A state-space model for estimating detailed movements and home range from acoustic receiver data

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Summary

We present a state-space model for acoustic receiver data to estimate detailed movement and home range of individual fish while accounting for spatial bias. An integral part of the approach is the detection function, which models the probability of logging tag transmissions as a function of distance to receiver. The same function is used to provide absence information at times where no detections occur. In a simulation study we found that the ability of the state-space model to estimate detailed movements outperform existing non-mechanistic techniques in terms of location error. We also found that the location error scales log-linearly with detection range and movement speed. This result can be used as guideline for designing network layout when species movement capacity and acoustic environment are known or can be estimated prior to network deployment. Finally, as an example, the state-space model is used to estimate home range and movement of a reef fish in the Pacific Ocean.

Introduction

Fixed networks of receivers detect presences of fish tagged with acoustic transmitters. Statistical methods for analysing these data are currently underdeveloped possibly because of spatial bias leading to uneven sampling. Here we present the first published statistical framework for analysing acoustic receiver data (Pedersen and Weng, 2013).

Materials and Methods

In terms of animal movement a state-space model (SSM) consists of two sub-models: the movement model and the observation model. We use an Ornstein-Uhlenbeck (OU) process as movement model. The OU process is highly flexible in that it is able to model both movement behaviour for fish with and without a home range and therefore has wide application. The observation model relies on the detection function, which describes the probability of detecting a fish as a function of distance to the receiver. Additionally, the detection function provides absence information when animals are undetected. The detection range is defined as the distance at which the detection probability is 0.05.

In order to compare studies with differing spatial or temporal scales, we develop dimensionless performance metrics functioning as universally comparable characteristics of fixed receiver networks. To represent the effective movement capacity of the animal in relation to the detection range, we use the ratio of the root mean squared (rms) displacement to the detection range. This ratio is termed phi, and is a dimensionless indicator of effective movement capacity, but can also be interpreted as a signal to noise ratio. Network sparsity is defined as the ratio between receiver closeness and the detection range. Receiver closeness is defined as the median of (a1,...,an), where ai is the distance from station i to its nearest neighbouring receiver. The network sparsity is termed delta, and is normalised such that if delta<1 the network mostly has detection functions that overlap, whereas delta>1 implies a sparser network with mostly non-overlapping detection functions.

In a simulation study we investigated the how the estimation error (Cc) of the state-space model relates to network sparsity and effective movement capacity. The estimation error is dimensionless and is defined as the ratio between rms location error and rms displacement. We compared the performance of the SSM with two popular alternatives: the weighted mean method, and local polynomial regression (Simpfendorfer et al. 2002; Hedger et al. 2008 respectively). Additionally, as illustration, we analysed a real data set from a humphead wrasse (*Cheilinus undulatus*).

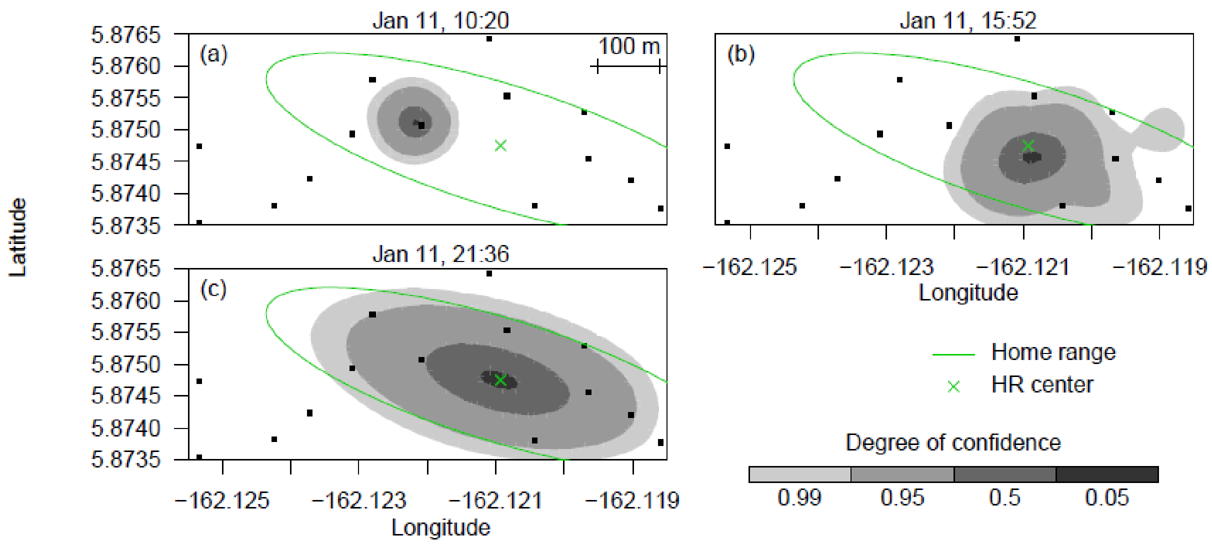

Figure 1: Confidence regions (grey contours) for the location of a humphead wrasse along with home range (HR, green line) estimated by the state-space model. Dark points are receivers. (a) A circular confidence region typical for day-light hours. (b) Absence information results in an oddly shaped distribution. (c) after sunset, the fish is believed to hide on the reef making it difficult to locate as indicated by the wide confidence region.

Results and discussion

The estimation error increased with increasing network sparsity for all values of effective movement capacity (Figure 2). For a fixed sparsity relative location error increased for decreasing movement speed, or put another way, relative location error increased when the signal to noise ratio (phi) decreased. Log-linear models proved a good descriptor of relative estimation error as a function of network sparsity (Figure 2). Thus, for given network properties this relationship provides a rough guideline for the expected estimation error. Location error of the local polynomial regression was on average 33% larger than that for the SSM. This increased error was constant for all network sparsities. The weighted-mean method showed a similar pattern with a 47% average increased error. Analysing n=342 detections resulted in a reasonable home range estimate for a humphead wrasse (Figure 1). During day-light hours, locations of the fish were estimated with a 95% confidence region radius of 50 m (Figure 1a). Absence information lead to confidence regions that 'avoided' receivers resulting in oddly shaped distributions (Figure 1b). Previous methods were unable to exploit this information.

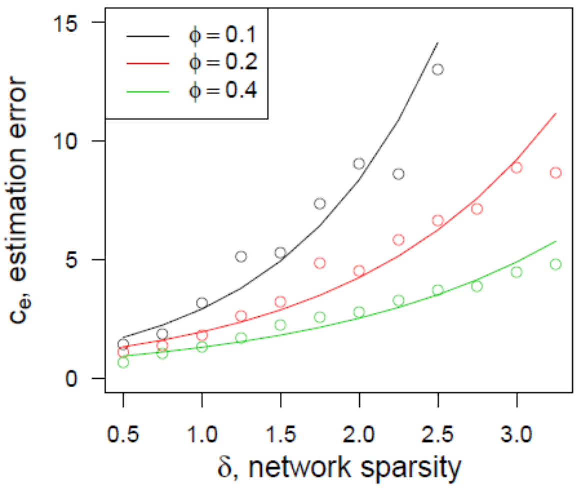

Figure 2: Relative location estimation error as a function of network sparsity and effective movement capacity.

References

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