Journal of Experimental Marine Biology and Ecology 450 (2014) 30–39

Contents lists available at ScienceDirect

Journal of Experimental Marine Biology and Ecology

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

Special issue: Charismatic marine mega-fauna

Modelling harbour seal habitat by combining data from multiple tracking systems

Helen Bailey [a,b,c,*], Philip S. Hammond [d], Paul M. Thompson [b]

[a] SMRU Ltd., New Technology Centre, North Haugh, St Andrews, Fife KY16 9SR, UK
[b] University of Aberdeen, Institute of Biological & Environmental Sciences, Lighthouse Field Station, Cromarty, Ross-shire IV11 8YJ, UK
[c] Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD 20688, USA
[d] Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, Fife KY16 8LB, Scotland, UK

ARTICLE INFO

Keywords:
Density
Habitat preference model
Phoca vitulina
Spatial ecology
State-space model
Telemetry

ABSTRACT

Technological developments over the last 20 years have meant that telemetry studies have used a variety of techniques, each with different levels of accuracy and temporal resolution. This presents a challenge when combining data from these different tracking systems to obtain larger sample sizes or to compare habitat use over time. In this study, we used a Bayesian state-space modelling approach to integrate tracking data from multiple tag types and standardise position estimates while accounting for location error. Harbour seal (*Phoca vitulina*) telemetry data for the Moray Firth, Scotland, were collated from three tag types: VHF, Argos satellite and GPS–GSM. Tags were deployed on 37 seals during 1989 to 2009 resulting in 37 tracks with a total of 2886 tracking days and a mean duration of 87 days per track. A state-space model was applied to all of the raw tracks to provide daily position estimates and a measure of the uncertainty for each position. We used this standardised tracking dataset to model their habitat use and preference, which was then scaled by the population size estimated from haul-out counts to give an estimate of the absolute number of harbour seals using different parts of the Moray Firth. As expected for a central place forager, harbour seals most frequently occurred in areas close to their inshore haul-out sites. However, our analyses also demonstrated consistent use of offshore foraging grounds, typically within 30 km of haul-out sites in waters <50 m deep. The use of these statistical models to integrate and compare different datasets is especially important for assessing longer-term responses to environmental variation and anthropogenic activities, allowing management advice to be based upon datasets that integrate information from all available tracking technologies.

1. Introduction

Technological developments over the last 20 years have meant that telemetry studies have used a variety of techniques, each with different levels of accuracy and temporal resolution (e.g. Costa et al., 2010; Hazen et al., 2012a). This presents a challenge when combining data from these different tracking systems to obtain larger sample sizes or to compare habitat use over time. Such studies are important for making population level inferences and assessing the effects of environmental change. They are also of great benefit to management for informing marine spatial planning, marine protected area designations, and environmental impact assessments.

Radio telemetry and acoustic telemetry allow animals tagged with transmitters to be tracked through the use of fixed or portable directional receivers. Radio signals transmit poorly in saltwater, but have been used to track the movements of fish within rivers and streams (David and Closs, 2002; Goclowski et al., 2013; Peters et al., 2006). They have also been used on marine species that regularly return to the surface, such as seabirds and marine mammals (Culik et al., 1998; Read and Gaskin, 1985; Thompson and Miller, 1990). However, these studies were constrained by the need to make contact with the tagged animal at sea and tended to be limited in duration and to more coastal areas. The development of satellite-monitored radio tags, which allows signals to be detected and localised across the globe, has resulted in a much greater understanding of the movements of marine species, particularly farther offshore (e.g. Block et al., 2011). It has also revealed the wide extent of migrations, such as that of sea turtles across entire ocean basins (Hays et al., 2004; Nichols et al., 2000). The low spatial accuracy, with several kilometres of error, for many positions at sea received through the ARGOS satellite location system has hindered its use for fine-scale studies, but this is now being overcome through the use of GPS (Global Positioning System) technologies, such as Fastloc and GSM (Global System for Mobile Communications) GPS (Costa et al., 2010; McConnell et al., 2004). These positions may be accurate to within 30 m (Cordes et al., 2011; Hazel, 2009).

Telemetry provides a valuable tool for determining spatial distributions and this can be combined with information on the environment to identify the habitat characteristics attracting animals to those locations. For example, a study combining electronic tagging data from 23 species of marine predators in the North Pacific utilised a state-

* Corresponding author at: Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD 20688, USA. Tel.: +1 410 326 7284.
E-mail address: hbailey@umces.edu (H. Bailey).

0022-0981/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jembe.2013.10.011

space modelling framework to account for the location errors from a mixture of tag types (Argos satellite, archival geolocation and pop-up satellite archival tags), which had substantially different levels of spatial accuracy (Block et al., 2011; Winship et al., 2012). A state-space model is a time-series model that predicts the future state of a system from its previous states probabilistically and is being increasingly used in animal movement studies (Jonsen et al., 2013; Patterson et al., 2008). The relative density of predator species based on these modelled locations have been related to oceanographic variables (Block et al., 2011) and used to assess the potential effect of climate change on their distribution (Hazen et al., 2012b). Characterising habitat preferences is important for identifying high-use areas and focusing management efforts for protected species (Bailey and Thompson, 2009; Benson et al., 2011). It also plays a role in the development of habitat-based stock assessment models for fisheries and understanding predator–prey relationships (Nelson et al., 2010; Schaefer et al., 2007; Semmens, 2008).

In this study, we used the state-space model framework for analysis of movement data (Jonsen et al., 2003, 2005, 2013) to integrate tracking data for harbour seals (*Phoca vitulina*) from multiple tag types and standardise position estimates while accounting for location error. Broad-scale surveys across Scotland have revealed that harbour seals have declined significantly in most areas (Lonergan et al., 2007). They are resident in the Moray Firth throughout the year, breeding and resting on inter-tidal sandbanks in the inner Moray Firth (Thompson et al., 1996), and making regular foraging trips into the central and outer Moray Firth (Thompson et al., 1998). Protection has mainly focused on the terrestrial haul-out sites, but the potential influence of food availability, predation, and competition with fishermen on the population decline has led to increased interest in their foraging areas and spatial distribution at sea (Cordes et al., 2011; Lonergan et al., 2007). Over the last 20 years, several different studies have used tracking devices to study the foraging movements of harbour seals from the Dornoch Firth and Loch Fleet (Cordes et al., 2011; Sharples et al., 2009, 2012; Thompson et al., 1996, 1997, 1998). In this study, we analysed the spatial distribution of harbour seals from these tracking studies (VHF, Argos satellite and GPS–GSM telemetry) to determine if there were any changes over time. These data were then related to environmental variables to identify the factors influencing their distribution and to characterise the habitat preferences of harbour seals.

Spatial predictions that incorporate environmental data provide a valuable tool for conservation by quantifying the relative or absolute abundance of animals within contiguous areas that may not have been evenly surveyed or where few observations exist (Cañadas et al., 2005; Forney et al., 2012). We used our habitat preference model and population abundance estimate to predict densities across the Moray Firth. This is of particular relevance to management because two sites have been proposed for offshore wind energy development in the outer Moray Firth and harbour seals are listed under Annex II of the European Commission Habitats Directive (Council Directive 92/43/EEC). This requires the designation of Special Areas of Conservation (SAC), and an assessment of the connectivity between proposed offshore wind energy sites and nearby harbour seal SACs. Our analysis of these telemetry data aimed to provide information on the origin of seals that may be encountered at the proposed wind energy sites, thereby informing assessments of the extent to which far-scale effects, such as construction noise, may overlap with areas used by harbour seals (see Thompson et al., 2013).

2. Materials and methods

2.1. Telemetry data

Telemetry data were available from 37 individual seals that were captured in either Loch Fleet or the Dornoch Firth in Scotland (Fig. 1) and tagged between 1989 and 2009 (Table 1). Seals were captured using either hand nets or beach seine nets, and then sedated with ketamine hydrochloride and diazepam or Zoletil. Standard length and girth measurements were taken and the sex identified. The tags were glued to the hair on the head or neck using a fast setting epoxy resin (Fedak et al., 1983). The capture and handling of seals were carried out under licences issued from the Scottish Government and the Home Office. The capture and handling techniques are described in Thompson et al. (1992).

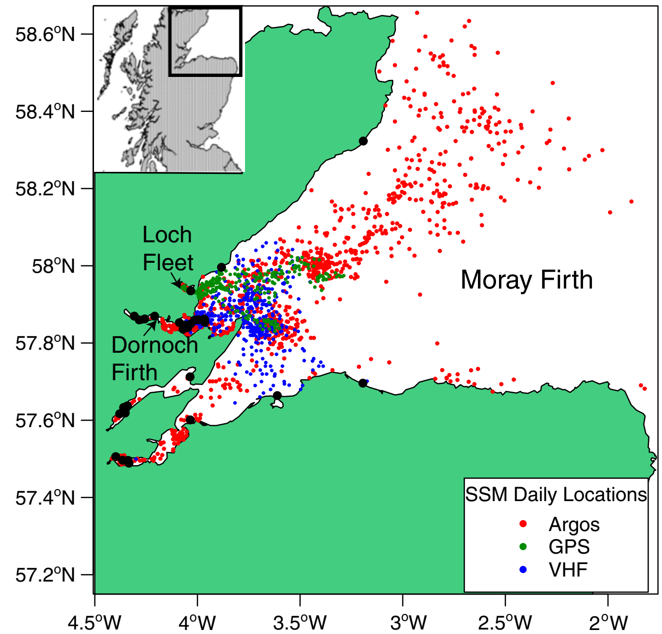

Fig. 1. Daily harbour seal state-space model (SSM) locations derived from Argos satellite (red), GPS (green), and VHF (blue) positions (circles). The haul-out sites are shown as black circles.

2.1.1. VHF telemetry

Between 1989 and 1991, 21 VHF (very high frequency) radio tags were attached to harbour seals to study their behaviour (Thompson et al., 1997) and foraging ecology (Thompson et al., 1998) (Table 1). Subsequent tracking of these individuals was designed to collect one position per day for 6 days per week. Radio-fixes were made from coastal vantage points with a three-element Yagi aerial using the null average method (Springer, 1979). The accuracy of fixes was estimated using a test transmitter, and the standard deviation of the error between estimated and true bearings used to produce 95% confidence limits for fixes on radio-tagged seals (Thompson and Miller, 1990).

2.1.2. Satellite telemetry

Between 2004 and 2007, 11 satellite relay data loggers (SRDLs) were attached to harbour seals in the Moray Firth as part of a broader study of harbour seal foraging distribution around the UK (Sharples et al., 2009) (Table 1). These SRDLs transmit data via the Argos system (McConnell et al., 1999). Service Argos allocates all positions to one of seven location classes, which describe the quality of those locations. Marine animal tracking studies using Service Argos typically result in low accuracy positions and location errors may be up to several kilometres (Costa et al., 2010).

2.1.3. GPS–GSM telemetry

In 2009, GPS–GSM tags were attached to five harbour seals in the Moray Firth to determine whether recent changes in haul-out distribution were linked to changes in foraging area use (Cordes et al., 2011) (Table 1). These GPS–GSM tags combine a GPS sensor with a mobile phone GSM modem to relay data ashore (McConnell et al., 2004). As a result, they are able to produce much more frequent locations, providing a mean of 37 GPS positions per day compared to 10 Argos positions per day. They