**Symposium: State-Space Models for Fish and Wildlife Population Dynamics**

**Monday, January 25 2016**
**10:40-4:00 in Meeting Room 8**
**Midwest Fish and Wildlife Conference, Grand Rapids, Michigan.**

Organizers: Bryan Stevens, Michigan State University; Reneé Reilly, Michigan State University; David Williams, Michigan State University

Abstract: State-space models represent a synthetic framework for statistical applications in fisheries and wildlife that link dynamic models of ecological systems with observation models for describing sampling processes. Such models are a special class of hierarchical model where data are time-series observations, and partially observed population states are dependent through time in a Markovian fashion. As such, state-space frameworks facilitate a more formal merging of hypotheses and models from theoretical and empirical ecology, as well as direct fitting of dynamic ecological models to real data from fish and wildlife populations. Despite the conceptual advantages of these tools they have not received widespread adoption into graduate curriculum and professional training courses, and thus many researchers and students are not familiar with the framework and its potential use in applied research. Our objectives are to: 1) provide a general introduction to state-space models and their applications for fish and wildlife scientists, 2) describe case studies using state-space methods to model fish and wildlife populations, and 3) summarize existing barriers and likely future directions for learning and implementing state-space approaches in applied fisheries and wildlife research. This symposium will start with a formal keynote talk to introduce the topic and conceptual framework, followed by multiple example applications using state-space methods to model fish and wildlife population dynamics, and finish with a panel discussion of future directions and barriers to implementation of state-space methods in applied fisheries and wildlife research.

**Keynote Address: 10:40am**

Title: **State-space models as a unifying framework for analyzing fish and wildlife time series data.**

Speaker: Ken Newman, U.S. Fish and Wildlife Service

Abstract: State-space models (SSMs) helped NASA complete a successful trip to the moon....and back in 1969. Ames Research Labs developed a SSM fitting algorithm, the extended Kalman filter, which aided navigation and control of the Apollo space capsule. SSMs are models for two time series occurring in parallel: one consisting of an unknown dynamic process and another consisting of imperfect, partial measurements of the process; for example, a time series of the true position of the capsule and a time series of estimates of the position. Such time series pairs are ubiquitous in fish and wildlife management and science, for example, the abundances of a gray whale stock from 1967 through 1997 and shore-based counts of whales. I present a general framework for SSMs as well as a selection of applications to fish and wildlife populations over the past 30 years. Model fitting methods are briefly discussed along with model formulation and

evaluation. Entry-level points for fish and wildlife biologists to some of the SSM literature on methodology and applications and to software for fitting SSMs are given.

**Invited and Contributed Talks:**

**11:20am**

Title: **Inferences on demographic rates using state-space models.**

Speaker: Elise Zipkin, Michigan State University

Contributing Author: Sam Rossman, Michigan State University

Abstract: Understanding a population's spatial and temporal dynamics requires unbiased, precise estimation of demographic rates, such as reproduction, survival, and movement. Yet estimating these quantities can be difficult, requiring years of intensive data collection. Often this is accomplished through the capture and recapture of individual animals, which is generally only feasible at a limited number of locations. In contrast, recently developed models using a state-space formulation allow for the estimation of abundance and spatial variation in abundance from count data alone for both closed (e.g., N-mixture model) and open (Dail-Madsen model, structured population count model) populations. The modeling framework uses a discrete distribution to estimate local abundance (e.g., Poisson or negative binomial), and a binomial distribution to account for imperfect detectability of individuals during sampling. This is in contrast to traditional state-space models which typically employ normal distributions for both process and sampling error. This approach requires repeated survey events during a time period when the population is closed and thus detection errors can be explicitly attributed to false-negatives in the data (e.g., failure to detect an individual when it is present). We review recent advances in state-space modeling for estimating demographic rates in populations using unmarked data. We also demonstrate how detection/nondetection (e.g., occupancy) data can be used either separately or in conjunction with count data to more precisely estimate recruitment, survivorship, colonization, and extinction rates. We discuss the data requirements (e.g., number of survey locations, years, and replicate sampling events) for both accurate and precise estimates of the parameters of interest.

**11:40am**

Title: **Estimating population abundance trends via presence-absence data.**

Speaker: Sam Rossman, Michigan State University

Contributing Author: Elise Zipkin, Michigan State University

Abstract: Monitoring a species population abundances across large geographic ranges is critically important to conservation efforts but generally requires precise abundance estimates from a large number of sites, and across many years which are often difficult to obtain. Mark

recapture studies provide precise estimates of abundance but are generally limited to small geographic ranges. Recently, developed N-mixture models can provide abundance estimates from counts of unmarked individuals, however, many species are predominately identified via presence-absence data (e.g., occupancy) such as those identified by call or scat analysis. We present a novel modeling framework in which we use only occupancy data to derive abundance estimates through time. This state space modeling uses an observation model in which non-detections are the conditional probability of failing to detect any individual present. This observational model provides a link between occupancy data and abundance estimation. We validate this model using simulation studies and discuss the required data. While, this approach requires a large amount of occupancy data it provides a means to monitor the abundance of species in which count data is difficult or impossible to obtain and could be particularly powerful in the analysis of citizen science data. We apply our model to examine population trends in the Northern Spotted Owl which is threatened by the invasive Barred Owl in Western Oregon. Previous to our analysis population abundance monitoring was not feasible for this threatened species.

**LUNCH BREAK (12:00 – 1:20pm)**

**1:20pm**

Title: **Fishery stock assessments: an overview of state-space applications.**

Speaker: James Bence, Michigan State University

Abstract: For the purposes of this presentation, a state-space model is one where the probability distribution of the system state at the next time step is determined by the system state at the current time step, and transition rules, and where system characteristics are observed with error. The estimation task is estimate parameters for the transition rules, the initial system state, and process errors. Given this definition, most recent statistically-based fishery stock assessments are state-space models. For fishery stock assessment, interest is in both identifying and parameterizing the transition rules, and in determining the likely system states over the observation period, particularly stock size and mortality rates at the end of the time-series. The underlying transition rules are critical for supporting evaluation of management strategies, whereas estimation of the current state is needed for applying a management strategy (e.g., setting a limit on annual harvest). A diversity of estimation approaches are currently applied in fishery stock assessment, including a "mixed-effect" approach where process errors are treated as random effects, penalized likelihood (from a Bayesian perspective highest posterior density), and full Bayesian hierarchical approaches where process errors are drawn from distributions, and inferences about the parameters of those distributions are also made. The strengths and weaknesses of these various approaches will be reviewed.

**1:40pm**

Title: **Performance of a Bayesian state-space model of semelparous species for stock-recruitment data subject to measurement error.**

Speaker: Zhenming Su, Michigan Department of Natural Resources

Abstract: Measurement errors in spawner abundance create problems for fish stock assessment scientists. To deal with measurement error, we develop a Bayesian state-space model for stock-recruitment data that contain measurement error in spawner abundance, process error in recruitment, and time series bias. Through extensive simulations across numerous scenarios, we compare the statistical performance of the Bayesian state-space model with that of standard regression for a traditional stock-recruitment model that only considers process error. Performance varies depending on the information content in data determined by stock productivity, types of harvest situations, and the amount of measurement error. Neither model performs best across all scenarios, but the Bayesian state-space model is most frequently best for informative data. However, the traditional model may be used for very low-productivity stocks having a moderate amount of measurement error.

**2:00pm**

Title: **Integrated assessment of harvested wild turkey populations in southern Michigan: a state-space approach.**

Speaker: Bryan Stevens, Michigan State University.

Contributing Authors: James Bence, Michigan State University; William Porter, Michigan State University; Michael Jones, Michigan State University; David Luukkonen, Michigan Department of Natural Resources.

Abstract: Methods for assessing abundance and understanding dynamics of wild turkey (Meleagris gallopavo) populations using widely available data have been recognized as a critical missing piece of turkey management for over 50 years. Turkeys are cryptic and irregularly distributed over large landscapes, and thus many traditional wildlife sampling techniques requiring individual capture or high rates of detection are either too costly or ineffective for assessing population patterns over broad scales. Consequently, hunter harvest remains the primary data collected on turkey populations in most areas. We used existing hunter harvest, effort, and auxiliary data sets from southern Michigan to develop an integrated model of turkey population and harvest dynamics based on the statistical framework of state-space models. This framework allowed us to effectively use all available data sources to simultaneously estimate patterns of turkey populations through time. The models also allowed us to evaluate hypotheses about the structural dynamics of turkey populations in their ancestral range of southern Michigan. Here we discuss development of the modeling framework, data sources used, and preliminary results from fitting these models. We also briefly discuss future use of these models for assessing harvest management strategies for turkeys in southern Michigan.

**2:20pm**

Title: **Use of dynamic factor analysis in analyzing mutlidimensional state space data over time.**

Speaker: Brian Maurer, Michigan State University

Abstract: Data on fish and wildlife communities are often collected over long periods of time. Such data are meant to represent dynamical processes going on in a multidimensional state space defined by the abundances of all species in the community. The intent of any analysis of such data is to infer something about the processes that affect the community from the multivariate time series that represents the community. Dynamic factor analysis provides a unique approach to this goal. The basic concept is that the measures of abundance for each species in a community are indicators of some latent trend common to all species in the community. The approach begins by modeling these latent trends as simple random walks. For each latent trend, a "loading" is estimated for each species that represents the degree to which that species is associated with that trend. I will discuss the model building process for DFA and address a few computational issues. A brief discussion R code implementation and results will be illustrated using data from a long term study of desert rodents.

**COFFEE BREAK (2:40 – 3:00pm)**

**3:00pm**

Title: **Assessing factors influencing population dynamics in Lake Huron fish communities using dynamic factor analysis.**

Speaker: Andrew Dennhardt, Michigan State University

Contributing Authors: James Bence, Michigan State University; Travis Brenden, Michigan State University; Brian Maurer, Michigan State University; William Fetzer, Michigan State University; Catherine Riseng, University of Michigan; Kevin Wehrly, University of Michigan; Danielle Forsyth, University of Michigan

Abstract: An important component to understanding the nature and structure of biodiversity in ecosystems is investigating how communities respond to changes in the environment in both space and time. Hastening our inquiries for better or worse, systems of great value to global biodiversity often contain ecological communities of considerable socioeconomic value as well. One such ecosystem is the Laurentian Great Lakes and its constituent waterways in North America. Amidst the world's largest surface freshwater system, Lake Huron supports a 5-year commercial fishery worth $4.6 million on average. Though Huron fish communities face numerous pressures from various ecological agents, anthropogenic or otherwise, factors associated with species' population dynamics are poorly understood due to deficient data across spatiotemporal scales. This motivates an important question: what factors influence fish populations in spatially-structured communities over time? To answer this question, we obtained abundance data on 12 fish species at five sites unevenly summarized during 1979 – 2012 in Lake

Huron. Following pilot investigations that described null models of species' abundance, we assessed these data for their linear association with environmental factors in Lake Huron. To elucidate population relationships to these variables, we applied multiple candidate models using Dynamic Factor Analysis—a state-space tool for multivariate time series' data. Preliminary results illustrate that factors associated with local harvest biomass as well as remotely-sensed upwelling events and water temperatures disproportionately impact fish populations in the lake. Furthermore, variable influences differ with respect to common temporal trends in fish abundance and associated factor loadings on particular species. In lieu of auxiliary environmental data, more of this ecological story remains to be told. To date, this community-level assessment demonstrates both the power and utility of Dynamic Factor Analysis as a tool for describing ecological patterns that constrain wild populations—factors useful to biodiversity conservation and management in the Anthropocene.

**3:20pm**

Panel Discussion: **Future directions and barriers to implementation of state-space methods in applied fisheries and wildlife research**

This symposium focused on both a general introduction to state-space models and their applications in fisheries and wildlife research, with several case studies highlighted that used state-space methods to model fish and wildlife populations. Here we plan to discuss barriers that exist to the development and implementation of state-space methods in applied fisheries and wildlife research, particularly from a developmental learning standpoint, e.g., the lack of incorporation into graduate curriculum and professional training courses. We hope to gauge the importance of various reasons for lack of widespread adoption and describe potential for pathways moving forward, drawing from our invited experts and keynote speaker.