Quantitative Marine Science

Thesis Abstract

Analysis of marine animal behavior from electronic tagging and telemetry data using state-space models

Toby A. Patterson
School of Zoology, University of Tasmania
CSIRO-UTAS Joint PhD Program in Quantitative Marine Science

But in fact, nothing do we know for having seen it; for the truth is hidden in the deep.
Democritus, B117. (translation, K.R. Popper)

The last few decades have seen a technological revolution in the collection of movement and other data from free roaming animals. Electronic tagging and telemetry (ETT) methods have been advanced by miniaturization of components and electronic storage capacity. Biologists now routinely collect data from animals in some of the least accessible habitats. However, until recently this data avalanche has not been matched by accompanying developments in analytical methods. In this thesis I present a series of methods and case-studies for analysis of ETT data using State-space models (SSMs). The SSM combines a stochastic model of movement or behaviour, and potentially other biological or physiological processes, with a model of the observation process.

Chapter 1 provides a review of individual movement analysis and recent SSM developments. Common threads running through the multitude of approaches of movement data proposed in the literature are contrasted with the SSM.

In chapter 2 the machinery of Hidden Markov Models (HMMs) is outlined. The HMM is the main SSM employed in this thesis for categorisation of discrete hidden behavioural states from movement data. To demonstrate HMMs incorporating an in situ covariate, I analyse data from juvenile southern bluefin tuna (*Thunnus maccoyii*) on their migration route across the Indian Ocean. Diagnostics are used to compare a two-state switching model against a two-state memoryless model and a one-state model.

While considerable effort has been applied to analysis of horizontal movements, analysis methods for vertical movement (VM) data are underdeveloped. Commonly used data compression systems make VM data analysis challenging. In chapter 3, I present a HMM approach for detecting behavioural shifts from compressed VM data. The HMM is made from two nested-HMMs; a continuous-time Markov model to handle the effects of data compression routines is nested within a discrete time HMM used to detect shifts in behaviour through time. The nested HMM is applied to data from summaries of southern bluefin tuna vertical movement data. The predictions of the HMM based only on summary data are compared to the actual behaviour in the raw data.

Chapter 4 quantifies error from state-space models fitted to data from service Argos. Service Argos is the ubiquitous provider of satellite telemetry for wildlife tracking. Therefore, correcting errors in Argos positions is a critical part of making movement inferences for a host of species. We evaluate a hybrid approach which removes aberrant positions using a heuristic speed filter and then uses Kalman filtering to construct a movement path between corrected positions. The method is applied to Argos data from grey seals (*Halichoerus grypus*) fitted with tags that also provide Fastloc GPS estimates of location. Importantly I present an approach for quantifying the accuracy of error estimation which can be applied to any state space technique.

Expanding upon the methodological developments given in chapter 2 and 4, chapter 5 presents a broader analysis of data from a highly-mobile, ocean toppredator, the southern elephant seal (*Mirounga leonina*). Movement data from four subpopulations are analysed using three different types of HMM. The chapter demonstrates the utility of this approach for comparison of behaviours between groups of animals; in this case from spatially separated breeding populations from four islands throughout the Southern Ocean. Each population lies within different oceanographic regimes resulting in the adoption of different strategies and habitat selection. The links to demographic differences between each population are explored.

I conclude the thesis with a discussion of further developments required in the analysis of movement data. These include the spatial prediction of core habitats from Markovian behavioural models. The interpretability of the stationary distribution of estimated Markov chains and how this may be affected by an animals choice of covariates is considered. Finally, the methods developed in this thesis are situated within the context of recent synthesis of movement ecology.