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All at sea with animal tracks; methodological and analytical solutions for the resolution of movement

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Abstract

Determining the movement of marine animals is logistically difficult and is currently primarily based on VHF and satellite-tracking telemetry, GPS, acoustic telemetry, and geolocation, all of which have substantial limitations in accurately locating the fine-scale movements of these animals. A recent development—that of dead-reckoning—is being increasingly used to examine the fine-scale movement of animals underwater. The advantages and drawbacks of this approach are quite different to those incurred by the other methods. This paper considers the advances that dead-reckoning can bring to the study of the often cryptic movement and behaviour of marine animals at sea. Methods used in determining position via dead-reckoning are presented and consideration is given to results derived from the use of dead-reckoning on cetaceans, pinnipeds, penguins and sea turtles; these are complemented by data on cormorants and albatrosses acquired using GPS systems. Suggestions are made as to how movement data derived from these devices can be analysed using indices that allow interpretation over a large variety of temporal and spatial scales.

Keywords: Data loggers; Dead-reckoning; Habitat selection; Navigation; Telemetry; Track tortuosity

1. Introduction

There are essentially six methods for determining the position of marine animals at sea when they cannot be observed directly. Four of these will only work if the animal is at the surface for some period;

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VHF telemetry (Hooker et al., 2002 and references therein), satellite tracking telemetry (Ferraroli et al., 2004; Hays et al., 2004a; Jouventin and Weimerskirch, 1990; Sims et al., 2005), GPS technology (Weimerskirch et al., 2005), and geolocation or global location sensing (e.g., Block et al., 2001; Hill, 1994; Wilson et al., 1994). Only two methods work underwater, these being acoustic telemetry (e.g., Hindell et al., 2002) and dead-reckoning (Wilson and Wilson, 1988). Acoustic telemetry necessitates that receivers be within a few hundred metres of the animal to be tracked so that fast and widely ranging species are difficult to access with this method. Dead-reckoning necessitates that animal speed, heading and change in depth (or swim angle) be known so that the three-dimensional movements of the animal can be calculated by use of vectors. Dead-reckoning also requires that either the device be recovered to access the data, or that the data be transmitted at the end of the wearing period. Although earlier attempts to use dead-reckoning principles were primitive (Wilson and Wilson, 1988), advances in solid state technology, particularly as regards to sensors and memories (Fedak, 2004; Kooyman, 2004), have meant that dead-reckoning is now coming of age with highly complex systems being used on a variety of air-breathing marine vertebrates (e.g., Davis et al., 1999; Wilson and Liebsch, 2003; Johnson and Tyack, 2003; Mitani et al., 2003; Zimmer et al., 2005).

The particular forte in dead-reckoning is that it produces temporally finely-resolved, regular, sequential positional data with no gaps (Wilson et al., 2002a), something that is generally, otherwise, particularly difficult to acquire in studies of marine vertebrates. As such, dead-reckoning is a unique tool for describing animal movements.

Effective descriptions of the foraging behaviour of animals should be able to identify systematic patterns (or even the lack of them) and ultimately allude to the adaptive significance of such movements (e.g., Bradshaw et al., 2004; Sims et al., 2005). Although there are extensive mathematical treatises devoted to e.g., fractal analysis (Fritz et al., 2003), sinuosity indices (Benhamou, 2004), and first passage times (Frair et al., 2005) many of these are intuitively difficult to access, which makes understanding for field biologists problematic. Such approaches are also often designed to deal with poor-quality positional data, this being dictated by the logistics of the study of the animals in the field. Finally, these methods generally look at e.g., changes in track tortuosity over various scales without due consideration of how patterns in space use vary over time.

In this work, we describe some of the dead-reckoning systems that we have used, and present examples of data that show the different types of movement exhibited by a variety of species we have studied. We also propose a new method to help in the analysis of animal movement that is particularly appropriate for data gathered by dead-reckoning because it benefits from the temporally regularly spaced data. This method allows workers to visualise the types of movement used by their study species with temporal and spatial elements in the foraging tracks clearly separated so that species-specific patterns become apparent. The dead-reckoning data are complemented by data on animal positions taken by using GPS logging systems on marine animals that spend extensive periods above the surface. This should serve as a useful reference for future studies and help define how dead-reckoning (and GPS) data can be used in a behavioural, rather than just a positional context.

2. Methods

2.1. Device deployments

This work presents location data gathered from 11 species of marine vertebrate including; turtles, birds and mammals. We also present some data from terrestrial applications (dogs, humans). Rather than presenting the details of all deployments here, relevant, necessary information is provided in the results. In essence, though, all positional data were derived from either dead-reckoning loggers or GPS loggers, and some data are also presented using accelerometer loggers. All units were programmed using computers with the appropriate interface, and dead-reckoning data were treated by specially written software (MT-Route and Route10; Jensen Software Systems, Laboe, Germany) to allow calculation of animal movement (see Section 2.3).

2.2. Sensors used in dead-reckoners

2.2.1. Speed

Speed was sensed using paddle-wheels (Wilson et al., 1993), differential pressure sensors incorporating Prandtl tubes (Wilson et al., 2002a, b), variation in signal from two absolute pressure sensors (one of which sensed simple hydrostatic