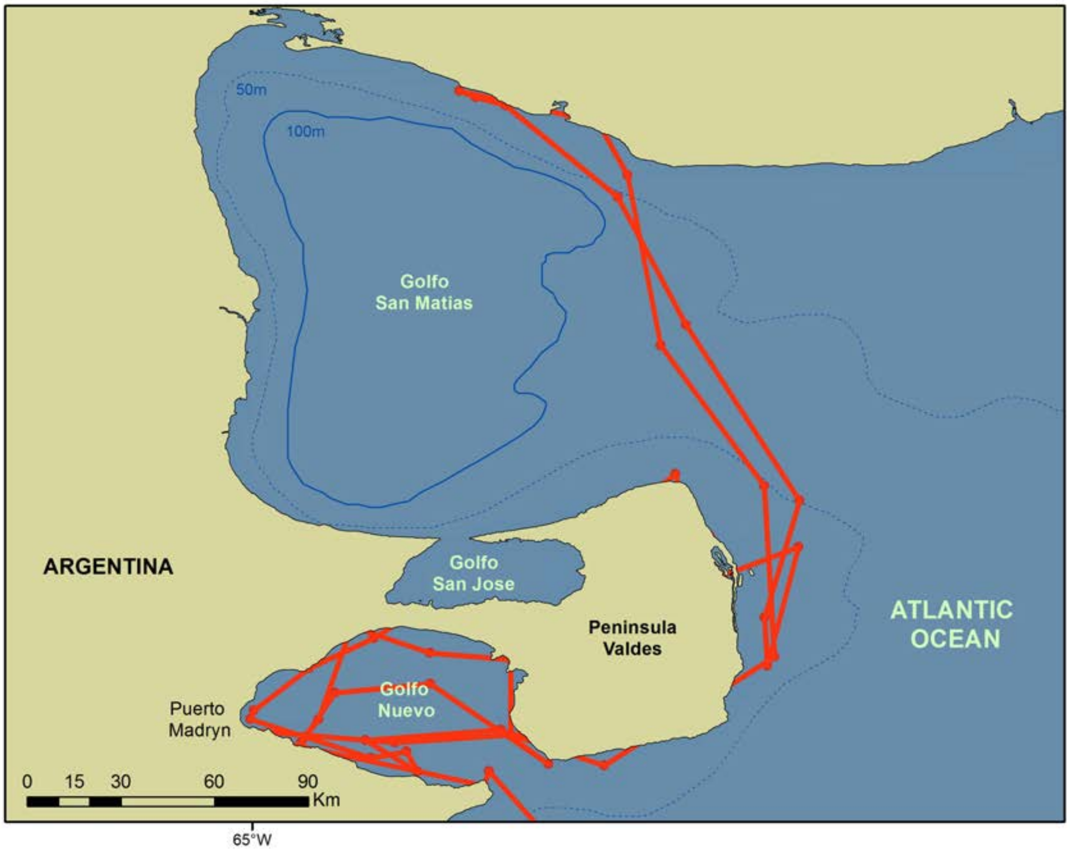


Fig. 2 – Track of individual PTT 121197 showing this individual moved outside of Golfo Nuevo towards the northern portion of Golfo San Matías.

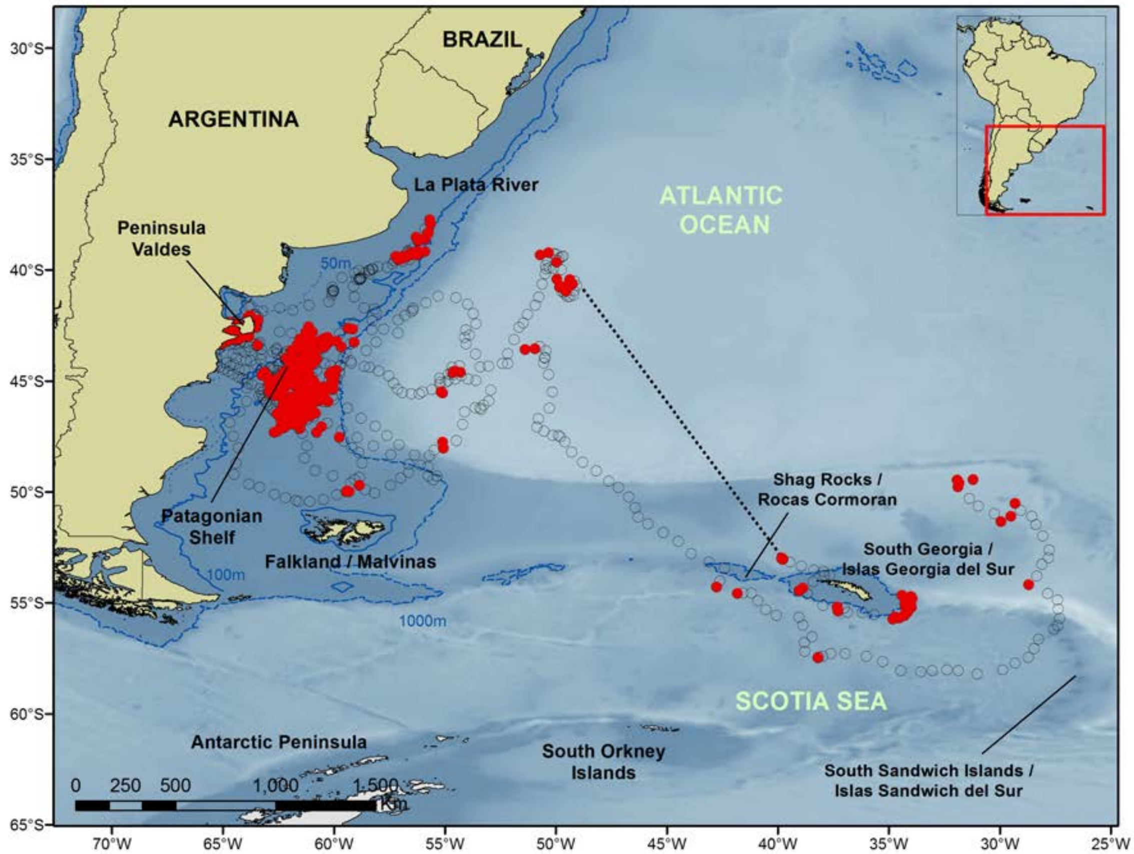


Fig. 3 –Areas of high use (locations estimated as Area Restricted Search – ARS – represented by the red dots) of Southern Right Whales tagged in Golfo Nuevo, Península Valdés, Argentina in 2015. Dotted lines connect tracks of individual whales in periods without tag transmission.

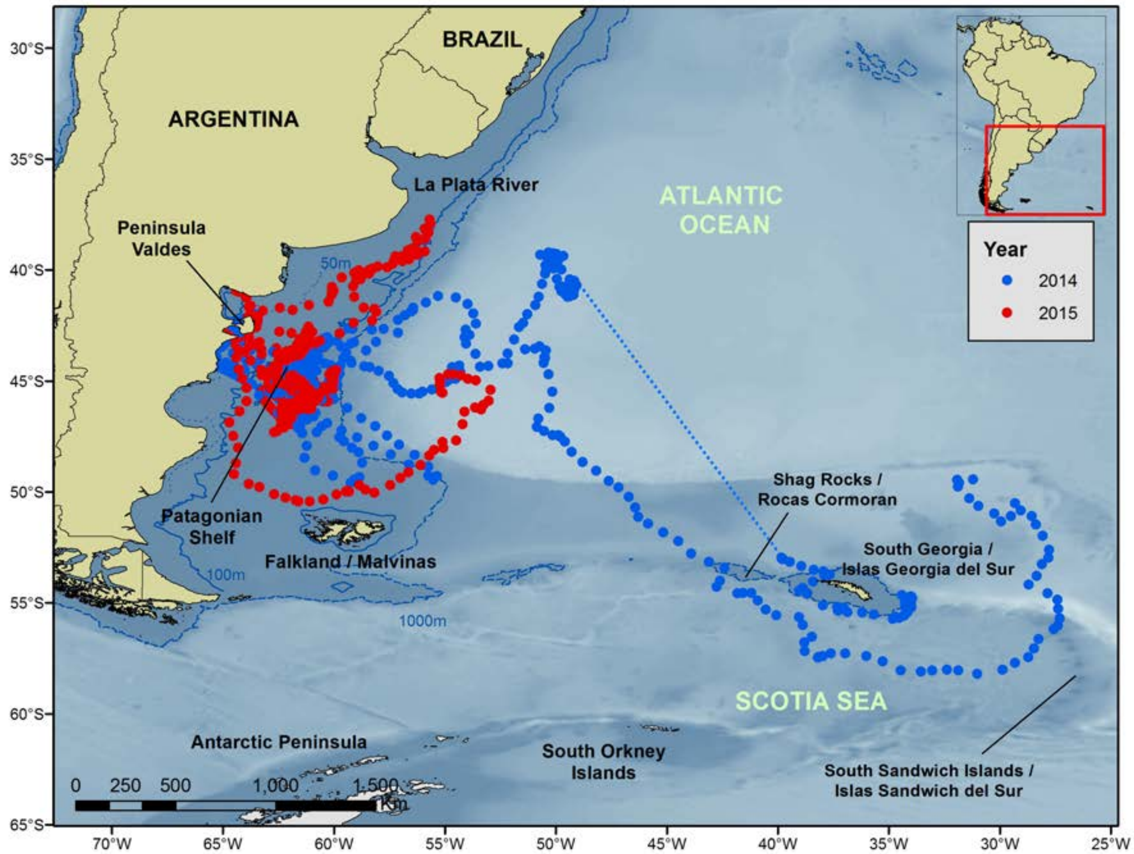


Fig. 4 –Tracks of SRWs tagged of Peninsula Valdés in 2014 and 2015. Dotted lines connect tracks of individual whales in periods without tag transmission.

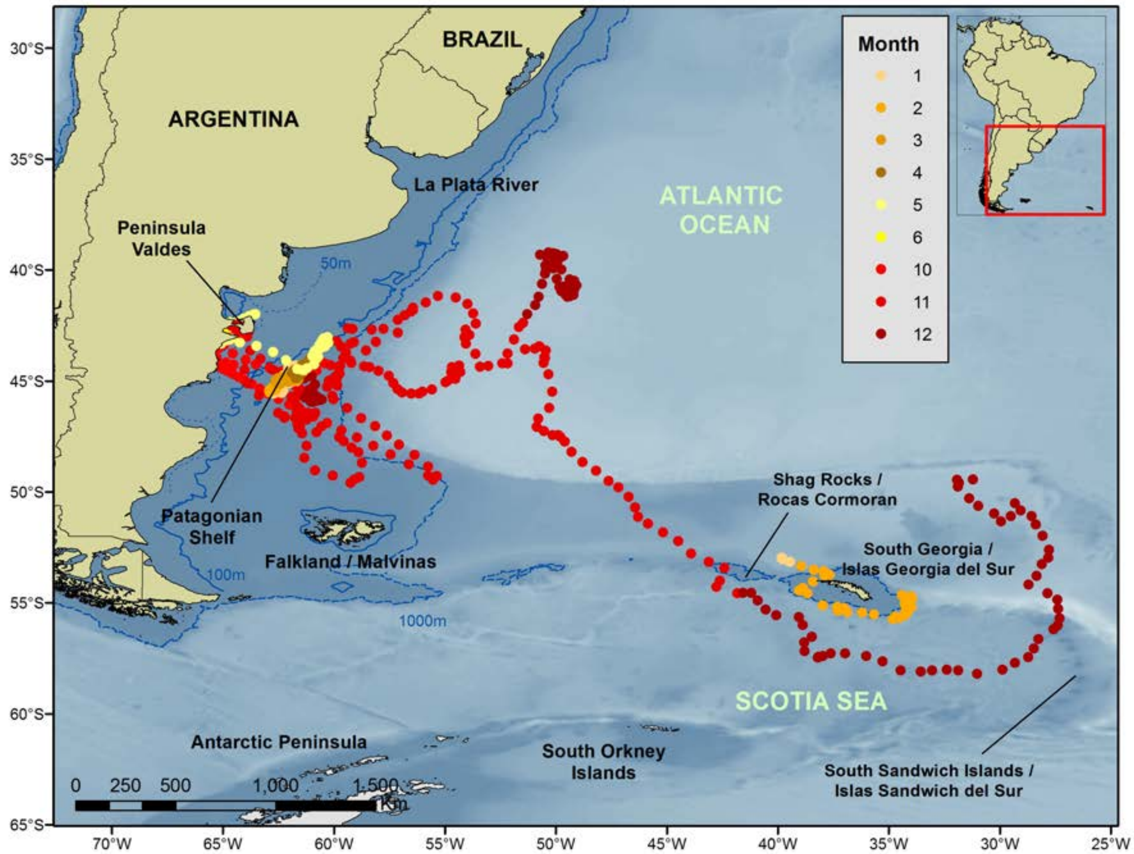


Fig. 5 – Predicted satellite tag locations of SRWs in the western South Atlantic Ocean in 2014.

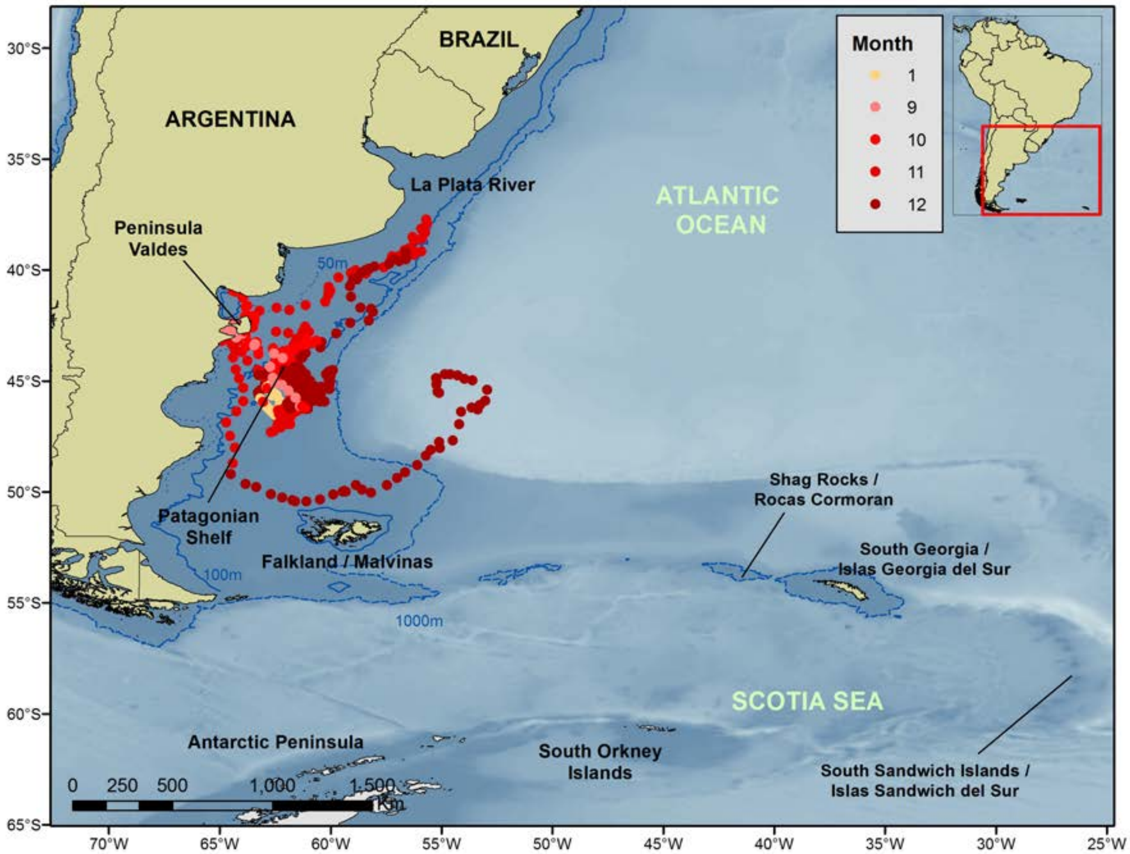


Fig. 6 – Predicted satellite tag locations of SRWs in the western South Atlantic Ocean in 2015.

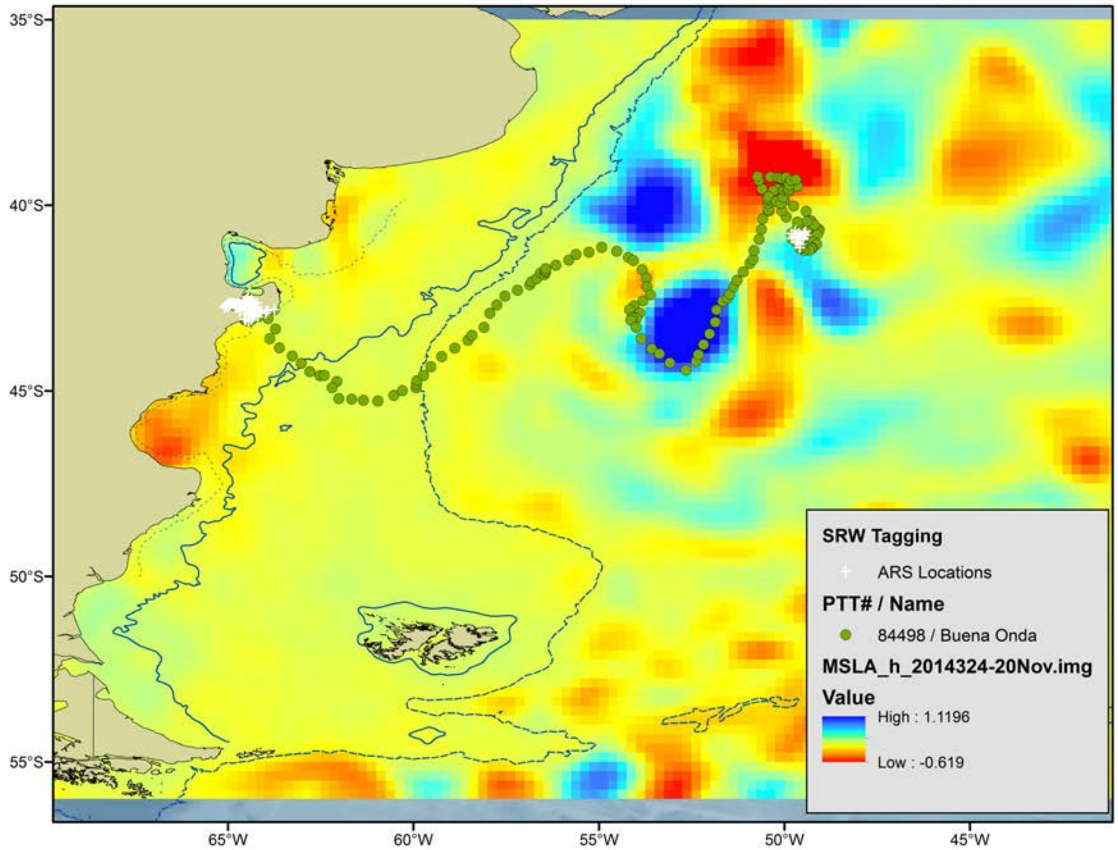


Fig. 7 - Track of whale PTT 84498 showing this individual transiting around an anti-cyclonic, warm eddy.

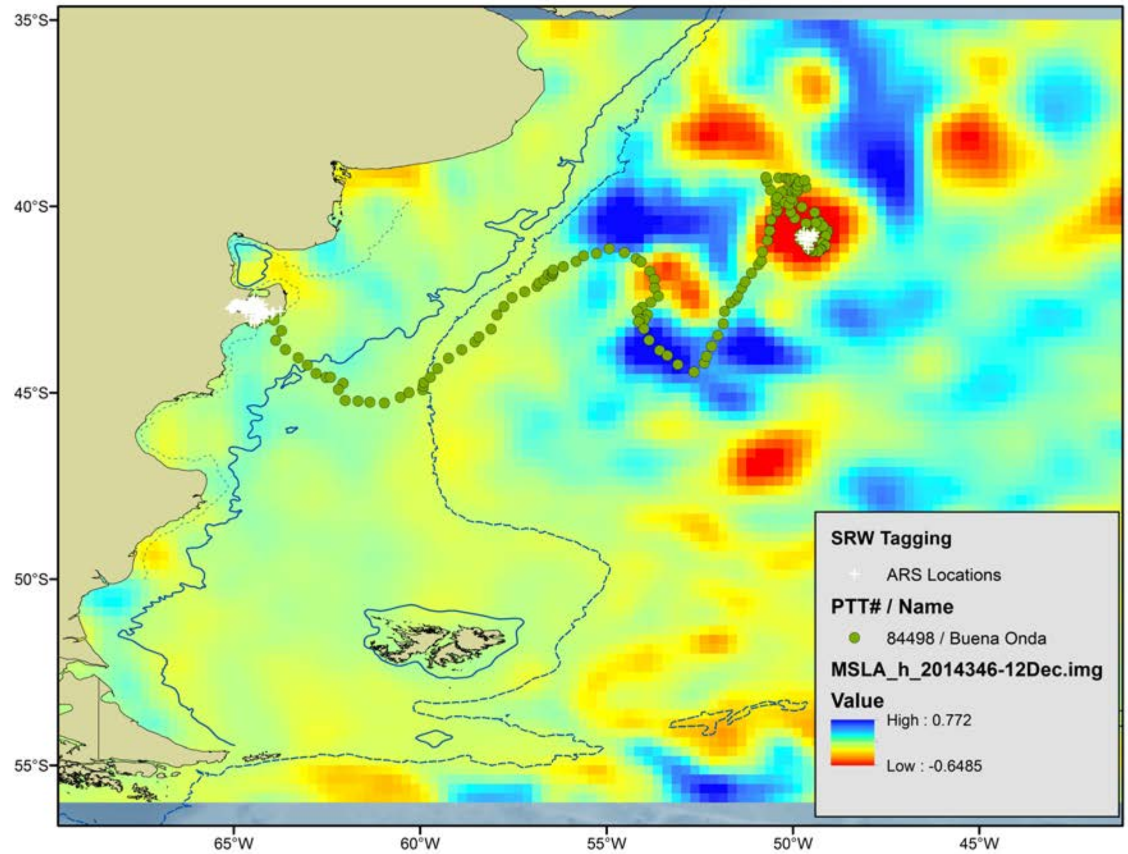
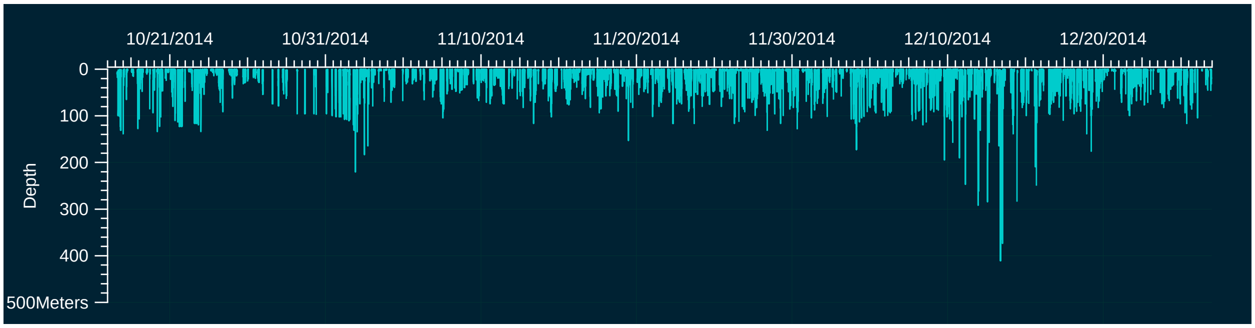
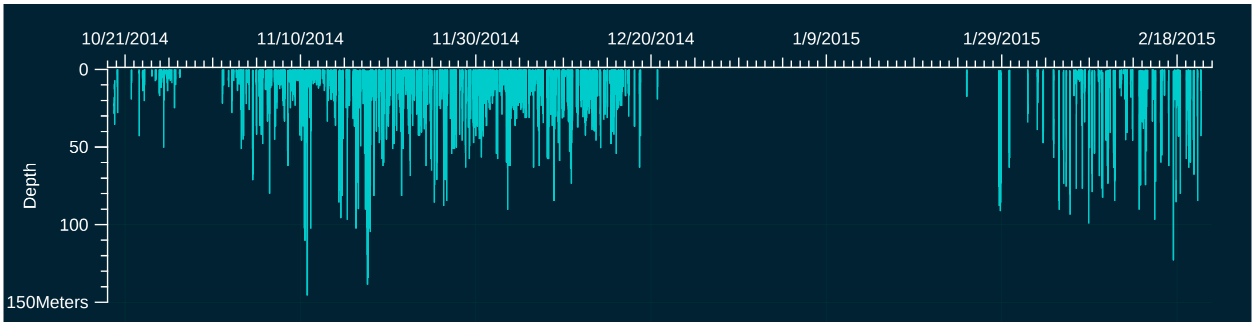


Fig. 8 – Track of individual PTT 84498 showing ARS behavior (represented by the white dots) associated with a cyclonic, cold eddy. ARS locations within the core of the eddy correspond to a period of three days.



A



B

Fig. 9 - Dive profiles of SRWs in the western South Atlantic PTT 84482 (A) and 84498 (B).