Journal of Experimental Marine Biology and Ecology 508 (2018) 27–34

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

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

Evidence of behavioural thermoregulation by dugongs at the high latitude limit to their range in eastern Australia

Daniel R. Zeh[a,b,c,*], Michelle R. Heupel[b,c], Mark Hamann[c], Rhondda Jones[c], Colin J. Limpus[d], Helene Marsh[c]

[a] AIMS@JCU, Australian Institute of Marine Science, College of Marine and Environmental Sciences, Townsville, Queensland 4811, Australia
[b] Australian Institute of Marine Science, Townsville, Queensland 4810, Australia
[c] College of Marine and Environmental Sciences, James Cook University, Townsville, Queensland 4811, Australia
[d] Aquatic Threatened Species Unit, Department of Environment and Science, 41 Boggo Rd., Dutton Park, Queensland 4102, Australia

ARTICLE INFO

Keywords:
Dugong
Movements
Behavioural thermoregulation
Acoustic telemetry
Satellite telemetry

ABSTRACT

Many species of marine mammals have evolved behavioural adaptations to minimize heat loss to the surrounding water. We tracked 21 dugongs (*Dugong dugon* Müller 1776) using acoustic and satellite/GPS transmitters in 2012, 2013 and 2014 in Moreton Bay, Queensland at the high latitude limit of the species' winter range in eastern Australia to examine if there was a relationship between movements and environmental temperature that might suggest behavioural thermoregulation. Oceanic waters immediately outside the bay where the dugong's seagrass food is unavailable exhibited temperatures from 5.5 °C warmer to 3 °C cooler than the Eastern Banks, the major dugong habitat in the bay. All tracked dugongs made at least one (and up to 66) return trip(s) from the Eastern Banks to the adjacent oceanic waters. The probability of making an outgoing trip was highest in 2014 and lowest in 2013 when the water temperature inside the bay was higher than the other two years. The odds of making an outgoing trip were lower when temperature differences (outside minus inside) were small or negative but increased by a factor of up to 2.12 for each 1 °C positive difference. Individual dugongs were most likely to travel out of the bay between midnight and noon on an outgoing tide or at slack high water and return to the bay on an incoming tide or slack low water between noon and midnight. The amount of time a dugong spent outside the bay on each trip was relatively short with an overall median of 5.9 h. The dugongs' individual activity spaces generally declined as winter progressed suggesting a change in the cost-effectiveness of moving outside the bay. Our analysis adds to the evidence that dugongs undertake behavioural thermoregulation at least at the high latitude limits of their range.

1. Introduction

Marine mammals live in thermally challenging environments. The thermal conductivity of water is nearly 25 times greater than air at 25 °C and water temperatures are almost always lower than the mammalian core body temperature of 35 - 38 °C (Gallivan et al., 1983; Irvine, 1983; Ponganis, 2015). Marine mammals have evolved a range of morphological, physiological and behavioural adaptations to minimize heat loss to the environment (Estes, 1989; Pabst et al., 1999). Much of the research has focused on pinnipeds, which face increased temperature challenges when they haul out (see Castellini, 2018 for references). Associations between sea surface temperatures (SST) and the movements and behaviors of some whales have also been quantified. For example, bowhead whales (*Balaena mysticetus*) move within a narrow temperature range of −0.5 to 2 °C in the Arctic (Chambault et al., 2018) as do North Atlantic right whales (*Eubalaena glacialis*) in their winter calving grounds off Florida (Keller et al., 2006). Nonetheless, as pointed out by (Ropert-Coudert et al., 2009), separating the direct effects of the physical environment on the movements of marine megafauna from the indirect effects of temperature on their food sources can be a significant challenge. Species such as sirenians that feed on stationary prey like benthic marine plants offer an opportunity to isolate the effects of temperature.

The extant sirenians (manatees and dugongs) are medium-sized marine mammals with limited morphological and physiological capacity to deal with heat loss (Elsner, 1999). Sirenians have generally been

* Corresponding author at: AIMS@JCU, Australian Institute of Marine Science, College of Marine and Environmental Sciences, Townsville, Queensland 4811, Australia.

E-mail address: daniel.zeh@my.jcu.edu.au (D.R. Zeh).

https://doi.org/10.1016/j.jembe.2018.08.004
Received 28 March 2018; Received in revised form 10 August 2018; Accepted 20 August 2018

restricted to tropical and subtropical waters throughout their evolutionary history (Marsh et al., 2011). The extinct Steller's sea cow was an exception, most likely due to its gigantism and resultant low surface area/volume ratio.

The behavioural response of sirenians to water temperature has been extensively studied in the Florida manatee, *Trichecus manatus latirostris* (see review by Marsh et al., 2011). Dugongs have higher metabolic rates than Florida manatees (Lanyon et al., 2006, Lanyon pers. comm. 2018), possibly enabling them to tolerate water a few degrees colder than the Florida manatee's lower limit of about 20 °C (Horgan et al., 2014; Marsh et al., 2011). Nonetheless, with morphological and physiological limitations to their thermoregulatory capacity similar to those of manatees, dugongs are also likely to have developed behavioural adaptations to cope with winter water temperatures at the higher latitude limits to their range. Indeed, dugongs exhibit different summer and winter distributions in widespread higher latitude habitats including Saudi Arabia (Preen, 2004), western Australia (Holley et al., 2006), eastern Australia (Sheppard et al., 2006) and New Caledonia (Cleguer, 2015).

Moreton Bay (27°S) is a large (~1500 km^2) shallow embayment at the high latitude limit of the dugong's winter range on the east coast of Australia (Allen et al., 2004; Marsh et al., 2002). Minimum winter water temperatures in Pumicestone Passage at the western edge of the bay average below 16° C (Lanyon et al., 2005). Nonetheless, as many as 15 dugongs may be sighted at the southern end of Pumicestone Passage even in winter (Lanyon et al., 2005) although it is not known how long each individual stays in this region. Opinions differ (see Horgan et al., 2014; Lanyon et al., 2015; Owen et al., 2015) on whether dugongs are susceptible to the cold stress syndrome that affects Florida manatees (Bossart et al., 2004; Deutsch et al., 2003) and the way dugongs respond to water temperatures lower than about 18 °C is not clear.

South Passage links the dugong's major seagrass habitat on the Eastern Banks in Moreton Bay to the adjacent oceanic environment (Fig. 1). Dugongs have been documented using oceanic areas that do not support seagrass close to South Passage in winter (Lanyon, 2003; Marsh and Sinclair, 1989; Preen, 1992). Preen (1992) suggested that the only obvious resource for dugongs in these oceanic waters would be as a refuge from the colder water temperatures inside Moreton Bay. We used animal-borne telemetry to study the movements of dugongs in and out of Moreton Bay in winter to explore whether these movements could be interpreted as behavioural thermoregulation.

We asked the following research questions:

- What factors are associated with the likelihood of a dugong making a local scale trip to the oceanic waters outside Moreton Bay on any monitored day?
- What factors are associated with the timing and duration of dugong movements outside the bay within any monitored day?
- How do individuals change their activity space inside the bay across the winter months?

2. Materials and methods

2.1. Tracking dugongs

Dugongs were captured opportunistically in seagrass habitats in Moreton Bay (see Fig. 1) during blocks of dedicated fieldwork in 2012, 2013 and 2014 and classified as adults, sub-adults and juveniles based on direct line measurement of body length (see Lanyon (2003) and Burgess et al. (2012) for size categories).

As described in Zeh et al. (2015), the tracking hardware was attached externally using a harness and consisted of an ARGOS GPS transmitter with Quick Fix Pseudoranging (QFP) technology (Gen 4 Marine Unit, Telonics, USA) and an acoustic transmitter which recorded the seawater temperature and the animal's depth (V16TP, Vemco, NS, Canada). The harness incorporated a weak link designed to break under stress if the tether snagged and a corrodible link to release the harness and tether after several months.

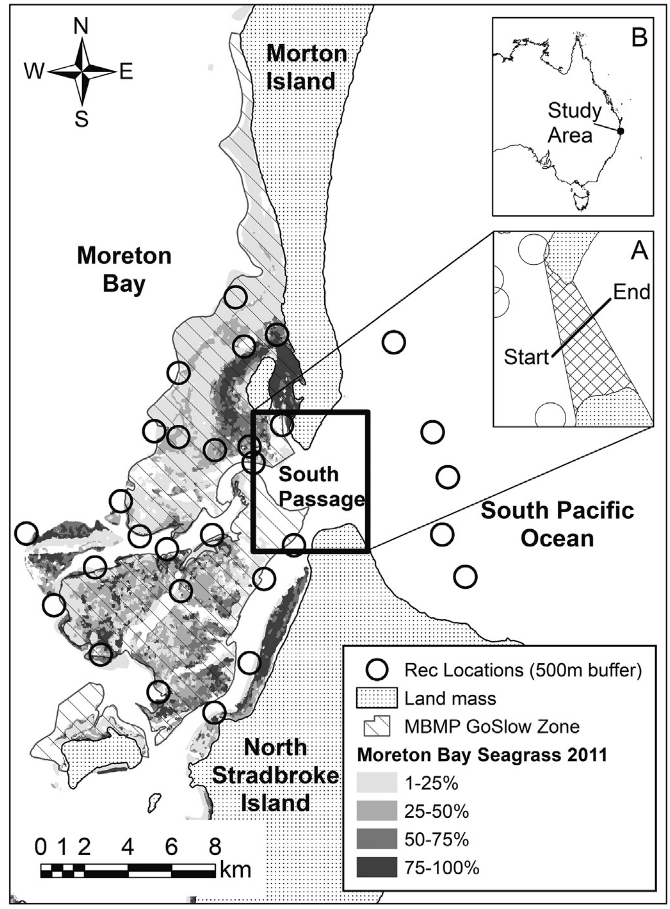

Fig. 1. Map of the Moreton Bay study area showing the distribution of seagrass and the locations of the recorders (Rec locations) in the acoustic array in the area where the dugongs were captured and tracked. Inset A highlights the South Passage polygon (also referred to as the exclusion zone) used to separate data as occurring inside the Eastern Banks or occurring in the oceanic waters immediately outside. A typical trip is shown and labelled with start and end points. Inset B shows the location of the study area in Queensland, Australia.

The ARGOS GPS (QFP) transmitters were programmed to emit a GPS position hourly. Location data for each dugong were compiled daily and collected through the ARGOS website from the time the telemetered dugong was released until the transmitter detached or stopped transmitting. The tag detachment time was determined by the clear difference between the pre- and post-detachment track patterns. The post-detachment tracks were much smoother as the detached transmitter floated with the current, enabling the overall GPS transmitter deployment time to be estimated accurately. All tracking data were truncated at the estimated detachment time to ensure that the activity space estimates excluded drift data.

The hourly GPS location data used to analyze movements between Moreton Bay and the regions outside the bay near South Passage (Fig. 1) were filtered but not binned to capture all available movements. Locations were filtered using a custom R (R Core Team, 2014) script based in part on previous speed-filters (Austin et al., 2003; Flamm et al., 2001; Freitas et al., 2008; McConnell et al., 1992) to: (1) eliminate duplicate times or duplicate consecutive locations, (2) retain only "Successful" and "Resolved QFD" data (i.e., the most accurate and most reliable data) and (3) remove spurious consecutive data points that resulted in calculated speeds either > 20 km/h for maximum burst swimming speed or > 10 km/h for maximum cruising speed (Marsh et al., 1981; Marsh et al., 2011). Locations on land were deleted.