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First Satellite-Tracked Long-Distance Movement of a Sei Whale (*Balaenoptera borealis*) in the North Atlantic

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Abstract

Long-distance migration for most species of baleen whales is poorly understood because of the practical difficulties and substantial expense involved in gathering relevant data. Presently, satellite tracking is the only method that delivers the necessary detail and quantitative data on movement patterns on far-ranging marine mammals. In this study, ARGOS satellite tags were deployed on North Atlantic sei whales (*Balaenoptera borealis*) at the Azores Islands. Data from one whale showed a cumulative 4,102-km movement from tagging at Faial Island in the Azores on 12 April 2005 via the Charlie Gibbs Fracture Zone (CGFZ) to the Labrador Sea where transmissions stopped on 7 June 2005. For a portion of the distance from CGFZ to the Labrador Sea, the whale moved in the prevailing direction of the surface current pattern. Erratic movement in five areas along the movement track indicates feeding behaviour, particularly in the CGFZ. The results show the large-scale movement potential of North Atlantic sei whales from wintering grounds to highly productive potential feeding areas in the Labrador Sea.

Key Words: sei whale, *Balaenoptera borealis,* satellite tracking, multidisciplinary, migration, currents, Regional Oceanic Modelling System, ROMS

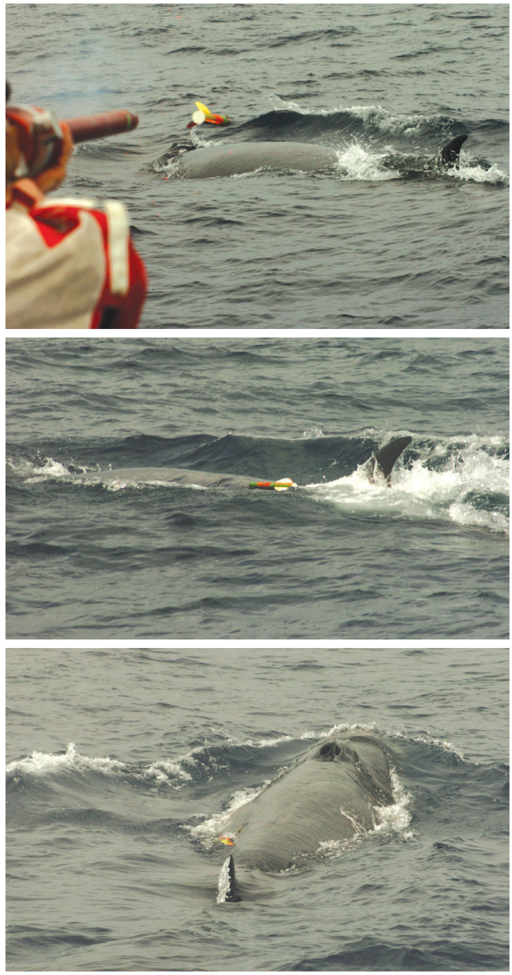
Introduction

Long-distance migration is one of the most spectacular and intriguing aspects of the life-history of animals as diverse as butterflies, birds, fishes, and whales. However, for most whale species, these migrations are poorly understood primarily because of the practical difficulties involved in gathering relevant data (Corkeron & Connor, 1999). The sei whale (*Balaenoptera borealis*) is an oceanic baleen whale that can grow up to 18 m in length (Gambell, 1985; Horwood, 1987). Like most baleen whales, it migrates from breeding grounds in subtropical and tropical waters to feeding grounds in high latitudes near either pole (Gambell, 1985; Horwood, 1987; Weir et al., 2001). Current knowledge of sei whale migrations in the North Atlantic is scant and is predominantly based on whaling records (Aguilar & Sanpera, 1982; Martin, 1983; Gambell, 1985; Kapel, 1985; Horwood, 1987; Sigurjonsson & Vikingsson, 1997), tagging studies (Ivashin, 1980; Horwood, 1987), and incidental observations (Martin, 1983). These data are mostly limited to historical whaling grounds around Nova Scotia, Labrador, Iceland, and off Norway. Studies of whale migration can be conducted using physical or biological tagging methods (Garrod & Brown, 1980; Agler et al., 1992). However, at present, the most practical and viable approach is satellite telemetry (Heide-Jørgensen et al., 2001b; Baumgartner & Mate, 2005). Furthermore, a multidisciplinary approach that examines both the physical and biological habitats of the species in question is necessary to better understand whale migrations. The present study was conceived following the 2004 MAR-ECO survey along the Mid-Atlantic Ridge with the *R/V G.O. Sars* to study whale movement patterns in the region using satellite telemetry.

Materials and Methods

Our satellite tagging experiment of sei whales around Faial Island in the Azores was conducted from 5 to 13 April 2005. Sei whales are known to aggregate in this area in early spring during the northward feeding migration. This migration has previously not been studied; however, according to traditional International Whaling Commission (IWC) Schedule stock divisions (Donovan, 1991), Azorean sei whales belong to the Iceland Denmark Strait Stock. Satellite transmitters (*Wildlife Computers SPOT 4, Mold 19*7) were tested prior to being deployed on three adult sei whales on 12 & 13 April 2005. The transmitters were attached using an ARTS (Aerial Rocket Transmitter System) airgun at 12 bar pressure at distances of ~10 m (Kleivane, 1998; Heide-Jørgensen et al., 2001a) (see photographs by Rui Prieto). The quality of the satellite fixes were evaluated based on ARGOS location quality (5 classes: A, B, Z, 0, 1, 2, and 3) and speed between consecutive fixes. ARGOS only guarantees location class accuracy for classes 3, 2, 1, and 0, while the A and B classes have no guaranteed accuracy. Vincent et al. (2002) analyzed the accuracy of all location classes and showed maximum error in longitudinal direction of 742 m for class 3, 1,355 m for class 2, 3,498 m for class 1, 15,361 m for class 0, 10,393 m for class A, and 41,219 m for class B. Errors in the latitudinal direction were smaller with a maximum of 15,535 m for class B. We *a priori* considered a maximum location error of ~41 km as acceptable when studying large-scale movement patterns of highly mobile cetaceans.

The movement track was compared with the Regional Oceanic Modelling System (ROMS) (Shchepetkin & McWilliams, 2005) and modelled the current pattern at 50-m depth from the same area and period (Lien et al., 2006) (Figures 2a & 2b). A water depth of 50 m was chosen because horizontal whale movement occurs at some depth below the surface. Area use patterns were studied by calculating cumulative time spent in 20 × 20-km grid cells assuming linear movement between consecutive locations.



Satellite tagging of sei whales (*Balaenoptera borealis*) off the Azore island Faial on 12 and 13 April 2005; the satellite transmitter is deployed using an ARTS airgun. (Photos by Rui Prieto)

Results

Two of the transmitters malfunctioned due to unknown causes as the transmitters were not recovered. All whales were followed after deployment, and the point of impact and location of attachment were verified by visual observations. The third, and functioning, transmitter yielded 112 positions over a period of 43 d from 25 April to 7 June 2005, where 34 positions were locations coded as class A, 61 of class B, 3 of class Z, eight of class 1, and two of class 2 (Figure 1). Because of the limited number of observations, we retained observations of all location classes, including Z, for initial filtering of locations. No satellite positions were disregarded as possible outliers because the highest recorded speed between consecutive positions (assuming linear movement) was 7.6 ms^{-1} (14.8 kts) lasting 8 min, which is possible based on previously recorded swimming speeds (Horwood, 1987). On average, 2.6 transmissions were received per day. Cumulative distance travelled was 4,102 km, giving a mean and median movement speed of 1.04 and 0.76 m/s, respectively (with an SD of 1.10) and were highly skewed towards lower movement speeds (70% < 1 m/s). This documents the potential of North Atlantic sei whales to undertake swift, long-distance movements, similar to what has been reported from the Southern Hemisphere (Horwood, 1987).

The analysis of time per 20 × 20-km cells identified 17 cells in five distinct areas along the track

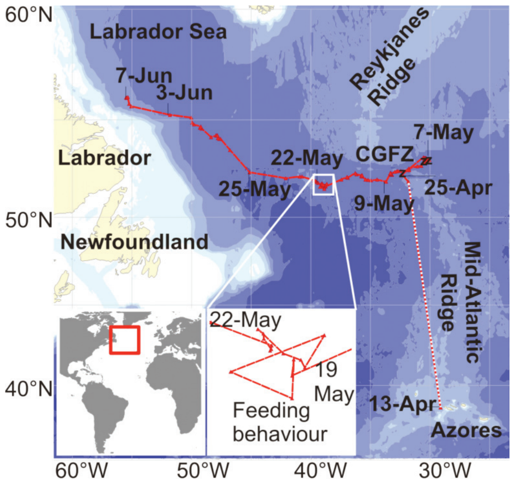


Figure 1. Movement of a sei whale (*Balaenoptera borealis*) followed by ARGOS satellite tracking from the Azores to the Labrador Sea (13 April to 7 June 2005) in relation to bathymetry and to geography in the North Atlantic study area; an example of apparent feeding behaviour is shown in the panel. Bathymetry depths (m) from white to dark grey: 200, 500, 1,000, 2,000, 3,000, 4,000, and > 4,000 m. Dotted line indicates gap from location of tagging to first transmission.

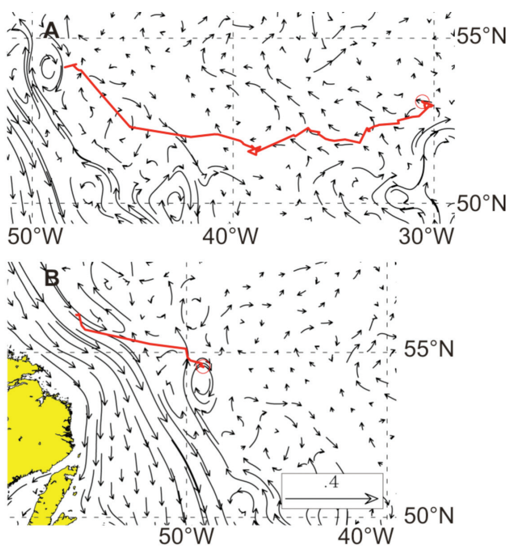


Figure 2. Monthly movement track of a sei whale in relation to the monthly mean current pattern (vector arrows); a reference vector of 0.4 ms^{-1} is shown in panel B: (A) May and (B) June 2005.

where the whale spent more than 8 h cumulative time (high-use areas; Figure 3). Together with erratic movement patterns in these areas, this suggested active feeding behaviour (Bailey & Thompson, 2006) (Figure 1). Most high-use areas were found along the Charlie-Gibbs Fracture Zone (CGFZ), an area of known high sei whale abundance (Sigurjonsson et al., 1991; Waring et al., 2009). The whale moved 1,495 km north to the CGFZ from the date it was tagged until 25 April 2005 when the first transmission was received (Figure 1). The whale swam 180 km northeast, in the same direction as the north-easterly current, from 25 April to 7 May, apparently exhibiting active feeding behaviour on its way. Thereafter, the whale moved southwest to the CGFZ and continued westward following the path of a strong westerly current from 7 to 9 May (Figure 2a). This ocean current extended from the CGFZ (30° W) to 38° W and was at its strongest in May in comparison to preceding or later months. The whale passed through an area with weak surface currents from 38° W to 42° W, avoiding areas of strong eastward currents to the south and areas with northward currents to the north of the track. It then crossed a southeasterly current moving into an area with weaker currents. After moving approximately 915 km west from CGFZ at 46° W, the whale changed direction, moving northwest along the Labrador continental shelf break. Again, the whale followed the direction of the surface currents for parts of the track (Figures 2a & 2b). The movement path in relation to the current gyre at 54° N and 49° W in Figure 2b is particularly interesting. The whale avoided entering the gyre, but after passing the gyre, the whale abruptly changed direction to follow a strong northerly current at the northern tip of the gyre. Afterwards, it turned almost 90° towards the west and continued towards Labrador following the path of weaker westward currents from 50° W to 53° W. From 5 to 7 June, the whale moved closer to the continental shelf, into the strong southeasterly current (Figure 2b). In relation to temperature, the whale moved northward and westward as the water temperature increased, arriving in the Labrador Sea after the SST rose above 3° C (Figures 2a & 3b).

Discussion

Marine mammals spend little time at the surface when at sea and therefore fewer high-quality location fixes are obtained. In the present study, only 10 of 112 fixes were of location classes 1 or 2 where ARGOS guarantees accuracy. Therefore, location fixes of poorer precision are commonly used (Vincent et al., 2002) with errors up to 41 km for some class B fixes. High errors in location fixes make inferences or analyses based purely on the movement track prone to error and we therefore chose an area-based analysis of time use to determine if the observed erratic movement patterns indicated feeding behaviour. An alternative

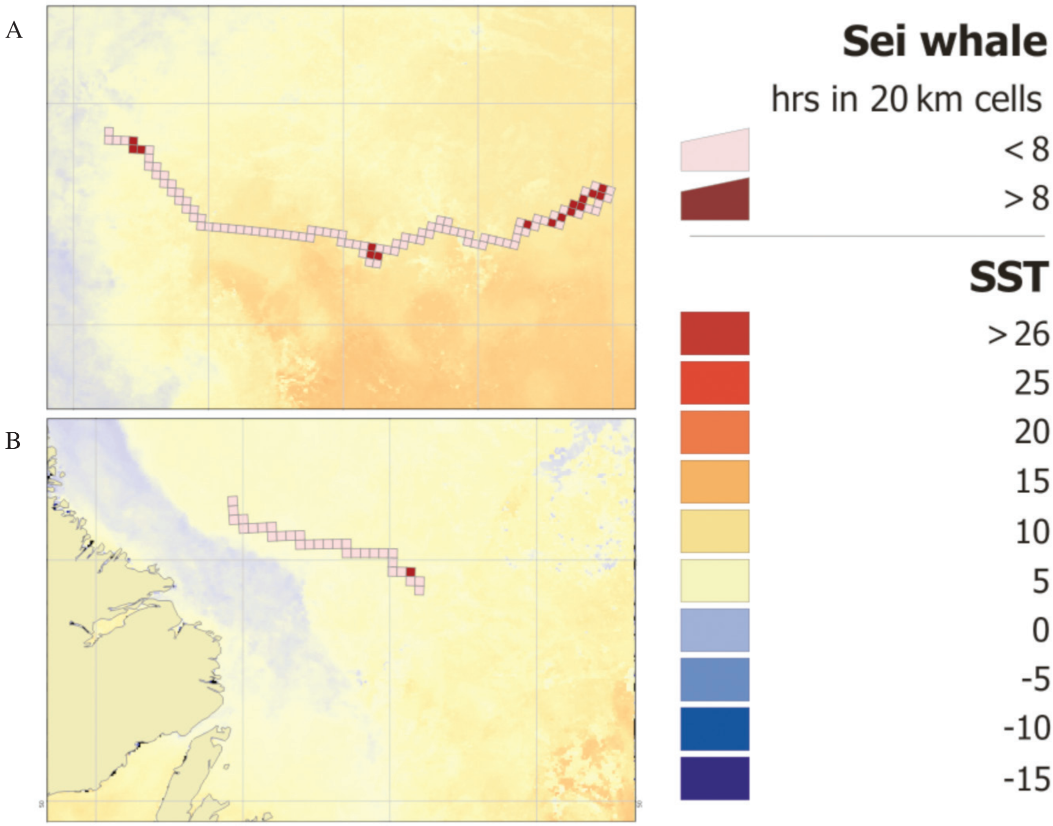


Figure 3. Cumulative time spent by a satellite-tracked sei whale in 20 × 20-km cells along the movement path and temperature fields (°C) at 50 m depth as computed with the ROMS ocean circulation model: (A) May and (B) June 2005.

method would have been to use a first-passage time (Fauchald & Tveraa, 2003; Bailey & Thompson, 2006) that is based on the raw satellite fixes and therefore directly affected by the location error whereas a 20 × 20-km area-based analysis is more robust as most location errors are contained within each cell.

Studies from the Pacific Ocean show that sei whales are strongly associated with ocean fronts and eddies (Nasu, 1966; Nemoto & Kawamura, 1977; Skov et al., 2008), oceanographic features that are in turn dependent on prevailing currents. However, these studies did not have the spatial and temporal resolution to reveal possible association between sei whales and current patterns as does the present one. Our study supports the notion that sei whales are closely associated with discrete physical and biological oceanographic features during their northward migration to feeding grounds, which also has been shown using habitat modelling by Skov et al. (2008). The whale seemed to be hitching a ride on the ocean current conveyor belts for a considerable part of its migration following the path of major current and temperature patterns. This medium-scale agreement between the whale's movement track and the spatial and temporal surface current patterns suggests that the whale chose a beneficial movement path in terms of feeding and energy conservation from the CGFZ to the Labrador Sea. Further work is needed to show the degree to which sei whales and other species conducting long-distance migrations capitalize on predictable current systems in open oceans as a means of reducing energy expenditure during migration.

Sei whales feed almost exclusively on zooplankton (Kawamura, 1974; Horwood, 1987; Sigurjonsson & Vikingsson, 1997; Baumgartner & Fratantoni, 2008). Concurrent measurements of oceanic zooplankton abundance in relation to the whale track are lacking, but investigations from the June 2004 MARECO survey (www.mar-eco.no) showed highest copepod concentrations close to the CGFZ (Gaard et al., 2008). This corresponds to the high density of sei whales observed in this area during the same (Waring et al., 2009) and previous (Sigurjonsson et al., 1991) surveys. Canadian oceanographic research data from the Labrador Sea show high densities (> 7,500 mg dry weight/m^2) of meso-zooplankton along the Labrador continental shelf from mid-May to the beginning of June 2005 (Head et al., 2003). However, even higher densities of zooplankton can be found in the Labrador slope waters and in the north central Labrador Sea (Head et al., 2003), areas where sei whales have been observed in June and July (Horwood, 1987). More recently, sei whales have been acoustically detected in the Great South Channel east of Cape Cod (Baumgartner et al., 2008), showing that western Atlantic coastal waters are important habitat and feeding areas for sei whales.

Although this study only showed the movement of a single individual, the observed feeding behaviour along the Mid-Atlantic Ridge indicates that individual sei whales are capable of using large sections of the North Atlantic Ocean for seasonal migration and feeding. Our results show that sei whales have the capacity to move large distances in short periods of time and that cross-ocean (east to west) movement occurs similar to pacific blue whales (Stafford et al., 2007), illustrating the complexity of the migration patterns of this and other species of balaenopterids. From an ecological perspective, these results illustrate the need for further telemetric and multidisciplinary studies of baleen whales to better understand their behaviour, migration, and ecology in these vast ecosystems. We need to elucidate how possible future changes in their habitat use caused by climate change may impact their distribution and ecological role.

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