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Short Note

Life Histories of Satellite-Tracked Southern Right Whales Through Photo-Identification and Citizen Science in Patagonia, Argentina

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In memory of Captain Rafael Benegas

The migratory behaviors that characterize many marine species pose a challenge for the study of their demographic parameters and movement patterns due to the remoteness or seasonal inaccessibility of their habitats (Witt et al., 2009). Photo-identification (hereafter photo-ID) is a non-invasive technique used to identify individuals by documenting natural markings of animals in the wild. In marine megavertebrates, photo-ID has been employed using the natural spot patterns of manta rays (*Mobula* sp.; Armstrong et al., 2020) and whale sharks (*Rhincodon typus*; Araujo et al., 2019), and the head callosity patterns, body scarring, and nicks and notches on dorsal fins and flukes of cetaceans (Wells, 2009). Photo-ID is a powerful technique for studying demographic parameters, it is relatively inexpensive, and it allows monitoring of representative samples of a population over time (Wells, 2009). However, its ability to provide insights into migratory patterns is limited by the need to photographically recapture the individual in multiple destinations that are frequently inaccessible.

Telemetry can complement photo-ID studies by documenting detailed information on the movements of individual animals at various geographic scales. For instance, photo-ID can be used to quantify the level of connectivity among endpoints where dedicated photo-ID programs are active (i.e., breeding and feeding grounds), while satellite tracking can reveal fine-scale space use patterns and unknown habitats, and both techniques can reinforce connections previously indicated by the other (Garrigue et al., 2010; Hauser et al., 2010; Araujo et al., 2019). In addition, long-term photo-ID studies provide insights into the life history of satellite-tagged whales and thus help understand sex-, age-, or family-related movement patterns. Long-term photo-ID studies also allow evaluation of tag placement healing and the potential long-term effects of implantable tags on survival and reproduction (Best et al., 2015; Norman et al., 2018).

Southern right whales (*Eubalaena australis*; SRWs) migrate seasonally between mid-latitude coastal wintering grounds where they mate and calve and high-latitude summer–fall offshore feeding grounds (International Whaling Commission [IWC], 2001). Several feeding

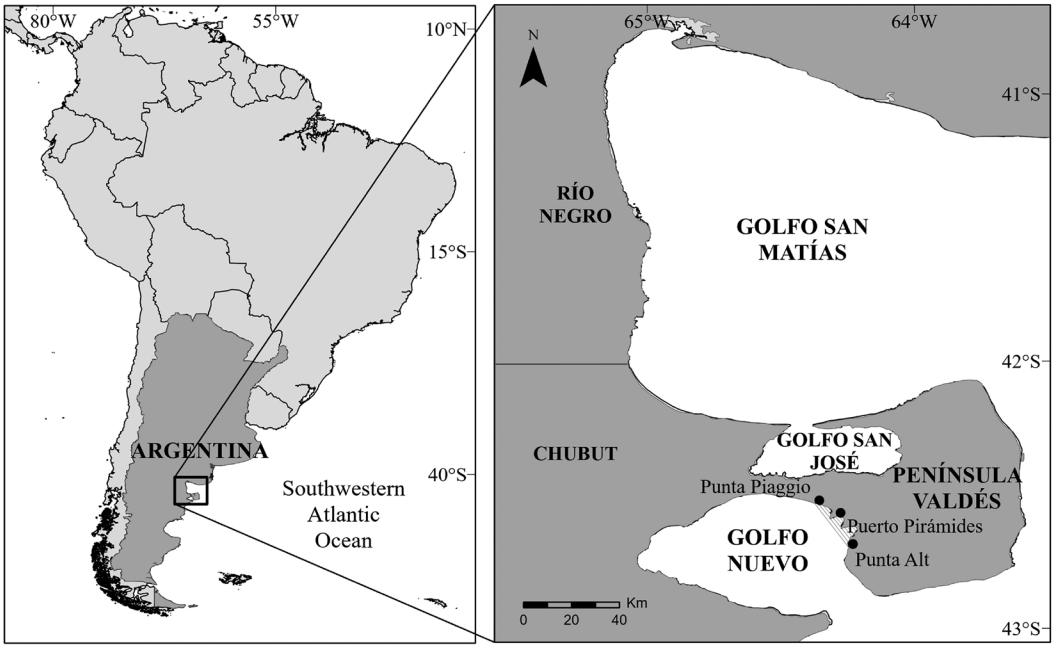

Figure 1. Study area showing southern right whale (*Eubalaena australis*) wintering grounds off Península Valdés (Chubut Province) and Golfo San Matías (Río Negro Province), Argentina. The map also shows the authorized area for whale-watching operations between Punta Piaggio (42° 19' S, 64° 16' W) and Punta Alt (42° 24' S, 64° 9' W) in Golfo Nuevo.

grounds have been identified for the SRW in the western South Atlantic based on historical catch records (Tormosov et al., 1998), stable isotope evidence (Rowntree et al., 2008; Valenzuela et al., 2009, 2018), and sightings of photo-identified individuals (Best et al., 1993; Moore et al., 1999). However, the precise locations and utilization pattern of the main feeding grounds for this whale population are still poorly known. A long-term satellite-tracking project was initiated in 2014 by a consortium of governmental, academic, and nonprofit institutions to study the migratory routes and feeding destinations of the SRWs that winter off the coast of Argentina (Zerbini et al., 2015, 2016, 2018).

Since 1971, a photo-ID catalog that at present contains over 4,000 individually identified SRWs and their associated life history data has been built for their calving ground at Península Valdés, Chubut, Argentina (Figure 1) through annual aerial photo-ID surveys (Payne, 1986). Valuable scientific data obtained using this methodology include calving intervals, mean age at first parturition, annual population growth rates (Cooke et al., 2001, 2015; Cooke & Rowntree, 2003), and habitat use patterns (Rowntree et al., 2001). However, the aerial surveys provide only a 1-d snapshot of whales present at the calving ground and, thus, do not include individuals that arrive after or leave the area before the survey is conducted at the peak of whale abundance in early September.

Citizen science represents a cost-effective tool to monitor wild animal populations across time and space (Dickinson et al., 2010; Vianna et al., 2014). For marine megavertebrates, citizen science has been used to understand distribution, demographics, abundance, and movement patterns (Araujo et al., 2017; Cheeseman et al., 2021; Wood et al., 2021; also see WhaleAlert.org). One of the largest whale-watching industries in the Southern Hemisphere was developed for SRWs in Puerto Pirámides, Península Valdés, Chubut, Argentina. Whale-watching operators have accumulated a wealth of high-quality whale photographs taken almost daily during the nearly 6-mo whale-watching season. The coastal preference and slow-moving nature of SRWs, together with the distinctive callosity patterns and touristic popularity, make them an ideal species for citizen science projects. Whale-watching vessels have been used to conduct a variety of scientific studies on cetaceans at Península Valdés (Rivarola et al., 2001; Coscarella et al., 2003; Fazio et al., 2015; Argüelles et al., 2016; D'Agostino et al., 2016; Sironi et al., 2019). Likewise, SRW photographs taken during whale-watching tours have been incorporated into the Península Valdés aerial-photo ID catalog to counter some limitations posed by the annual aerial surveys (Vilches et al., 2018).

Herein, we describe how a long-term photo-ID study on SRWs can integrate scientific research with whale watching, citizen science, and public outreach and can contribute relevant information to enhance a satellite telemetry study and its outcomes. Such a contribution will serve as a baseline for better understanding the potential long-term effects of implantable tags on SRWs.

For photo-ID, SRWs were surveyed between 1971 and 2017 during the time of peak whale abundance (September) by flying along the bays of Península Valdés and photographing each whale encountered (Payne et al., 1983; Rowntree et al., 2001; Figure 1). The whales' location and whether a calf accompanied them were recorded. The whales were later individually identified by the callosity pattern on their heads and/or pigmentation marks on their bodies (Payne et al., 1983). Photographs of identifiable whales were compared to those in the catalog using a software designed to identify individual SRWs from aerial photographs (Hiby & Lovell, 2001). The boat-based photographs were taken opportunistically by five photographers between 2003 and 2007 during whale-watching tours throughout the SRW calving season (June through December). The tours operated within a 25-km segment off Península Valdés's coast in Golfo Nuevo (Figure 1), and they followed the guidelines of the Patagonian Whale-Watching Technique (Sironi et al., 2009). Through an agreement of cooperation, photographs of SRWs were contributed by the Puerto Pirámides Whale Watching Guides Association to the Instituto de Conservación de Ballenas. We compared photo-identifiable whales to those in the catalog using *BigFish* software, which is designed to identify individual SRWs from boat-based or aerial photographs (Pirzl et al., 2006).

We deployed consolidated (Type C; Andrews et al., 2019) Argos satellite tags (SPOT5, SPOT6, and SPLASH10; Wildlife Computers, Redmond, WA, USA) on 47 SRWs: nine in Golfo San Matías, Río Negro Province, and 38 in Golfo Nuevo off Península Valdés between September and October 2014 to 2019 (Figure 1). The tags and deployment methods are described in Zerbini et al. (2015, 2016, 2018). The sex of tagged individuals was determined by their role in a social group (e.g., mother with a calf), by examining photographs of the genital area, or by molecular methods whenever a biopsy was collected. We obtained boat-based or drone photographs of their callosity patterns and any other distinctive features (i.e., pigmentation marks and scars) for photo-ID. A field name was assigned to each tagged animal at the time of tag deployment. Tagged whales were either matched to a known individual in the photo-ID catalog or incorporated as a new whale.

Of the tagged individuals, 38 SRWs (81%) were searched for in the catalog using a combination of both identification softwares or using only *BigFish* when aerial photographs of whales (i.e., via drone) were not available (see details in Table 1). The remaining whales could not be searched in the catalog due to poor photo quality (4%) or because the whales were not photographed at the time of tagging (15%). As a result of the search, 16 whales (42%) were known individuals, and 21 whales (55%) were added as new individuals to the catalog. One whale was not added to the catalog due to poor photo quality. Two matches were possible thanks to contributions from whale-watching photographers since only boat-based photographs were available for these individuals (see "Antenita" [A7138] and "Cebollita" [A7040] in Table 1).

Determining mother–calf relationships from boat-based photographs can be challenging due to the narrow field of view. Even when an adult and a calf are shown together in the same photograph, these individuals may not be related to each other as they could be the calf of an unphotographed adult or the mother of an unphotographed calf. However, this limitation could be overcome if the citizen scientists, in addition to taking the photographs, take field notes that include date, time, type of individual(s) (e.g., mating group, mother–calf pair, lone individual), age class, sex, location, and file name. This was the case for "Borboleta" (A2963; see Table 1). When she was tagged in 2015 (Zerbini et al., 2016), her sex could not be determined, but through the whale-watching photograph of this individual accompanied by a calf, and from the sighting information reported by the photographer in 2004, she was identified as female.

Aerial photographs seldom have enough resolution to document the details in the callosity pattern of the small heads of calves, thus hindering the identification of whales in their birth year. This is especially true for early (analog) photographs in the catalog such as those of "Espuma" (A0071-75-87-94) as a calf taken in 1994 (see Table 1). However, Espuma had a distinctive body coloration, being predominantly white with a splatter of black pigmentation, described by Schaeff et al. (1999) as a grey-morph phenotype. Therefore, it was still possible to record the general pigmentation pattern and thus assign him an identifier number as a calf from an aerial perspective. Grey-morph calves have their white skin darken to grey over their first few years of life (Payne et al., 1981). In contrast, the photographs of Espuma as a yearling taken in 1995 from a whale-watching boat included close-up detail of the pigmentation pattern, which enabled finding the match with

Table 1. Sighting histories of tagged southern right whales (*Eubalaena australis*; SRWs) identified in the Península Valdés SRW catalog. The number of tagged SRWs searched for using different photo-ID softwares and the number of matches and new individuals added to the catalog are shown. Catalog identification numbers (in parentheses, beneath names) are given for each known individual in addition to the source of the sighting (BB = boat-based photo; AS = aerial survey; TAG = tagging event), the year, the location, and the age class at the time of record. Records marked with (*) indicate individuals that were resighted by whale-watching tours or the tracking team that season after being tagged.

38 SRWs tagged Adults: 20 ♀, 4 ♂, 2 unknown sex Juveniles: 2 ♀, 10 unknown sex	*BigFish* software (n = 12) Matches: n = 2 New individuals: n = 10	Antenita (A7138)	BB	2007 Golfo Nuevo Lone adult	TAG	2015 (21 Sept.) * Golfo Nuevo Female + calf		
		Cebollita (A7040)	BB	2006 Golfo Nuevo Lone adult	TAG	2019 (26 Sept.) * Golfo Nuevo Female + calf		
	BigFish & *Hiby-Lovell* software (n = 26) Matches: n = 14 New individuals: n = 11 Not incorporated: n = 1	Borboleta (A2963)	BB	2004 Golfo Nuevo Female + calf	AS	2015 (3 Sept.) Golfo Nuevo Lone adult	TAG	2015 (20 Sept.) Golfo Nuevo Lone adult
		Espuma (A0071-75-87-94)	AS	1994 Golfo Nuevo Calf	BB	1995 Golfo Nuevo Yearling	TAG	2017 (20 Sept.) Golfo San Matías Adult male
		Paciencia (A0071-75-87-08)	AS	2008 Golfo Nuevo Calf	TAG	2019 (26 Sept.) * Golfo Nuevo Female + calf		

the photographs taken by the tracking team when Espuma was 23 y old (Zerbini et al., 2018)—22 y after his last recorded sighting in Península Valdés. Espuma (field name: "Mariposa"; catalog number A0071-75-87-94) belongs to a family with five known generations (Figure 2): he is the great-grandson of whale A0071, grandson of whale A0071-75, and son of whale A0071-75-87. Although almost all opportunistic boat-based photographs were taken between 2003 and 2007, whale-watching photographs of Espuma were contributed in 1995 because he was considered an iconic whale among the local community due to his unusual coloring and friendly demeanor.

Individual SRWs vary in their use of wintering habitats according to their sex, age, and reproductive status (Rowntree et al., 2001; Elwen & Best, 2004). Mothers and calves are most commonly in shallow, nearshore protected waters off Península Valdés, which are covered by the aerial photo-ID surveys. Adult males and non-calving females are more commonly found in the deeper waters of the peninsula's gulfs (Rowntree et al., 2001; Sueyro et al., 2018) or along the coast of Golfo San Matías (Arias et al., 2018), either alone or in mating groups. Adult males show significantly less site fidelity than calving females and juveniles (Rowntree et al., 2001). This could in part explain why Espuma was not photographically recaptured by the aerial surveys as a juvenile or as an adult, although he was born at and returned to Península Valdés as a yearling. The match between Espuma and whale A0071-75-87-94 represents the first evidence of an inter-annual connection between Golfo San Matías and Península Valdés based on photo-ID.

"Paciencia" (A0071-75-87-08) was tagged in Golfo Nuevo (Table 1) with her calf, a grey-morph male named "Aconcagua." She matched whale A0071-75-87-08 in the catalog, which indicates she was born in 2008 and belongs to a family with four known generations. She was 11 y old when tagged. In addition, Paciencia and Aconcagua turned out to be Espuma's sister and nephew, respectively (Figure 2). Paciencia was previously sighted only in her birth year during the annual aerial survey. As a result of the second sighting recorded during the satellite tag deployment, it was possible to determine Paciencia's sex and to add her calf, whale A0071-75-87-08-19, the fifth generation of individually identified whales, to her family.

The combination of a well-studied population, such as the Península Valdés SRW, and its long-term life history dataset with whale-watching photographers' identifications and satellite tagging efforts offers an array of research applications at

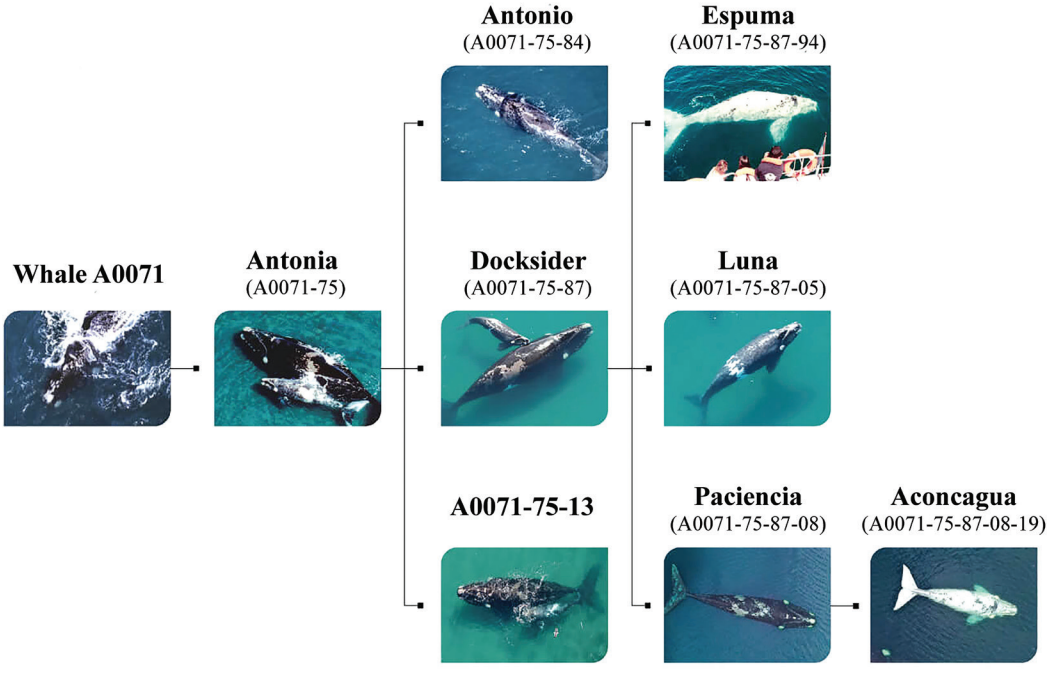

Figure 2. Five generation family tree of southern right whales off Península Valdés (Chubut Province) and Golfo San Matías (Río Negro Province), Patagonia, Argentina, described in this study.

both the individual and population levels. SRW calves at Península Valdés died in unprecedented numbers in some years between 2007 and 2013, with a significant inter-annual variation in the number of deaths from 2003 to 2017 (Rowntree et al., 2013; Sironi et al., 2018). SRWs give birth once every 3 y on average, and calving intervals of 2, 4, and 5 y are indicative of calving failures (Cooke et al., 2001; Cooke & Rowntree, 2003; Marón et al., 2015). Considering that calves learn feeding locations from their mothers, and that the timescale of site fidelity to feeding grounds is at least several generations (Valenzuela et al., 2009), long-term photo-ID coupled with sustained tagging efforts could provide insights into whether there is a correlation between females feeding in certain locations and a higher frequency of calving failures.

Although satellite tagging offers advantages for better understanding large whale movements at a fine scale, there are still concerns about the potentially adverse effects of implantable tags (Moore et al., 2013). Tissue reactions at the site where the tag was placed (divots and swellings) may persist for many years (Best et al., 2015; Norman et al., 2018), but their effects on the whale's health is poorly understood. Follow-up studies of tagged individuals are relevant to assess immediate and long-term behavioral, physiological, and health effects that could have sublethal or demographic consequences (Andrews et al., 2019). In particular, testing for long-term responses to tag placement, such as impaired survival or reproduction, requires monitoring an individual's post-tagging history over multiple years. For example, tagging effects on survival can be assessed by comparing the resighting rates of tagged vs untagged whales (Kraus et al., 2000). Tagging effects on reproductive success, on the other hand, can be tested by comparing either pre- vs post-tagging reproductive intervals of tagged whales (Best & Mate, 2007) or post-tagging reproductive intervals of tagged vs untagged whales (Best et al., 2015). Prior studies found no significant changes in survival or reproductive rates of tagged North Atlantic right whales (*Eubalaena glacialis*; Kraus et al., 2000), SRWs (Best & Mate, 2007; Best et al., 2015), and humpback whales (*Megaptera novaeangliae*; Mizroch et al., 2011; Robbins et al., 2013). However, reactions to tag placement differ among species (e.g., wound severity, duration; Norman et al., 2018), and available studies in SRWs (Best & Mate, 2007; Best et al., 2015) are based on small sample sizes that may be insufficient for effect detection. A well-studied population such as the Península Valdés SRW and its life history dataset spanning five decades, coupled with the work of experienced photographers on whale-watching boats, offer an exceptional opportunity for monitoring potential long-term effects of implantable tags.

Incorporating boat-based photographs into the Península Valdés SRW catalog developed from aerial surveys has provided novel, valuable, and supplementary information (Vilches et al., 2018). It has also enriched life history information of the SRWs tracked by satellite telemetry. These results, a product of citizen science collaboration and long-term projects, are shared with the local community during annual meetings. The daily work at sea of the whale-watching industry increases the chances of resighting and photographing individuals that were tagged in the season (see examples in Table 1) and/or in previous years, which will allow long-term evaluation of the condition of tag placement sites, including the presence of scars and divots (Norman et al., 2018), the overall body condition, and the potential effects on the survival and reproduction of the tracked animals. For that reason, we created a digital catalog that includes photographs, sighting history, and tag information from all the tracked SRWs so that the whale-watching operators can search individuals and report resightings within and between seasons.

Matches between individual whales photo-identified in different wintering grounds, and in both wintering and feeding grounds, provide a non-invasive method for investigating a population's migratory destinations. Coupled with satellite telemetry, the life histories and family trees of the tracked individuals add relevant information to our understanding of how different whale matrilines use the western South Atlantic and whether and how they can adapt to a changing environment (Agrelo et al., 2021). For the western South Atlantic SRW, photo-ID catalog comparisons previously demonstrated inter-annual movements between the calving grounds off Península Valdés and southern Brazil (Rowntree et al., 2020), and between Península Valdés and Georgias del Sur/South Georgia (Best et al., 1993; Moore et al., 1999), one of the known feeding grounds of the species. Also through a photo-ID match, we provide evidence in this short note for inter-annual movements between Península Valdés and Golfo San Matías in Argentina. However, this method provides only destinations, thus omitting information on movements between capture and recapture locations. A comparison of catalogs from all wintering (i.e., Península Valdés, Golfo San Matías, southern Brazil, and Uruguay) and known feeding grounds, and the continuation of satellite telemetry studies are needed to better understand the degree of overlap among these areas and the inter- and intra-annual movement patterns of SRWs in the western South Atlantic.

Long-term post-tagging follow-up studies require high-quality images for the identification of tagged individuals, larger sample sizes, and more frequent and extended period observations (Norman et al., 2018). Collaboration among research groups conducting photo-IDs, and between researchers and whale-watching citizen scientists, together with the continuation of tagging and follow-up efforts at Península Valdés, will help build a broader and more comprehensive suite of observations to understand and remediate potential long-term effects of the tags on SRWs, maximizing outcomes of these technological advances.

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