A Hidden Markov Movement Model for rapidly identifying behavioral states from animal tracks

1. Electronic telemetry is frequently used to document animal movement through time. Methods that can identify underlying behaviors driving specific movement patterns can help us understand how and why animals use available space, thereby aiding conservation and management efforts. For aquatic animal tracking data with significant measurement error, a Bayesian state-space model called the first-Difference Correlated Random Walk with Switching (DCRWS) has often been used for this purpose. However, for aquatic animals, highly accurate tracking data of animal movement are now becoming more common. 2. We developed a new Hidden Markov Model (HMM) for identifying behavioral states from animal tracks with negligible error, which we called the Hidden Markov Movement Model (HMMM). We implemented as the basis for the HMMM the process equation of the DCRWS, but we used the method of maximum likelihood and the R package TMB for rapid model fitting. 3. We compared the HMMM to a modified version of the DCRWS for highly accurate tracks, the DCRWSnome, and to a common HMM for animal tracks fitted with the R package moveHMM. We show that the HMMM is both accurate and suitable for multiple species by fitting it to real tracks from a grey seal, lake trout, and blue shark, as well as to simulated data. 4. The HMMM is a fast and reliable tool for making meaningful inference from animal movement data that is ideally suited for ecologists who want to use the popular DCRWS implementation for highly accurate tracking data. It additionally provides a groundwork for development of more complex modelling of animal movement with TMB. To facilitate its uptake, we make it available through the R package swim.
Choosing the observational likelihood in state-space stock assessment models

Data used in stock assessment models result from combinations of biological, ecological, fishery, and sampling processes. Since different types of errors propagate through these processes it can be difficult to identify a particular family of distributions for modelling errors on observations a priori. By implementing several observational likelihoods, modelling both numbers- and proportions-at-age, in an age based state-space stock assessment model, we compare the model fit for each choice of likelihood along with the implications for spawning stock biomass and average fishing mortality. We propose using AIC intervals based on fitting the full observational model for comparing different observational likelihoods. Using data from four stocks, we show that the model fit is improved by modelling the correlation of observations within years. However, the best choice of observational likelihood differs for different stocks, and the choice is important for the short-term conclusions drawn from the assessment model; in particular, the choice can influence total allowable catch advise based on reference points.

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources
Authors: Albertsen, C. M. (Intern), Nielsen, A. (Intern), Thygesen, U. H. (Intern)
Pages: 779-789
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Canadian Journal of Fisheries and Aquatic Sciences
Volume: 74
Issue number: 5
ISSN (Print): 0706-652X
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.56 SJR 1.322 SNIP 1.163
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.256 SNIP 1.051 CiteScore 2.22
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.443 SNIP 1.379 CiteScore 2.6
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.421 SNIP 1.081 CiteScore 2.25
Connecting single-stock assessment models through correlated survival

Fisheries management is mainly conducted via single-stock assessment models assuming that fish stocks do not interact, except through assumed natural mortalities. Currently, the main alternative is complex ecosystem models which require extensive data, are difficult to calibrate, and have long run times. We propose a simple alternative. In three case studies each with two stocks, we improve the single-stock models, as measured by Akaike information criterion, by adding correlation in the cohort survival. To limit the number of parameters, the correlations are parameterized through the corresponding partial correlations. We consider six models where the partial correlation matrix between stocks follows a band structure ranging from independent assessments to complex correlation structures. Further, a simulation study illustrates the importance of handling correlated data sufficiently by investigating the coverage of confidence intervals for estimated fishing mortality. The results presented will allow managers to evaluate stock statuses based on a more accurate evaluation of model output uncertainty. The methods are directly implementable for stocks with an analytical assessment and do not require any new data sources.
Spatiotemporal modelling of marine movement data using Template Model Builder (TMB)

Tracking of marine animals has increased exponentially in the past decade, and the resulting data could lead to an in-depth understanding of the causes and consequences of movement in the ocean. However, most common marine tracking systems are associated with large measurement errors. Accounting for these errors requires the use of hierarchical models, which are often difficult to fit to data. Using 3 case studies, we demonstrate that Template Model Builder (TMB), a new R package, is an accurate, efficient and flexible framework for modelling movement data. First, to demonstrate that TMB is as accurate but 30 times faster than bsam, a popular R package used to apply state-space models to Argos data, we modelled polar bear Ursus maritimus Argos data and compared the locations estimated by the models to GPS locations of these same bears. Second, to demonstrate how TMB’s gain in efficiency and frequentist framework facilitate model comparison, we developed models with different error structures and compared them to find the most effective model for light-based geolocations of rhinoceros auklets Cerorhinca monocerata. Finally, to maximize efficiency through TMB’s use of the Laplace approximation of the marginal likelihood, we modelled behavioural changes with continuous rather than discrete states. This new model directly accounts for the irregular sampling intervals characteristic of Fastloc-GPS data of grey seals Halichoerus grypus. Using real and simulated data, we show that TMB is a fast and powerful tool for modelling marine movement data. We discuss how TMB’s potential reaches beyond marine movement studies.

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources, Dalhousie University, Macquarie University, University of Alberta, Bedford Institute of Oceanography
Authors: Auger-Méthé, M. (Ekstern), Albertsen, C. M. (Intern), Jonsen, I. D. (Ekstern), Derocher, A. E. (Ekstern), Lidgard, D. C. (Ekstern), Studholme, K. R. (Ekstern), Bowen, W. D. (Ekstern), Crossin, G. T. (Ekstern), Flemming, J. M. (Ekstern)
Pages: 237-249
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Marine Ecology Progress Series
Volume: 565
ISSN (Print): 1616-1599
Ratings:
- Web of Science (2018): Indexed yes
- Web of Science (2017): Indexed yes
- Scopus rating (2016): CiteScore 2.4
- Web of Science (2016): Indexed yes
- Scopus rating (2015): CiteScore 2.56
- Web of Science (2015): Indexed yes
- Scopus rating (2014): CiteScore 2.75
- Web of Science (2014): Indexed yes
- Scopus rating (2013): CiteScore 2.79
- ISI indexed (2013): ISI indexed no
- Web of Science (2013): Indexed yes
- Scopus rating (2012): CiteScore 2.9
- ISI indexed (2012): ISI indexed no
- Web of Science (2012): Indexed yes
- Scopus rating (2011): CiteScore 2.85
- ISI indexed (2011): ISI indexed no
- Web of Science (2011): Indexed yes
- Web of Science (2010): Indexed yes
- Web of Science (2009): Indexed yes
- Web of Science (2008): Indexed yes
- Web of Science (2007): Indexed yes
- Web of Science (2006): Indexed yes
- Web of Science (2005): Indexed yes
- Web of Science (2004): Indexed yes
- Web of Science (2003): Indexed yes
- Web of Science (2002): Indexed yes
Validation of ecological state space models using the Laplace approximation

Many statistical models in ecology follow the state space paradigm. For such models, the important step of model validation rarely receives as much attention as estimation or hypothesis testing, perhaps due to lack of available algorithms and software. Model validation is often based on a naive adaptation of Pearson residuals, i.e. the difference between observations and posterior means, even if this approach is flawed. Here, we consider validation of state space models through one-step prediction errors, and discuss principles and practicalities arising when the model has been fitted with a tool for estimation in general mixed effects models. Implementing one-step predictions in the R package Template Model Builder, we demonstrate that it is possible to perform model validation with little effort, even if the ecological model is multivariate, has non-linear dynamics, and whether observations are continuous or discrete. With both simulated data, and a real data set related to geolocation of seals, we demonstrate both the potential and the limitations of the techniques. Our results fill a need for convenient methods for validating a state space model, or alternatively, rejecting it while indicating useful directions in which the model could be improved.

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources, Department of Applied Mathematics and Computer Science
Authors: Thygesen, U. H. (Intern), Albertsen, C. M. (Intern), Berg, C. W. (Intern), Kristensen, K. (Intern), Nielsen, A. (Intern)
Pages: 317-339
Publication date: 2017
Main Research Area: Technical/natural sciences

Publication information
Journal: Environmental and Ecological Statistics
Volume: 24
Issue number: 2
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 0.82 SNIP 0.569 SJR 0.437
Scopus rating (2015): CiteScore 0.73 SNIP 0.594 SJR 0.454
Scopus rating (2014): CiteScore 1.1 SNIP 0.856 SJR 0.768
Scopus rating (2013): CiteScore 1.03 SNIP 0.853 SJR 0.49
Scopus rating (2012): CiteScore 1.18 SNIP 1.115 SJR 0.404
Scopus rating (2011): CiteScore 1.29 SNIP 1.065 SJR 0.729
Scopus rating (2010): SNIP 1.122 SJR 0.756
Scopus rating (2009): SNIP 0.537 SJR 0.448
Scopus rating (2008): SNIP 0.784 SJR 0.547
Scopus rating (2007): SNIP 0.754 SJR 0.498
Scopus rating (2006): SNIP 1.094 SJR 0.68
Scopus rating (2005): SNIP 1.007 SJR 0.92
Scopus rating (2004): SNIP 0.772 SJR 0.481
Scopus rating (2003): SNIP 0.375 SJR 0.242
Scopus rating (2002): SNIP 1.086 SJR 0.71
Scopus rating (2001): SNIP 0.898 SJR 0.8
Scopus rating (2000): SNIP 0.916 SJR 0.605
Scopus rating (1999): SNIP 0.924 SJR 0.688
Original language: English
Life Sciences, Ecology, Statistics, general, Mathematical and Computational Biology, Evolutionary Biology, SC3.
Maximum likelihood estimation, Model validation, Residual analysis, Statistical ecology, State space methods, Time series analysis
Evaluation of otolith shape as a tool for stock discrimination in marine fishes using Baltic Sea cod as a case study

In the Western Baltic Sea two genetically distinct cod stocks "Eastern Baltic cod" and "Western Baltic cod" occur with considerable mixing of stocks. In this study we evaluated the applicability of otolith shape analysis for classification of individuals caught in the mixed stock cod fishery, using SNP (single nucleotide polymorphism) based genetic assignment of otolith shape baselines. We further developed a management aimed approach for mixed stock assignment by robust stochastic baseline selection and posterior bias correction by individual reassignment of the least likely classifications into the alternate stock. Classification criteria selected by Monte Carlo runs of Linear Discriminant Analysis were captured by otolith area and 20 Elliptic Fourier Descriptors of primarily low frequency harmonics. Classification success was considerably lower when using a baseline of spawning individuals only, compared to the better spatial coverage of a combined baseline also including genotyped individuals from the mixed stock area. Furthermore, the inclusion of genotyped individuals balanced the baseline size composition and to a large extent removed a strong size related bias in classification success. These results demonstrate the interplay of environmental, ontogenetic and genetic influences on otolith shape, which complicates the application of otolith shape for stock discrimination in mixed-stock scenarios. Rigorous genetic validation and further studies on the temporal dynamics of shape formation are necessary.
State-space models' dirty little secrets: even simple linear Gaussian models can have estimation problems

State-space models (SSMs) are increasingly used in ecology to model time-series such as animal movement paths and population dynamics. This type of hierarchical model is often structured to account for two levels of variability: biological stochasticity and measurement error. SSMs are flexible. They can model linear and nonlinear processes using a variety of statistical distributions.

Recent ecological SSMs are often complex, with a large number of parameters to estimate. Through a simulation study, we show that even simple linear Gaussian SSMs can suffer from parameter- and state estimation problems. We demonstrate that these problems occur primarily when measurement error is larger than biological stochasticity, the condition that often drives ecologists to use SSMs. Using an animal movement example, we show how these estimation problems can affect ecological inference. Biased parameter estimates of a SSM describing the movement of polar bears (Ursus maritimus) result in overestimating their energy expenditure. We suggest potential solutions, but show that it often remains difficult to estimate parameters. While SSMs are powerful tools, they can give misleading results and we urge ecologists to assess whether the parameters can be estimated accurately before drawing ecological conclusions from their results.

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources, University of Alberta, Macquarie University, Dalhousie University
Validation of state-space models using Template Model Builder

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Living Resources, Section for Ecosystem based Marine Management
Publication date: 2016
Main Research Area: Technical/natural sciences
Publication: Research › Conference abstract for conference – Annual report year: 2016

Aggregation and attachment responses of blue mussels, Mytilus edulis—impact of substrate composition, time scale and source of mussel seed
Survival after transplantation of mussel seeds is crucial for the production output of blue mussels (Mytilus edulis L.) in bottom cultures. Hence, an understanding of the interactions between bed formation, habitat structure and performance of mussel seed of different origins can contribute to an optimization of the production. The effect of substrate composition and timing of formation of a mussel bed in relation to aggregation and attachment of mussels were investigated with mussel seeds obtained from two different sources: mussel seed dredged from a natural mussel bed and mussel seed collected from a suspended long line culture. The mussels were applied to experimental units of complex and smooth substrate on the sea bed. Data on aggregation (day 0, day 1 and day 2), attachment strength (day 2 and 30), loss (day 2
and 30) and growth (day 0–30) of mussels were collected during the experiment. The results showed that complex substrate indeed had a stabilizing effect on the mussel structure resulting in less aggregation and increased attachment strength. The 3D matrix forming a mussel bed was achieved faster on complex substrate, and led to reduced mortality of transplanted mussels. Despite significantly lower specific growth rates on the complex substrate, the total biomass of mussels was significantly higher on complex substrate compared to on smooth substrate due to the higher survival of mussels. Furthermore, suspended mussels aggregated more and faster and had a stronger and more rapid attachment as compared to bottom mussels. Consequently, it was concluded that when transplanting mussels, seeding with substrate increases surface complexity on the seabed and increases survival of the mussels.

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Ecosystem based Marine Management, Section for Marine Living Resources, Roskilde University, University of Southern Denmark
Authors: Christensen, H. T. (Intern), Dolmer, P. (Intern), Hansen, B. W. (Ekstern), Holmer, M. (Ekstern), Kristensen, L. (Intern), Poulsen, L. K. (Intern), Stenberg, C. (Intern), Albertsen, C. M. (Intern), Støttrup, J. (Intern)
Pages: 245-251
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: Aquaculture
Volume: 435
ISSN (Print): 0044-8486
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.75 SJR 1.101 SNIP 1.524
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.103 SNIP 1.254 CiteScore 2.12
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.002 SNIP 1.34 CiteScore 2.16
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.136 SNIP 1.3 CiteScore 2.18
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.212 SNIP 1.487 CiteScore 2.32
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.294 SNIP 1.542 CiteScore 2.39
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.151 SNIP 1.394
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.941 SNIP 1.263
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.909 SNIP 1.173
Choosing the observational likelihood in state-space stock assessment models
By implementing different observational likelihoods in a state-space age-based stock assessment model, we are able to compare the goodness-of-fit and effects on estimated fishing mortality for different model choices. Model fit is improved by estimating suitable correlations between agegroups. We show by simulations that modelling catch as numbers-at-age is more suitable than proportions if the uncertainty of age-classifications is small.

Fast fitting of non-Gaussian state-space models to animal movement data via Template Model Builder
State-space models (SSM) are often used for analyzing complex ecological processes that are not observed directly, such as marine animal movement. When outliers are present in the measurements, special care is needed in the analysis to obtain reliable location and process estimates. Here we recommend using the Laplace approximation combined with automatic differentiation (as implemented in the novel R package Template Model Builder; TMB) for the fast fitting of continuous-time multivariate non-Gaussian SSMs. Through Argos satellite tracking data, we demonstrate that the use of continuous-time t-distributed measurement errors for error-prone data is more robust to outliers and improves the location estimation compared to using discretized-time t-distributed errors (implemented with a Gibbs sampler) or using continuous-time Gaussian errors (as with the Kalman filter). Using TMB, we are able to estimate additional parameters compared to previous methods, all without requiring a substantial increase in computational time. The model implementation is made available through the R package argosTrack.
From fishing to fish processing: Separation of fish from crustaceans in the Norway lobster-directed multispecies trawl fishery improves seafood quality

Fishing gears have negative impacts on seafood quality, especially on fish in the mixed trawl fishery targeting Norway lobster (Nephrops norvegicus). In this fishery, which is worth about €80 millions in Denmark alone, the quality of fish can be significantly improved by simple gear changes. A trawl codend divided into an upper and lower codend was designed to separate fish from Norway lobster during the fishing process by encourage fish to swim into the upper codend by using a frame at the entrance of the lower codend. Separate codends for fish and Norway lobster in the same gear provide the opportunity to selectively reduce small low-value fish, which will reduce catch weight and sorting time onboard the vessel. For this horizontally divided test codend and a standard codend, in which the catch was mixed, quality assessments were performed on the same batches of fish during three steps of the value chain: i) aboard the fishing vessel; ii) at the Fishermen’s Collection Central, and iii) in the production plant. Four species of fish and fillets from fish caught in the upper codend of the test codend were of significantly better quality for several of the assessed parameters compared with those caught in the standard codend: i) newly caught fish showed significantly less scale loss and discolorations and had significantly better texture; ii) landed fish had significantly better skin appearance and texture and significantly fewer discolorations; and iii) fillets showed significantly fewer blood spots and had significantly better texture. There were no differences in injuries for newly caught fish or gaping and bruises for fillets between the test and standard codends. The decrease in catch-related damages in the test codend is explained by little contact between fish and animals with hard or spiny surfaces due to successful separation of fish and Norway lobster into the upper and lower codends, respectively, and by lower catch weight in the upper codend of the test codend compared with the standard codend. The decrease in damages may also improve quality indirectly by inflicting less stress to the fish and subsequently give better texture, which offers advantages such as pre-rigor filleting and fresher products for the market.
Stock mixing of eastern and western Baltic cod in SD 24

General information
State: Published
Organisations: National Institute of Aquatic Resources, Section for Marine Ecology and Oceanography, Section for Marine Living Resources, Section for Ecosystem based Marine Management
Authors: Hüssy, K. (Intern), Mosegaard, H. (Intern), Albertsen, C. M. (Intern), Hansen, J. H. (Intern), Eero, M. (Intern)
Publication date: 2015
Event: Abstract from ICES Annual Science Conference 2015, Copenhagen, Denmark.
Main Research Area: Technical/natural sciences

Bibliographical note
ICES C.M. 2015/Q:01
Publication: Research › Conference abstract for conference – Annual report year: 2015

Depth preference in released juvenile turbot Psetta maxima
Hatchery-reared juvenile turbot Psetta maxima were tagged with Passive Integrated Transponder (PIT) tags and released at three different depths in a sandy bay in Denmark. About 2–7% of the released fish were registered daily to monitor their distribution using a tag antenna mounted on a modified beam trawl, thus avoiding actually sampling the fish. The change in distribution of the three groups was adequately represented by a twodimensional movement model. Movement along the shorewas described by a Brownian motion with group specific drift. Movement perpendicular to the shorelines was described by a Cox–Ingersoll–Ross process with a group specific attraction point. All
three groups exhibited similar depth preferences of 1.7 m. Immediately after the release, fish were concentrated around the release points but after one day, fish had moved to the preferred depth and subsequently maintained their position at this depth. Farmed turbot exhibited strong site fidelity and an innate behaviour for selecting a preferred depth.
Værdioptimering af fiskefangsten i dansk blandet fiskeri (VærdiFisk) - forbedret kvalitet og selektion som følge af redskabsudvikling

General information
State: Published
Authors: Karlsen, J. D. (Intern), Krag, L. A. (Intern), Lund, H. S. (Ekstern), Lewy, P. (Intern), Albertsen, C. M. (Intern), Kajgaard, L. (Ekstern), Clausen, B. (Ekstern), Thomsen, F. (Ekstern), Jensen, L. P. (Ekstern), Kajgaard, J. (Ekstern), Kusk, M. (Ekstern), Pedersen, C. (Ekstern), Madsen, N. (Intern), Frandsen, R. (Intern)
Number of pages: 60
Publication date: 2014

Projects:
Assessment and management of linked stocks (39325)
The purpose of this project is to develop operational models for linked stocks.

Fish stocks are not isolated units. Fish eat, and are eaten, by fish from other stocks. The definition of fish stocks is often arbitrary or determined by management considerations. The bottom line is that some linkage must be expected between the defined stocks. For some stocks these effects are essential to give reliable assessment and management.

Single species assessment and management does not include effects from linked stocks.

Ecosystem and multi-species assessment models are not practically operational for assessment and management. These models are designed to describe all interactions between all important species in an ecosystem. These models often attempt to estimate detailed effects between all length- or age groups. These models often require data, which are not routinely available.

This project will develop models, which are directly applicable in the scientific advice. The aim is not to describe all interactions, but simply to harvest the main benefits of considering two or more stocks in a joint model. The aim is to identify few links between the stocks, which describes the main part of the interaction, and to base the models only on standard data sources.

The models will be developed to be generally applicable, but applied to two important cases (Cod EB and WB, and Cod stocks around Kattegat).

Final tool will be available via stockassessment.org, so it can easily be applied to any stocks defined there.
This project is coordinated by DTU Aqua.

The project is funded by the Ministry of Environment and Food of Denmark and the European Maritime and Fisheries Fund (EMFF).

National Institute of Aquatic Resources
Section for Marine Living Resources
Period: 14/12/2015 → 13/12/2017
Number of participants: 5
Research area: Marine Living Resources
Project participant:
Berg, Casper Willestofte (Intern)
Kristensen, Kasper (Intern)
Thygesen, Uffe Høgsbro (Intern)
Phd Student:
Albertsen, Christoffer Moesgaard (Intern)
Project Coordinator:
Nielsen, Anders (Intern)

Project State-Space Modelling in Marine Science
National Institute of Aquatic Resources
Period: 01/12/2014 → 30/11/2017
Number of participants: 6
Phd Student:
Albertsen, Christoffer Moesgaard (Intern)
Supervisor:
Thygesen, Uffe Høgsbro (Intern)
Main Supervisor:
Nielsen, Anders (Intern)
Examiner:
Andersen, Ken Haste (Intern)
Cadigan, Noel G. (Ekstern)
Fernández, Carmen (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD