Abstracts

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Plenary

Implications of Resilience Thinking for a Decision-Analytic Approach to Biodiversity Conservation

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"Resilience thinking," with its focus on interacting ecological and social systems, on non-linear system dynamics, and on ecosystem services as well as goods, has much to offer those concerned with the sustainablity of natural resources. Resilience thinking has been criticized, however, for failing to provide much practical advice to decision makers. On the other hand, advocates of a resilience perspective have criticized decision analysis as an inappropriate, if not antithetical, tool for sustaining ecosystem resilience. We argue that a key source of tension between resilience thinking and application of decision theory is the pursuit of efficiency in the latter (i.e., choosing the "best" management option), versus a desire to maintain the adaptive capacity of systems by keeping options open in the former. We describe how a careful framing of resource-management problems, particularly in terms of management objectives and predictive models, can help reduce or eliminate this tension. Contrary to some arguments, decision analysis need not be restricted to well-understood systems with linear responses, and it certainly can accommodate management objectives other than maximizing the expected return. We illustrate some of these points by focusing on the conservation of biodiversity, recognizing that it is increasingly seen as an important contributor to resilience in socio-ecological systems. We conclude by arguing that any systematic approach to decision making in natural resource management at a minimum must include projections of system response(s) to alternative decision choices, as well as some means of selecting among them. This is true even if the primary concern of decision making is the maintenance or enhancement of system resilience.

Evaluating Some Aspects of the Framework for Adaptive Management of Delaware Bay Horseshoe Crab and Red Knots

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A multi-species adaptive management framework was recently adopted by the Atlantic States Marine Fisheries Commission for harvest management of Delaware Bay horseshoe crabs with constraints for red knot population abundance. The predictive model set includes structural uncertainty regarding the relationship between red knot vital rates and horseshoe crab spawning abundance during the stopover. Decision matrices were calculated using ASDP, but incorporation of stochasticity was limited by computational constraints. We used a heuristic simulation approach to reintroduce the parametric uncertainty and evaluate the performance of the adaptive management framework. Aspects that were evaluated included the value function for red knot abundance, alternative harvest packages, and model updating. We found that value of information for reducing structural uncertainty is low given the current harvest packages and model updating based on monitoring of adult red knots.

The Native Prairie Adaptive Management Initiative: Innovations, Challenges, and Process Ownership

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Our intent is to introduce the Native Prairie Adaptive Management Initiative that was implemented on participating National Wildlife Refuge System complexes in the northern Great Plains. We will lead with a general overview of the management problem, a diagnosis of uncertainties facing managers, and a description of the decision framework. Following, we will present some of the technical innovations that we used to parameterize models in the absence of empirical data, to account for management and monitoring realities, and to centralize and automate the assessment and decision support processes. We will also illuminate some of the technically-rooted challenges that we face, including the fact that the overall performance of the model set cannot yet be empirically assessed and the possibility that the underlying system dynamics are not well represented by any model in the model set. Finally, the project enjoys substantial ownership by the participants, and we will discuss how project governance, process deliberations, and technical components contributed to this outcome.

An Adaptive Management Framework for Control of Infectious Disease: Foot and Mouth

Katriona Shea[1], Michael Tildesley[2], Michael Runge[3], Christopher Fonnesbeck[4], and Matthew Ferrari[5]

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Optimal decision-making for management interventions during epidemic outbreaks is often hampered by severe uncertainty. *Post hoc* analysis of the 2001 Foot and Mouth (FMD) outbreak in the UK provided valuable information about both the dynamics of disease spread and the efficacy of management actions. However, a novel FMD outbreak will not necessarily progress in the same manner; a key uncertainty is the dispersal kernel for farm-to-farm transmission. Using a spatially explicit farm-level model of FMD spread in the UK, we discuss the potential for adaptive management to resolve model uncertainty and update management tactic recommendations in response to real-time evaluation of alternative models. We also briefly discuss the application of adaptive management to vaccination strategies for measles outbreaks.

Differential Games in a Stochastic Fishery

Jon Conrad

Cornell University, Dyson School of Applied Economics and Management

Let X = X(t) denote the biomass of a fish stock at instant t. Suppose that the fish stock is subject to harvesting by i = 1, 2,…,n countries, each having adopted a feedback policy taking the form Yi = Yi(t) = $\phi_i(X)$. The fish stock is an Itô variable, evolving according to $dX = [rX(1 - X/K) - \sum_i \phi_i(X)]dt + \sigma X dz$. This stochastic process assumes that the expected change in the fish stock is logistic net growth less harvest, but with a standard deviation rate of σX, where $dz = \epsilon(t)\sqrt{dt}$ is the increment of a Wiener Process with $\epsilon(t) \sim N(0, 1)$. An n-country differential game is solved for the subgame perfect harvest policies. The Kolmogorov forward equation can be solved for the stationary density for X(t). There are analytic expressions for the expected value of this distribution and for expected harvest. The parameters r, K, and σ are fitted to the Norwegian spring-spawning herring, a straddling stock that migrates from Norway's Exclusive Economic Zone (EEZ) to Iceland's EEZ while passing through international waters where the stock might be harvested by other countries. The stationary distribution, its expected value, and expected harvest are determined for n = 1 (sole ownership) and n = 5 countries, all with the same rate of discount.

Stochastic Dynamic Programming for Reservoir System Operation: Computational Improvements and Descriptions of Uncertainty

Jery Stedinger

Cornell University, School of Civil and Environmental Engineering

Stochastic dynamic programming (SDP) is a natural methodology for modeling reservoir operations with stochastic inflows and imprecise flow forecasts. Reservoir operation requires a series of decisions that must be made in view of reservoir storage levels, uncertain future demands, and particularly uncertain future flows. Streamflow uncertainty can be reduced by use of flow forecasts, which themselves have limited precision. This talk describes SDP reservoir operating models, the inclusion of forecast information, efforts to challenge the curse of dimensionality using higher-order approximations of the future value function and composite and compact system representations, and the use of streamflow traces and decision trees to represent the unfolding over time of streamflow-forecast uncertainties.

Addressing Structural and Observational Uncertainty in Resource Management: the Generalized POMDP Model

Krishna Pacifici and Paul Fackler

North Carolina State University, Department of Agriculture and Resource Economics

Most natural resource management and conservation problems are plagued with high level of uncertainties, which make optimal decision making difficult. Although some kinds of uncertainties are easily incorporated in decision making, two types of uncertainty present more formidable difficulties: structural uncertainty, which represents our imperfect knowledge about how a managed system will respond to management actions and observational uncertainty, which arises because the state of the system must be inferred from imperfect monitoring systems. The former type of uncertainty has been addressed in ecology using Adaptive Management and the latter using the Partially Observable Markov Decision Processes (POMDP) framework. Here we present a new analytical framework called Generalized-POMDP (GPOMDP) that encompasses both standard POMDP and adaptive management. This approach permits the use of additional information signals (or observed variables) to update belief about system models other than just realizations of the state variable. GPOMDP also allows for mixed observability in which some state variables are observed and others are not, allowing one to focus on those aspects of a model in which uncertainty plays the largest role. Finally, this framework allows the possibility to account simultaneously for both structural uncertainty and partial observability. We illustrate the features of the GPOMDP framework with a simple resource management problem. Code to implement GPOMDPs is available in a software toolbox written in MATLAB.

A Modeling and Solution Framework for MDPs

Paul Fackler

North Carolina State University, Department of Agriculture and Resource Economics

One of the biggest constraints in applying Markov Decision Process (MDP) approaches to solve environmental and resource management problems arises due difficulties in both formulating and solving problems and the relative scarcity of trained analysts to undertake these tasks. Even experienced analysts using the available software can take a long time to set up, verify and analyze results. A number of proposals are made here to address this situation including the use of Influence Diagrams to specify MDPs, the separation of model specification from the model solution phases by developing a common model specification language that serves as a standard way to define an MDP, the development of algorithm independent, user friendly model specification and analysis tools, especially graphical tools, that take input from a user and create a file in the scripting language and return and analyze solution results, and the use of remote servers to allow solutions to be obtained via the internet.

Application of POMDP to the Adaptive Management of Hiking Activities Near Golden Eagles in Denali

Paul Fackler[1], Krishna Pacifici[1], Julien Martin[2], James Nichols[3], and Carol McIntyre[4];

Presenter: Julien Martin

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Most natural resource management and conservation problems are plagued with high levels of uncertainty, which make optimal decision making difficult. Adaptive management has been developed to address structural uncertainty, which recognizes that decisions must be made without full knowledge of how a system behaves. This paradigm attempts to use new information that develops during the course of management to learn how the system works. To date, however, adaptive management has been restricted to using state transitions to update beliefs which limits the amount of learning possible. We used a newly developed extension of the Partial Observability Markov Decision Problem (POMDP) framework which allows for the inclusion of any observable variable to update beliefs. This feature can potentially increase the speed of learning through adaptive management, and lead to better management in the future. We apply this framework to a case study wherein interest lies in managing recreational restrictions around Golden Eagle nesting sites. The ultimate management objective is to maintain an abundant eagle population in Denali while minimizing the regulatory burden on park visitors. In order to capture this objective, we developed a utility function that trades off expected breeding success with hiker access. Our work is relevant to the management of human activities in protected areas, but more generally demonstrates some of the benefits of POMDP in the context of adaptive management.

Plenary

Computational Sustainability

Carla Gomes

Cornell University, Institute for Computational Sustainability, Department of Computer Science

Computational Sustainability is a new interdisciplinary research field with the overall goal of developing computational models, methods, and tools to help manage the balance between environmental, economic, and societal needs for a sustainable future. In this talk Gomes will provide an overview of Computational Sustainability, highlighting research challenges and computational themes, with examples ranging from wildlife conservation and poverty mapping to pattern identification for materials discovery for fuel cell technology and the design of portfolios of renewable energy sources.

Optimal Cost-Effective Conservation Planning for Landscape Connectivity

Bistra Dilkina

Cornell University, Department of Computer Science

While conservation biologists have historically set conservation objectives and plans irrespective of their cost, multiple studies in recent years have shown that it is possible to achieve conservation objectives at a fraction of the price if costs are formally considered from the outset of the planning process. In particular, preserving and restoring habitat connectivity has been identified as a key strategy for enhancing species resilience to disturbance events and accommodating long-term ecosystem adaptations, but resources for conservation are extremely limited. Ecologists have developed models of landscape resistance that capture the difficulty or probability of movement of a species individual from one location to another in a habitat matrix. Under the least-cost model, ecologists measure the connectivity between two habitat patches as the shortest resistance-weighted distance between them. Without conservation management, the resistance of landscape parcels might increase due to human development and land-use change. We study the conservation planning problem of identifying critical land parcels to protect, such that the future ladnscape connectivity among important habitat patches is maximized. In particular, we provide a mathematical model that generates conservation plans with optimality guarantees while satisfying strict budget constraints. We evaluate our approaches on a case study concerning wolverines in Montana.

Poaching and the Dynamics of a Protected Species

Adrian Lopes and Jon Conrad

Cornell University, Dyson School of Applied Economics

Protecting endangered species is a difficult task in developing countries, especially so because individuals living on the edge of a protected area may not place a value on the resource stock in the next period. We develop a model in which an individual derives utility from the consumption (C_t) of harvested bushmeat or the protected species, income from employment (I_t) in the protected area, and time spent on leisurely activities (T_t^L). The myopic individual maximizes a Cobb-Douglas utility function $\mathrm{E}[U_t] = \alpha \mathrm{E}[I_t]^\beta (T_t^L)^\gamma (1 + \eta C_t^\omega)$ in each time period t, subject to a Schaefer harvest function $H_t(T_t^H, X_t) = qT_t^H X_t$ for a given population of the protected species X_t. The protected species evolves according to a logistic growth function net of harvest $X_{t+1} = X_t + rX_t(1 - (X_t/K)^z) - qT_t^H X_t$, where T_t^H is the time spent poaching or harvesting the protected species. Poaching is subject to *risky* open access, whereby a fine is incurred by the individual if he/she is caught poaching by anti-poaching units. The probability of getting caught increases in time spent poaching as per the function $\phi(T_t^H) = (T_t^H/T)\exp\big(-\kappa(T - T_t^H)\big)$. A static labor allocation problem for each time period, is coupled with the dynamics of the protected species, to study how the individual maximizes utility by allocating time to wage employment and poaching. The model is solved numerically for steady states for a set of parameter values. Approach paths are studied for different initial conditions for the protected species. In certain cases we observe oscillatory convergence to the analytical steady state; for other parameter values we observe 2^n-point cycles. When n becomes sufficiently large it leads to deterministic chaos in the dynamics of the protected species. Economic or policy parameters include the wage rate (W) for employment in the protected area, the fine (F) if caught poaching, the level of enforcement or effectiveness $(-\kappa)$ of anti-poaching units, and the black market price of the protected species (P). Increases in the wage rate and fine lower the time spent poaching. Increasing the effectiveness of anti-poaching patrols and lowering black market prices also reduce the time spent poaching. The model reveals that the dynamics of the protected population goes through bifurcation for changes in W, P, F and $-\kappa$ and in some cases gives way to deterministic chaos. Consequently we find that the time spent poaching is influenced by the abundance or scarcity of the protected population. The results of this stylized model of time allocation to poaching and wage employment, and the dynamics of the protected population, point to the importance to studying the effects of conservation policy. Economic or policy parameter changes may induce bifurcation or changes in the qualitative behavior of a protected species' population dynamics.

Robust Dynamic Optimization and Fisheries Management

Rich Woodward[1] and David Tomberlin[2]

Presenter: David Tomberlin

[1]Texas A & M, [2]NOAA Fisheries

In this paper we present a numerical approach to robust dynamic optimization using an approach developed by Nilim and El Ghaoui (2005) and apply it to a problem of marine fisheries management. The approach has the advantage of being directly tied to the data, using statistical characteristics of the data to define the robust bounds. Robust dynamic optimization provides a useful framework for addressing recent legislative requirements to better capture uncertainty federally managed marine fisheries.

Triggering Double-Loop Learning: Detecting the Failure of a Model Set

Michael Runge[1] and Eve McDonald-Madden[2]

[1]USGS, Patuxent, [2]The University of Queensland/CSIRO

The basis of adaptive management, in the sense conveyed by the Decision-Theoretic school, is the *a priori* specification of a set of models that collectively expresses the relevant uncertainty about system dynamics. Our ability to learn and make good management decisions within an adaptive framework will depend on whether the true model is contained within, bounded by, or close to our set of pre-specified models. Two possibilities, both forms of "unknown unknowns", could undermine this ability: first, the truth might not be bounded by our model set, because we failed to anticipate some important elements of the system; or second, the system might change in unanticipated ways that lead the true dynamics outside behavior predicted by our model set. What is needed is a second layer of learning that enables us to determine if the system is responding as we might expect given the models we have specified, or if, instead, unpredicted responses are occurring. That is, how can we determine when our model set is failing, and use that knowledge to trigger double-loop learning? We have developed an analytical solution to this problem.

Beyond Adaptive Management: How Uncertainty Shapes Ecologists' Contribution to Managing Socio-Ecological Systems

Drew Tyre

University of Nebraska, School of Natural Resources

Making decisions under uncertainty is a core component of Adaptive management under all definitions. However, not all forms of uncertainty, or as I'll call it, indeterminism, are amenable to reduction by the application of the scientific method. Irreducible uncertainty is here to stay. Moreover, the presence of some forms of uncertainty constrains when science can make policy recommendations that stick. We outline a roadmap for determining when science can stick, and describe what to do when it won't.

Maximizing YOY Spot *Leiostomus xanthurus* Export From a South Carolina Estuary: An Evaluation of Coastal Impoundment Management Alternatives via Structured Decision-Making

Kelly Robinson[1] and Cecil Jennings[1,2]

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Estuaries are among the most productive of all ecosystems and provide critical nursery habitat for many young-of-the-year (YOY) marine fishes. Along the South Carolina coast, former ricefield impoundments in some estuarine areas now are managed to provide habitat for waterfowl. Marine fishes that enter these structures during water-level manipulation become trapped and suffer high mortality rates. Because these fishes cannot emigrate back to coastal waters to complete their life cycles, these impoundments appear to act as sinks for marine-transient species. Our goal was to identify which of a set of management options would maximize YOY spot *Leiostomus xanthurus* export from the Combahee River, SC, to the coastal population. We used a structured decision-making approach to evaluate four decision alternatives. These decision alternatives were to: maintain status quo, close all impoundments while YOY spot are most abundant in the river, change the water-level manipulation strategy to improve fish passage from impoundments, or breach all impoundments. We also wanted to evaluate how impoundments and natural mortality influence YOY spot export. The optimal management decision was to change the water-level manipulation strategy to increase fish passage from the impoundments. Spot export was most sensitive to juvenile settlement in the estuary and natural mortality. The results of this model can be used adaptively for impoundment management along the Combahee River and can be modified for other estuarine areas or other fish species.

Capacity Building for Structured Decision Making and Adaptive Resource Management in Argentina

Michael Conroy[1], Andrea Goijman[1,2], Jeffrey Thompson[2], María Elena Zaccagnini[2], Jaime Bernardos[2], Verónica Rusch[2]

[1]Warnell School of Forestry and Natural Resources, University of Georgia [2]Instituto Nacional Tecnología Agropecuario, Argentina

I describe ongoing efforts to build capacity in quantitative resource management in Argentina, using structured decision making (SDM) and adaptive resource management (ARM) as organizing principles. Recent or ongoing activities include training workshops in SDM/ ARM and organization of symposia, conducted either solely in Spanish or jointly in English and Spanish; training of Argentine students at the University of Georgia; development of a technical guide to SDM/ARM in Spanish, to be published in Argentina; and conducting of joint research projects and monitoring programs based SDM/ARM. I briefly describe 3 applications of SDM/ARM underway in Argentina: control of agricultural damage by doves in La Pampa, impacts of intensive agriculture on bird populations in Entre Ríos, and sustainable forest management in Patagonia.

Application of SDM/ARM to Balancing Conservation of Bird Diversity with Landowner Values in Entre Ríos, Argentina

Andrea Goijman[1,2], Michael Conroy[1], Rebecca Moore[1], María Elena Zaccagnini[2]

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I describe development of a research and monitoring program in an intensively cultivated landscape in Entre Ríos, Argentina, where the objective is to maintain bird diversity and related ecosystems services in the face of strong market pressures for maximizing production. We produced a probabilistic decision network based on soybean crop management, identifying objectives, alternative decisions, and influence of important system variables. The network integrates farmers' perceptions and our knowledge on the system, with key relationships parameterized by bird monitoring data. Further work will require an updating process through monitoring, to reduce uncertainty of the system; this in turn will need to be discussed with and supported by stakeholders. However, this is a first approach towards a SDM and ARM process in this region of Argentina.

Structured Decision Making as an Approach for Addressing Interagency and Cross-Jurisdictional Management Challenges: Two Case Studies Involving the Management of Sea Otters and Brown Bears in Alaska

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Federal and state management agencies are faced with the difficult task of the long-term protection and management of resources under their jurisdiction. This task is further complicated when resources span agency jurisdictional lines, particularly when fundamental differences exist in the laws and policies governing agencies responsible for making management decisions. These differences can result in a wedge that broadens the gap between the collaborative relationships required to achieve successful cross-jurisdictional and interagency management. Linguistic uncertainty (especially in agency enabling legislation), hidden objectives, and unstated assumptions about system dynamics can further impede decision making. The collaborative and integrative nature of formal decision analysis is ideal for providing an explicit and transparent means for addressing cross-jurisdictional and interagency management issues. We present 2 case studies to illustrate how we used a structured decision making approach to address management challenges that spanned agency jurisdictional lines in Alaska. First we discuss the development of an integrated modeling and decision support program as a means for addressing interagency management challenges of federally threatened sea otters in Southwest Alaska. Next we evaluate cross-jurisdictional issues associated with management of brown bear populations in Noatak and Katmai National Parks in Alaska.