Deep-Sea Research II 88–89 (2013) 14–22

Contents lists available at SciVerse ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Identifying foraging events in deep diving southern elephant seals, *Mirounga leonina*, using acceleration data loggers

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ARTICLE INFO

Available online 23 September 2012

Keywords:
Kerguelen island
Predator prey interactions
Marine ecology
Diving behaviour
Accelerometers
Mirounga leonina

ABSTRACT

Southern elephant seals (*Mirounga leonina*) range widely throughout the Southern Ocean and are associated with important habitats (*e.g.*, ice edges, shelf) where they accumulate energy to fuel their reproductive efforts on land. Knowledge of the fine scale foraging behaviour used to garner this energy, however, is limited. For the first time, acceleration loggers were deployed on three adult southern elephant seals during a translocation study at Kerguelen Island. The aims of the study were to (1) identify prey capture attempts using 2-D accelerometer tags deployed on the head of southern elephant seals, (2) compare the number of foraging dives identified by simple dive depth profiles and accelerometer profiles and (3) compare dive characteristics between prey encounter and non-prey encounter dives. The 2-D loggers recorded depth every second, surge and heave accelerations at 8 or 16 Hz and were carried for periods between 23 and 121 h. Rapid head movements were interpreted to be associated with prey encounter events. Acceleration data detected possible prey encounter events in 39–52% of dives whilst 67–80% of dives were classified as foraging dives when using dive depth profiles alone. Prey encounters occurred in successive dives during days and nights and lasted between tenths of a second and 7.6 min. Binomial linear mixed effect models showed that seals were diving significantly deeper and increased both descent rate and bottom duration when encountering prey. Dive duration, however, did not significantly increase during dives with prey encounters. These results are in accordance with optimal foraging theory, which predicts that deep divers should increase both their transit rates and the time spent at depth when a profitable prey patch is encountered. These findings indicate that this technique is promising as it more accurately detects possible prey encounter events compared with dive depth profiles alone and thus provides a better understanding of seal foraging strategies.

1. Introduction

Southern elephant seals, *Mirounga leonina*, are a large and abundant phocid predator at the top of the Southern Ocean food web (Guinet et al., 1996; Hindell et al., 2003). During long migrations, individuals typically make ocean journeys of thousands of kilometres in order to feed sufficiently to fuel their brief reproductive effort on land (McConnell et al., 1992). These deep-diving predators are associated with important habitats such as the ice edges and the continental shelf (Bailleul et al., 2010; Biuw et al., 2007). The details of their diet, however, are still largely unknown because their stomach contents are usually entirely digested by the time they return to land. Recent studies using isotope analyses suggest that female and juvenile elephant seals feed mainly on myctophids and not predominantly on cephalopods as previously assumed (Bailleul et al., 2010; Cherel et al., 2008; Newland et al., 2011). The spatial and vertical distribution of potential prey is also poorly understood. Several behaviour-derived foraging metrics (*e.g.* transit swim speed, diving depth, diving duration, drift rate, wiggles) have been used to identify foraging habitats and/or foraging success for elephant seals (Biuw et al., 2007; Bailleul et al., 2007, 2008; Dragon et al., 2012a, 2012b; Field et al., 2001; Hindell et al., 1991; McConnell et al., 1992; Robinson et al., 2010; Thums et al., 2011), and although these studies are crucial for investigating key habitats they cannot provide the necessary fine-scale information of when and where these top predators encounter their prey.

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0967-0645/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2012.09.002

Despite its importance, the feeding behaviour of most marine mammals is poorly understood because it usually occurs at great depth, over large spatial scales and in a particularly challenging environment. Bio-logging technology can overcome these problems by enabling the remote measurement of data for free-ranging animals (Cooke et al., 2004; Ropert-Coudert and Wilson, 2005; Rutz and Hays, 2009). Animal-borne video recorders and acoustic tags have provided new insights into the functionality of dive types and the detail of fine-scale foraging behaviour (Arranz et al., 2011; Davis et al., 2003; Fuiman et al., 2002; Hooker et al., 2002; Johnson et al., 2004; Madsen et al., 2005; Marshall et al., 2007; Watanabe et al., 2003). Due to restrictions in the amount of digital memory, however, the data cover a relatively short periods of time when recording continuously (Watanabe et al., 2003). More recently accelerometer tags have emerged as a powerful tool for investigating the foraging behaviour of marine predators. For example, some of the first evidence of the relationship between prey capture attempts and increases in dynamic acceleration were observed in toothed whales by relating acoustic indicators of feeding (buzzes) with body movements (Johnson et al., 2004; Miller et al., 2004). Accelerometer tags can measure body acceleration in up to three dimensions (*i.e.* surge, stroke and rolling). Using measurements in these three dimensions, prey capture and biting motions associated with biting are used to quantify feeding events (Aguilar Soto et al., 2008; Kokubun et al., 2011; Naito, 2007; Naito et al., 2010; Ropert-Coudert et al., 2004; Sato et al., 2008; Suzuki et al., 2009; Viviant et al., 2010). Accelerometer tags have the advantage of being externally mounted, providing a simple and practical field technique, compared with previously used internal data loggers (*i.e.* stomach and oesophageal temperature sensors) (Ancel et al., 1997; Charrassin et al., 2001; Kuhn et al., 2009; Wilson et al., 1992) or intra-mandibular angle sensor methods (Fossette et al., 2008; Liebsch et al., 2007; Wilson et al., 2002).

Several studies have shown that for seals, feeding and capture motions are especially visible in the surging axis when using jaw- or head-deployed acceleration data-loggers (Naito et al., 2010; Skinner et al., 2009; Suzuki et al., 2009; Viviant et al., 2010). Seals have a high propulsive efficiency which is due to the maintenance of nearly continuous thrust production during the stroke cycle and a hydrofoil morphology which enhances high thrust with reduced drag (Fish, 1994). Any stroking movements will increase drag and the cost of locomotion; thus swimming with discrete stroke and glide phases, as seals do, has been identified as a particularly efficient way of travelling (Williams and Kooyman, 1985). As deep divers, southern elephant seals are expected to adopt the most energetically efficient mode of locomotion and thus should avoid any unnecessary movements that would increase their drag and therefore their cost of swimming when diving. In this study, we used rapid head movements that are not associated with the propulsive activity of southern elephant seals to identify prey encounter events. More specifically, the aims of the study were to (1) identify prey capture attempts using 2-D accelerometer tags deployed on the head of southern elephant seals, (2) compare the number of foraging dives identified by dive depth profiles and accelerometer profiles and finally (3) compare dive characteristics between prey encounter and non-prey encounter dives.

2. Materials and methods

2.1. Study sites and animals

Three pre-moulting adult female southern elephant seals (T3, T4 and T5) were equipped with data loggers during a translocation study in 2005 on the Kerguelen Plateau (49 35S 70 26E). All seals were caught with a canvas head-bag and anaesthetized with a 1:1 combination of tiletamine and zolazepam (Zoletil 100) injected intra-venously (Field et al., 2002; McMahon et al., 2000). Individuals were equipped with Relayed Data Logger tags (SRDL) (SMRU, St. Andrews, UK) and 2D acceleration data loggers (Loggend, CNRS, France). The accelerometers were positioned on the head (T4 and T5) and the neck (T3) of the animals. The position of the accelerometer was lower on seal T3 as this individual was also equipped with an intra-mandibular angle sensor placed on the head and jaws of the animal to record mouth opening movements that unfortunately did not function. Tags were glued onto the seal fur using a two-component quickset epoxy. Individuals were then placed in specially designed wooden boxes, and then transported by R/V ‘La Curieuse’ approximately 240 km away from the Island (approximately 24 h journey time) to be released. As seals had already come ashore to moult they were likely to return to land, thereby increasing the likelihood of recovering the tags. Table 1 provides descriptive information on the study animals.

2.2. Instruments

We used accelerometer tags: 2-D loggers (0.009 m length, 0.003 m width, 0.002 m height, 0.063 kg in air, Loggend, CNRS, France). The accelerometer tags recorded pressure at 1 s intervals and 2-D accelerations to detect head movements at 8 Hz for individuals T4 and T5 and at 16 Hz for individual T3 with a memory of 16 Mb. Seals were also equipped with SRDL satellite tags to provide an estimate of the location of the animals at sea and on land.

The 2-D loggers require physical recovery for data retrieval. We used the Argos positions received through the satellite tags to

Table 1
Descriptive information about the three adult female southern elephant seals.

Seal	Body mass[a](kg)	Capture date (dd/mm/yyyy) and location	Release date (dd/mm/yyyy) and location	Recapture date (dd/mm/yyyy)[b]	Accelerometers' recording duration (h)
T3	407	24/01/2005 49°20.900S/70°13.683E	25/01/2005 49°16.812S/73°35.999E	27/01/2005	41.4
T4	317	04/02/2005 49°20.900S/70°13.683E	05/02/2005 49°02.237S/72°24.252E	09/02/2005	73.5
T5	489	04/02/2005 49°20.900S/70°13.683E	05/02/2005 49°02.237S/72°24.252E	09/02/2005	21.7

[a] Body mass at first capture.
[b] The precise location of recapture was not recorded but it was between 49°20.900S/70°13.683E and 49°25.100S/70°17.033E.