An update on research on migratory routes and feeding destinations of Southwest Atlantic humpback whales

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ABSTRACT

Humpback whales wintering off the eastern coast of South America were instrumented with satellite transmitters in 2003 and 2009 to investigate migratory routes and destinations in the western South Atlantic. In this study, the movements of 13 individuals were described for part or the full migration to higher latitude feeding grounds. These whales were monitored for periods ranging from 31 to 205 days and distances ranging from 2000 to 8000km. Except for one individual, all whales departed from the coast of Brazil from late October to late December between ~20 and 24°S and gradually moved away from the South American coast as they moved towards high latitudes. They followed a somewhat direct, linear path, with an approximate geographic heading of 170° and arrived in feeding grounds located to the east of the Scotia Sea. Preliminary analysis using a switching state-space model (SSSM) suggested that area restricted movement (ARS) consistent with feeding behavior was approximately correlated with the southern boundary of the Antarctic Circumpolar Current. One individual followed a previously undescribed migration route. This whale initiated its migration at ~10°S and headed southeast towards the mid Atlantic ridge. A change in movement patterns suggest that it may have exploited feeding opportunities at middle latitudes (~45°S) near the boundary of the Subtropical Front for a period of 20 days. This whale then changed direction and headed southwest towards the South Sandwich Islands. Two whales crossed the stock boundary between breeding stock (BS) A nucleus area and BSA and BSB fringe area, supporting current IWC catch allocation scenarios.

INTRODUCTION

Southwest Atlantic humpback whales (Breeding Stock A) winter off the coast of Brazil where mating and calving occurs from June to November (Siciliano, 1997; Martins *et al.*, 2001, Zerbini *et al.*, 2004, Andriolo *et al.*, 2010). While nearly 80% of this population inhabits a large coral reef area that extends from nearshore to about 150 nautical miles offshore known as the Abrolhos Bank (between 16 and 18°S, Siciliano, 1997; Andriolo *et al.*, 2010), whales are regularly found further to the north up to the NE tip of the South American continent (~5°S) and to the south near Cabo Frio (~23°S) (Zerbini *et al.*, 2004; Andriolo *et al.*, 2010). In addition, an increasing number of sightings have been reported for the northern Brazilian coast (north and west of 5°S) and along many oceanic islands (Fernando de Noronha, Sao Pedro and São Paulo Archipelago and Trindade and Martin Vaz Archipelago) as far offshore as 600 miles (e.g. Siciliano *et al.*, this meeting).

The migratory routes and feeding destinations of this population remained unknown until the early 2000s. In 2003, satellite transmitters were deployed on 11 individuals in the Abrolhos Bank and two individuals were tracked to feeding grounds in offshore areas off the NE coast of South Georgia and the South Sandwich Islands (Zerbini *et al.*, 2006). Subsequent satellite tagging in the wintering grounds as well as photo-identification and molecular genetic data from both wintering and feeding grounds provided further evidence that sub-Antarctic waters to the west of the Scotia Sea corresponded to a migratory destination for this population (Stevick *et al.*, 2006; Engel *et al.*, 2008; Engel and Martin, 2009; Zerbini *et al.*, in press).

Satellite tagging work conducted off Brazil in 2008 and 2009 provided additional information on migratory routes and feeding destinations of western South Atlantic humpback whales. In particular, a previously undescribed migration route and further information on preferred habitats in the feeding grounds were observed and are presented here.

METHODS

Satellite Transmitter Deployment

Between 2003 and 2009, 65 satellite transmitters (variants of molds 177 and 193, SPOT3, SPOT4 and SPOT5 PTT-only configurations, Wildlife Computers, Redmond, WA, USA) were deployed in humpback whales

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wintering grounds off the coast of Brazil from late August to early November. Five anchoring system types were used (Heide-Jørgensen *et al.*, 2003; 2006; Zerbini *et al.*, 2006; Gales *et al.*, 2009). The average transmission time for tags lasting longer than 5 days (n=60) was 40 days, but substantial variation was observed across tag and anchor configuration, deployment month and year, deployment location and depth of tag penetration. Lower and greater average durations were 29 (in 2007) and 64 days (in 2009), respectively. For the purpose of this paper, only data from whales tracked during part of or the total spring migration, and while on the summer feeding grounds were considered. Table 1 summarizes information on transmitter configuration and duty cycling for these individuals.

Tag deployment was conducted from an inflatable boat using a fiberglass pole or a modified pneumatic gun (ARTS) at ranges of 3-8m (Heide-Jørgensen *et al.*, 2003; 2006; Gales *et al.*, 2009). Biopsies samples were collected concurrently to tag deployment with the tagging pole (which is equipped with a biopsy tip) or with a crossbow (for ARTS deployment). Biopsies were used for DNA extraction and sex determination of each individual as described by Bruford *et al.* (1992) and Bérubé and Palsbøll (1996).

Data Analysis

Argos location data presented in this document were filtered using the R package 'argosfilter' (Freitas *et al.*, 2008), which remove locations considered 'unrealistic' based on speed, distance and turning angles of successive locations, assuming a maximum swimming speed of 8km/h and default turning angles. Argos locations type 3, 2, 1, 0, A, and B were included in the analysis,

Location data were also analyzed in a preliminary fashion using a switching state-space model (Jonsen *et al.*, 2005; 2007; Bailey *et al.*, 2009) with the objective of assessing behavioral states of individual whales. 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 thought to represent transiting (mode 1) and an 'area restricted search' (ARS) behavior (mode 2). The model was fit using a Bayesian approach in software WinBUGS. Two chains were run in parallel, each for a total of 20,000 Markov Chain Monte Carlo (MCMC) 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 modeled, the means of the MCMC samples provide a continuous value from 1 to 2. Predicted locations with mean behavioral modes <1.25 and >1.75 were considered transiting and ARS behavior, respectively. Locations with mean modes between 1.25 and 1.75 were considered uncertain (Jonsen *et al.*, 2007; Bailey *et al.*, 2009). In this document locations estimated as ARS behavior were used to examine high-use habitats in the feeding grounds. A more detailed analysis of location data using this space state model will be performed in the future to describe movement of humpback whales within the whole range of this population.

RESULTS AND DISCUSSION

Migratory Routes

Migratory routes used by whales wintering off Brazil are illustrated in Fig. 1. Except for one individual, all whales left the breeding grounds and moved south of the Abrolhos Bank either over the continental shelf along the coast (18-21^{o}S) or from the SE tip of the Bank straight into deeper waters (18^{o}S). After departure (leaving shelf waters), whales followed a SW bearing towards offshore waters to the east of South Georgia and the South Sandwich Islands, approximately 4000/5000 km further to the south. These routes are consistent with migratory movements of the first BSA humpback whales tracked with satellite telemetry (Zerbini *et al.*, 2006) and suggest that a migratory corridor about 800km wide represents the primary pathway between the wintering grounds off eastern South America and feeding grounds in sub-Antarctic waters of the South Atlantic Ocean. Whales following these routes completed their migration in 40-60 days and, unlike in other areas (e.g. Gales *et al.*, 2009; Garrigue *et al.*, 2010), there was no evidence that migration was paused (e.g. presumably for feeding) until they reached an area to the south of ~52^{o}S.

The only exception was whale 87783.09, which followed a previously undescribed route. This individual initiated the migration at ~10^{o}S off the NE coast of Brazil and followed a SE bearing that crossed the Vitoria-Trindade submarine chain while heading towards the mid Atlantic Ridge. It crossed the 20^{o}W meridian and at ~40^{o}S, it shifted direction and migrated S-SW toward the South Sandwich Archipelago. While previously not described, this migratory route is consistent with observations of humpback whales in offshore, deep water of the Atlantic. This whale migrated just 200km SW of the Trindade and Martin Vaz Archipelago where humpback

whales have been occasionally seen during the wintering season (Siciliano *et al.*, this meeting). Pre-modern whaling records have also shown the presence of humpback whales in the region through which this whale migrated. For example, Best (2008) reported on humpback whales seen early in the season (July-August) by the whaling ship *Jones* in 1831/32 between 16° and 28°S at the 30°W meridian and concluded that these were likely whales migrating to the coast of Brazil.

The westernmost location visited by this whale (at the mid Atlantic Ridge) was located at could potentially correspond to an area of overlap with eastern African humpback whales (breeding stock B). Darling and Sousa-Lima (2006) showed that songs of eastern and western South Atlantic humpback whales were similar and therefore some temporal and spatial overlap between whales from the two sides of this ocean basin should occur, either in the breeding grounds but also potentially on migratory routes or feeding destinations (see also, IWC, 2006). Rosenbaum and Mate (2006) reported that a whale tagged off western Africa migrated south along Walvis Ridge, the southernmost portion of which is located 800km east of the mid Atlantic Ridge.

Feeding Grounds

The primary feeding destinations of western South Atlantic humpback whales is a region to the east of the Scotia Sea, outside of the Scotia Ridge (Fig. 2A). Whales remained in offshore waters 250-750km east-northeast of South Georgia (SG) and to the east of the South Sandwich Islands (SSIs) in a region bounded by the 52° and 60°S parallels. Two individual (87783.09) crossed the 20°W meridian, which is the current boundary between the Nucleus area associated with breeding stocks A and the Margin area between breeding stocks A and B for catch allocation purposes (IWC, 2010).

Locations for which ARS behavior was estimated suggested that most areas of high-use are spatially correlated with the southern boundary of the Antarctic Circumpolar Current (Fig. 2A). Areas to the east of South Georgia and north of the South Sandwich Archipelago were primarily used by whales monitored in 2003, 2005 and 2008. Whale 24642.03 remained in this region earlier from January to March and subsequently moved towards the SSIs. Whales tracked in 2009 migrated directly to a region further to the south, close to the SSIs and to the 60°S parallel (i.e. not using habitats further to the north, east of SG). In addition, there was no particular clear qualitative relationship between habitat use by humpback whales and the position of the Antarctic ice edge in this region (Fig. 2B). This provide further evidence that space use in high-latitude feeding grounds may change seasonally on a relatively small scale, but the feeding grounds remained consistent over the years and the period tracking was conducted.

A new finding of this study was that some individuals might be pausing their migration to exploit localized foraging opportunities in middle latitude areas. Whale 87783.09 showed a change in its movement patterns for 20 days at ~45°S (Figs 1 and 2). During this period, the typical migratory state observed at these latitudes was replaced by an ARS pattern in a region that approximately corresponds to the southern boundary of the subtropical convergence in the South Atlantic.

Further analysis will focus on a more thorough description of the habitat and will quantify relationships of whale movements and the biological and physical environment in the South Atlantic Ocean.

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Table 1 – Whales tracked through satellite telemetry in the western South Atlantic Ocean (2003, 05, 08, 09)

Whale ID No. (year)	Sex	Duty Cycling	Daily Emissions	Transmission Time	Tagging Date	Tag Longevity (days)	No. of locations after filtering	Distance traveled (km)
21810.03	M	eod[2]	300	6-21hs	18 Oct 2003	76	84	4383
24642.03	F	eod	300	6-21hs	27 Oct 2003	205	624	7258
10946.05	F	Out/Nov – eod, Dec/July – e4d[3]	300	7-22hs	19 Oct 2005	80	150	4895
24641.05	F[1]	Out/Nov – none Dec/July – e4d	300	7-22hs	19 Oct 2005	112	185	5023
37234.05	F	Out/Nov – daily Dec/July – e4d	300	7-22hs	11 Oct 2005	32	27	3445
87760.08	-	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	28 Aug 2008	44	221	4923
87761.08	M	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	28 Aug 2008	31	155	3169
87769.08	-	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	12 Sep 2008	42	71	5230
87773.08	F	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	12 Sep 2008	43	260	1980
87775.08	F[1]	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	16 Sep 2008	39	212	2582
87771.09	-	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	14 Sep 2009	61	351	6429
87783.09	F	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	9 Sep 2009	139	533	8024
88727.09	F	Aug/Nov – daily Dec/July – e2d	300	2-8, 14-20hs	19 Sep 2009	65	152	6130

[1] Assumed to be a female because it was the adult individual in a cow-calf pair; [2] eod – every other day; [3] – e4d – every fourth day

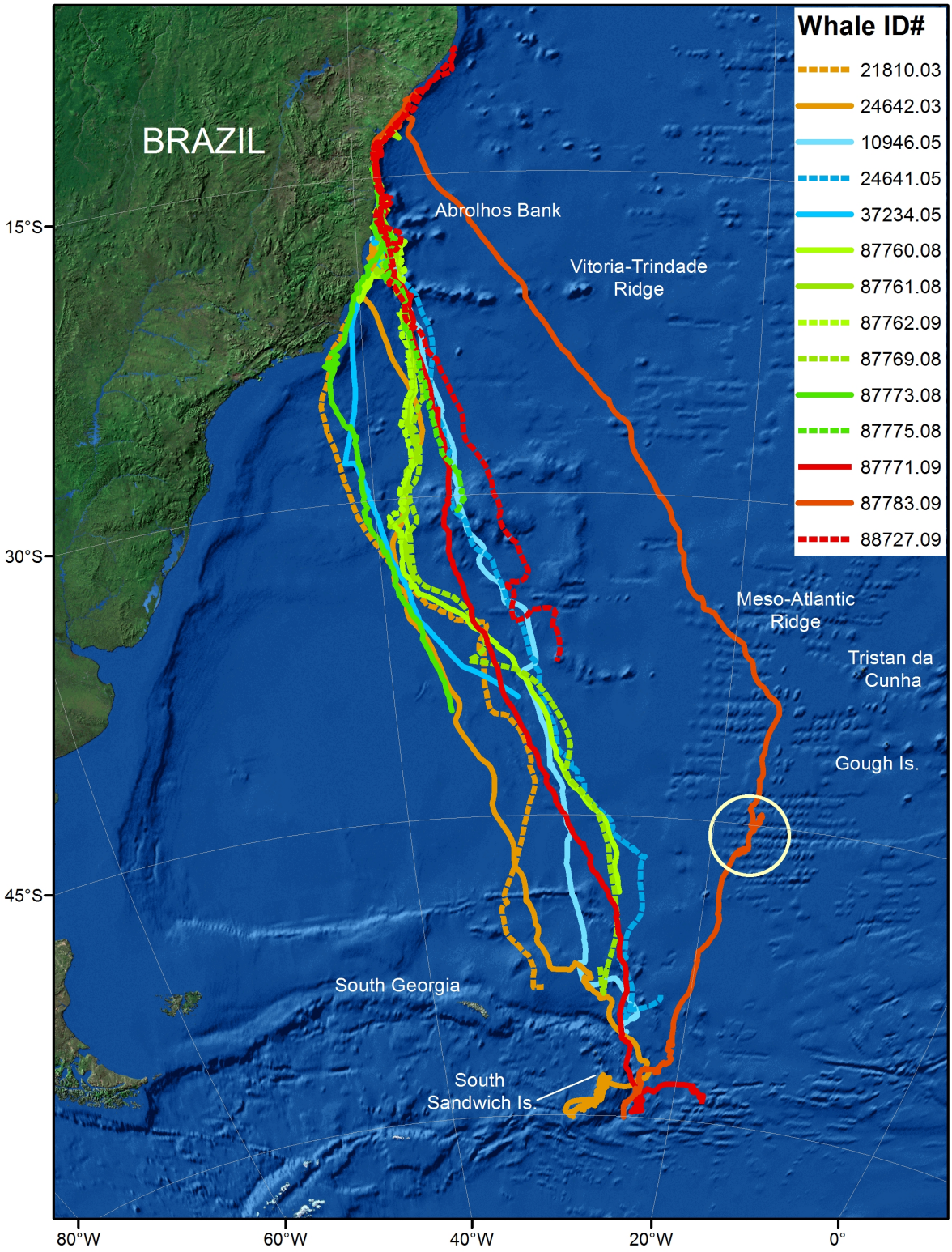
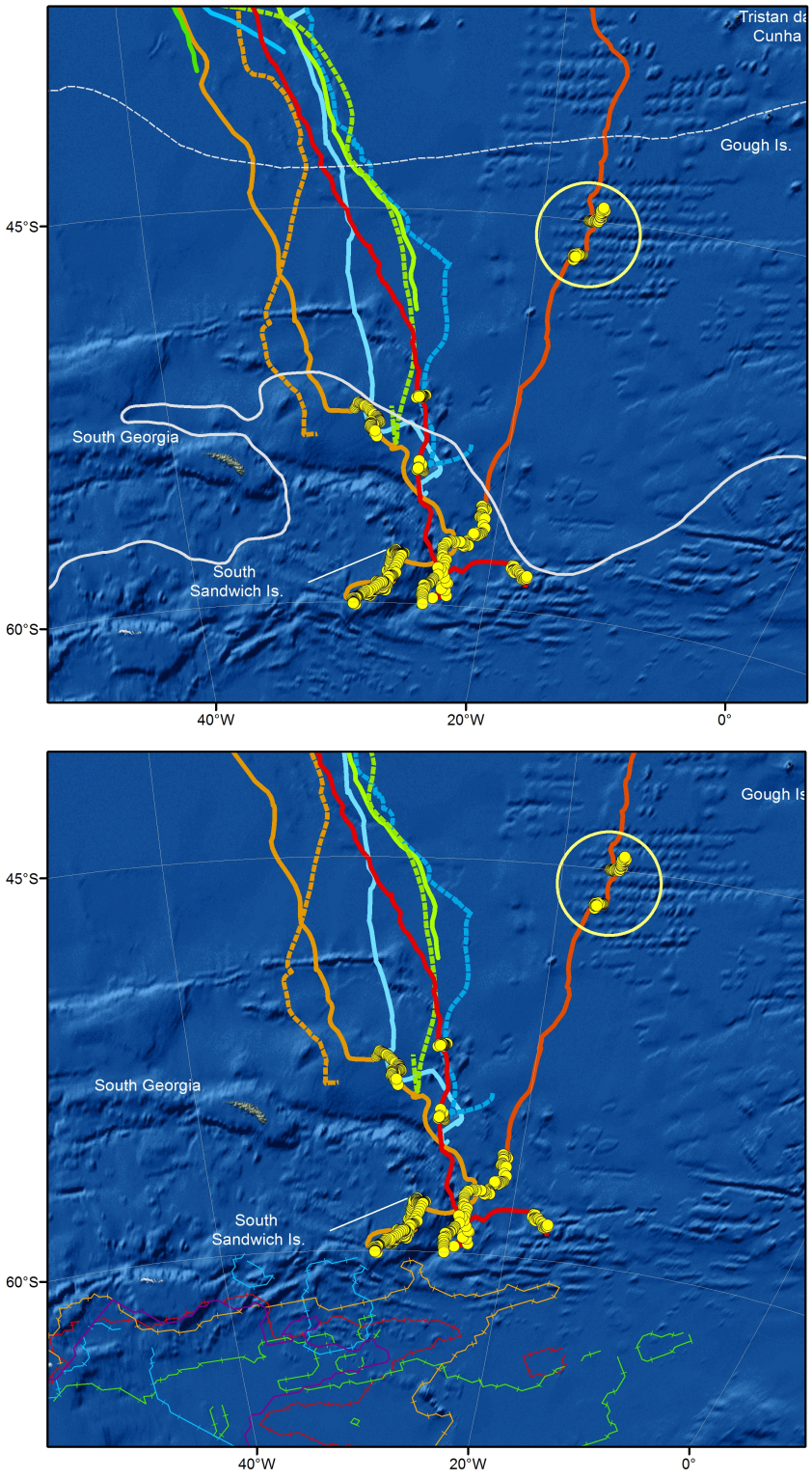


Fig 1 – Migratory routes and feeding destinations of humpback whales wintering off the eastern coast of South America. Tracks are color coded for year (2003 = orange, 2005 = blue, 2008 = green and 2009 = red).



Figs 2A (top) and 2B (bottom) showing tracks of western South Atlantic humpback whales (lines) and locations estimated as ARS by the SSSM (yellow dots). The top panel illustrates the Subtropical Front (dashed while line) and the southern boundary of the Antarctic circumpolar current (bold white line) (from Orsi *et al.*, 1995). The bottom panel shows the average pack ice extent in the summer (Dec-Mar) and is color-coded by year (2003/4 = orange, 2005/6 = blue, 2008/9 = green and 2009/10 = red) (from NSIDC, www.nsidc.org).