

# RMA

*The Resource Modeling Association is an international association of scientists working at the intersection of mathematical modeling, environmental science, and natural resource management. We formulate and analyze models to understand and inform the management of renewable and exhaustible resources. We are particularly concerned with the sustainable utilization of renewable resources and their vulnerability to anthropogenic and other disturbances.*

RMA Newsletter

Spring 2016



## *Flagstaff Conference* by Bob Fray

The 2016 World Conference on Natural Resource Modeling, the 35th annual meeting of the Resource Modeling Association, will take place June 14 – 17 in Flagstaff, Arizona. The theme of this year's conference is "Quantitative Modeling for Managing Natural Resources in an Era of Climate Change." This theme will be addressed by four keynote speakers. Joining our RMA participants will be scientists from the Grand Canyon

National Park and from the Southwest Biological Science Center.

Flagstaff is an excellent location for this conference. It is both a university town (Northern Arizona University) and a tourist center. As a result there is a wide variety of accommodations and restaurants. The weather in June is ideal; the average temperature is 80°F (27°C) and the humidity is low. Northern Arizona is an area of natural beauty and the home of several

Native American cultures. This area of the United States is the most ecologically diverse in the country and is the center for much environmental research.

The conference will open with the customary opening reception on Tuesday evening, June 14, at the historic Weatherford Hotel in downtown Flagstaff. The conference sessions will begin the morning of June 15 at the High Country

*continued on next page*

Modeling Animal Behavior in a Changing Environment | p. 3



### Inside

President's Column.....	13
Rollie Lamberson Award .....	14
Editor's Column.....	15



Conference Center, a modern, fully-equipped meeting facility. These sessions will occupy all of Wednesday the 15th and Friday the 17th. On Thursday sessions will be held in the morning; in the afternoon the conference participants will be transported to the Grand Canyon National Park for a presentation by park scientists, free time for sightseeing and the conference banquet. The presentation at the park will be given by scientist from the Science and Resource Management Center, who will describe the Grand Canyon's Dark Skies Initiative. The center manages the park's resources which include the aquatic and riparian resources of the Colorado River and its tributaries, the forests on the lands adjoining the rims of the canyon, and the plant and wildlife native to these lands.

in the Department of Mathematics and the School of Biological Sciences at the University of Queensland and Professor of Conservation Decisions at Imperial College London, will ask, "What is the value of knowledge?" In his talk he will discuss his personal struggle with the question of how much knowledge is enough using several examples. Then he will propose a simple solution to the problem. The address of Graciela Ana Canziani, Professor of Mathematics, National University of Central Buenos Aires, is titled "Improving the rigour and usefulness of scenarios and models for biodiversity and ecosystem assessment." She will discuss her work with the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. The goal is to provide guidelines for additional research on the state of the

Mathematics at Andrews University, have been collaborating for many years on a study of the effects of environmental change on colonial sea birds at Protection Island in the Strait of Juan de Fuca in Washington state. In a two-part presentation titled "The effects of climate change on marine birds" they will provide models of observed changes in seabird behavior as mean sea temperatures rise and hypothesize that these changes will become prevalent in the long term.

For much more information about the conference, including accommodations, transportation and deadlines for abstract submission and registration go to the conference website [scholarexchange.furman.edu/rma](http://scholarexchange.furman.edu/rma). In particular, note that the deadline for submitting abstracts is May 1, 2016. The middle of June is the height of the tourist season in Flagstaff, so do not procrastinate making travel plans, especially obtaining accommodations. The conference hotel is the Drury Inn which has reserved a block of rooms for conference participants. These rooms will be held until May 14 at a discounted rate. Air transportation to Flagstaff is through the Sky Harbor Airport in Phoenix, Arizona. There are six daily flights to Flagstaff from Phoenix. In addition there is a van shuttle service between the Phoenix airport and Flagstaff. See [arizonashuttle.com/schedules/flagstaff-phoenix](http://arizonashuttle.com/schedules/flagstaff-phoenix)

The RMA looks forward to welcoming you to the 2016 World Conference on Natural Resource Modeling. If you have the opportunity to extend your visit to northern Arizona, you will discover a wealth of natural beauty, places of historic interest and a center for art and crafts. More information on these subjects is available at the conference website and at the website of the Flagstaff Convention and Visitors Bureau. [flagstaffarizona.org](http://flagstaffarizona.org)



Four keynote speakers with a wealth of experience using mathematical models to study the environment and the effects of climate change will address the conference. Hugh Possingham, the ARC Laureate Fellow

planet's biodiversity that is required to take the use of models to a whole new level of rigour and utility. Jim Cushing, Professor of Mathematics at the University of Arizona, and Shandelle Henson, Professor of





## Modeling Animal Behavior in a Changing Environment

Shandelle M. Henson  
Department of Mathematics,  
Andrews University

J. M. Cushing  
Department of Mathematics  
Program in Applied Mathematics,  
University of Arizona

James L. Hayward  
Department of Biology,  
Andrews University

*The following article describes the joint research the three authors have conducted for many years at Protection Island, a federally protected National Wildlife Refuge in the Strait of Juan de Fuca in Washington State, and at Galápagos National Park, Ecuador. Their research, which is sponsored by the National Science Foundation, includes a great number of students. Two of the authors, Shandelle Henson and Jim Cushing, are keynote speakers at the World Conference on Natural Resource Modeling to be held in June 2016 in Flagstaff, Arizona. They will make a joint, two-part presentation on their recent research.*

Planet Earth has entered the Anthropocene Epoch, an era in which humans have earned the dubious distinction of acting both as biologic and geologic forces of environmental change (Waters et al. 2016). The rapid pace and enormous scale of planetary change driven by human activity is leading rapidly to abrupt changes in ecological and social systems, some of which may be irreversible. Mathematical approaches for understanding the dynamics and bifurcations of such systems are imminently important.

For the past 14 years, we have studied the effects of environmental change on the behavior of marine birds, mammals, and reptiles. We have focused primarily on colonial seabirds breeding in the Pacific Northwest. To this end our group engages in three main activities. 1) We collect large sets of temporally-dense behavior data in the field; 2) we construct realistic models, tied rigorously to data, which describe, explain, and predict behavioral dynamics as functions of environmental variables; 3) we construct simplified proof-of-concept models to probe dynamic mechanisms, to clarify ideas and suggest testable hypotheses, and to study population dynamic consequences of environmental perturbations and evolving traits.

*continued on next page*

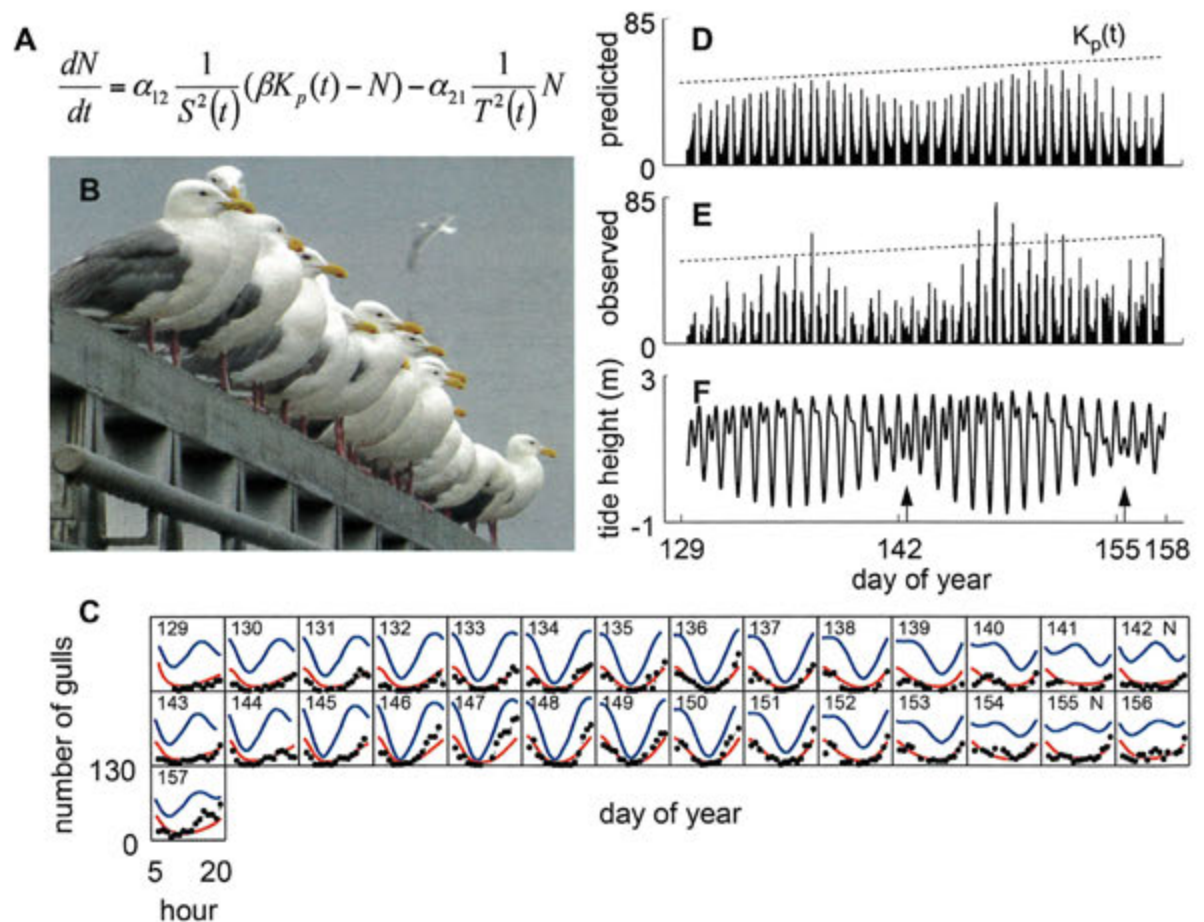


## Modeling the aggregate: Scale and determinism

We use ordinary differential equation (ODE) and difference equation models in which state variables measure the density of organisms in a particular behavioral state at a particular time. Thus, our models aggregate individuals under simplifying assumptions and track dynamics at the aggregate or population level. Some researchers feel that this approach is too coarse, that modeling animal behavior must involve individual-based models. Although our approach is not the only

way or always the best way to model animal behavior, our results show that ODEs and difference equations can indeed accurately predict the dynamics of animal groups (Henson et al. 2007a, Henson and Hayward 2010).

Dynamic patterns depend, of course, on scale (Levin 1992). A seabird colony, for example, is a complicated place at the scale of the individual. Single birds appear quite autonomous, and exhibit a wide variety of complicated behavioral choices; yet we have shown that some behaviors at the aggregate level are highly deterministic and can be predicted as a function of



**Fig. 1**

Loafing in glaucous-winged gulls (*Larus glaucescens*) depends on the tide height  $T$ , solar elevation  $S$ , and a seasonal envelope  $K_p$ .

**A.** Model equation.

**B.** Gulls loafing on a pier.

**C.** A priori model prediction (red), data from spring 2002 (circles),

and tide height (blue). Each daily panel is identified with the day of the year. Each row of 14 panels corresponds to one 2-week tidal cycle. Tidal nodes (N) occur on or near days 142 and 155. Each column of panels contains similar patterns in data.

**D.** Model predictions for the spring of 2002. Oscillations are present on daily, bi-weekly, and yearly time scales. The dotted curve is the seasonal envelope oscillation  $K_p$ .

**E.** Data observations corresponding to the predictions in D.

**F.** Tidal oscillation for the data collection time period in 2002. The tidal nodes are indicated with arrows. See Henson et al. (2004) and Hayward et al. (2009).

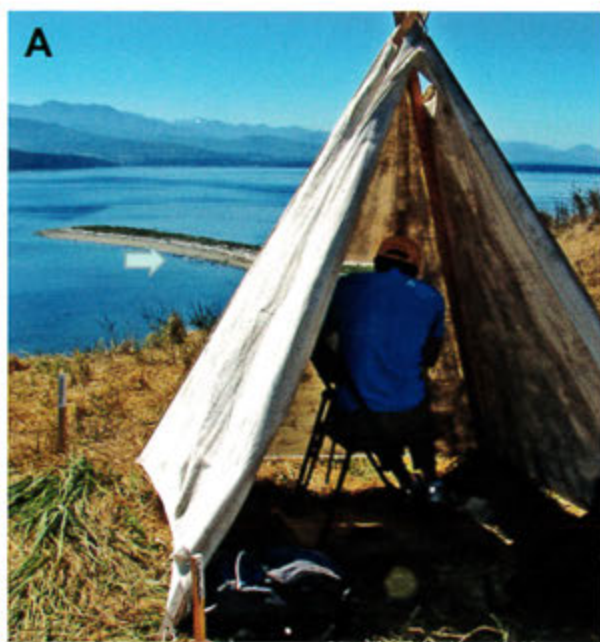
environmental variables. For example, gulls leave colony loafing areas in large numbers to feed when the tide is going out and the sun is high, and they return with an incoming tide in the evening (Fig. 1; Henson et al. 2004, Hayward et al. 2009); harbor seals leave the beach and move into the water with rising tides because the incoming current brings in food (Fig. 2; Hayward et al. 2005, Cowles et al. 2013); Galápagos marine iguanas move from land to feeding sites in the sea primarily in response to changing patterns of solar radiation (Fig. 3; Payne et al. 2015). Some behaviors are more deterministic than others, and it is possible to rank them according to the degree of determinism (Fig. 4).

continued on next page

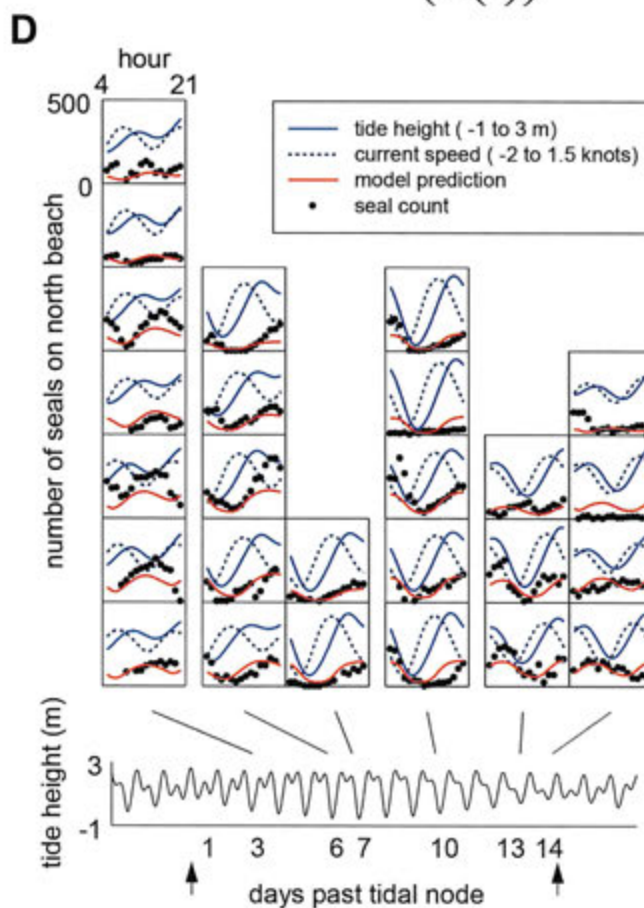
**Fig. 2**

Harbor seal (*Phoca vitulina*) haulout depends on current speed  $C_e$  and tide height  $T$ .

- A. Student research assistant uses spotting scope (arrow) from a blind on Protection Island, Washington.
- B. Harbor seals hauled out on the beach.
- C. Algebraic model for steady state dynamics.
- D. Model prediction (red), seal haul-out data (circles), tidal curve (blue solid curve), and current velocity (blue dashed curve). Each panel corresponds to one day. A typical 14-day tidal period for Protection Island is shown at the bottom; tidal nodes are indicated with arrows. See Hayward et al. (2005) and Cowles et al. (2013).



$$N(t) = \frac{\beta e^{-\gamma(\text{day of year} + t/24 - \delta)^2}}{1 + \alpha \frac{(C_e(t))^q}{(T(t))^r}}$$





## ODE and difference equation models of animal behavior

Models designed to quantitatively predict animal behavior in field populations function as testable scientific hypotheses, with measurable dependent and independent variables operating on scales at which deterministic trends emerge from variability among individuals.

We use compartmental models in which each compartment represents a specific behavioral state at a specific spatial location, and in which the state variables track the densities of individuals in each compartment (Henson et al. 2007a). If all individuals in each compartment are eligible to move to any other compartment, then (ignoring birth and death processes) the dynamics of the  $i^{\text{th}}$  compartment are governed by

$$(1) \quad N_i(t+1) = \sum_{j=1}^m p_{ij} N_j(t)$$

for discrete-time systems and

$$(2) \quad \frac{dN_i}{dt} = \sum_{j=1}^m r_{ij} N_j - \sum_{j=1}^m r_{ji} N_i$$

for continuous-time systems, where  $N_i$  is the density of individuals in the  $i^{\text{th}}$  behavioral state,  $p_{ij}$  is the discrete-time probability that an individual in the  $j^{\text{th}}$  state will move to the  $i^{\text{th}}$  state, and  $r_{ij}$  is the continuous-time per capita rate at which individuals move from compartment  $j$  to compartment  $i$ . If some animals in a compartment are not eligible to make a given transition, then the discrete-time equation for the  $i^{\text{th}}$  compartment is

A

$$N(t) = \frac{\beta(247.7 + 125.2 \sin(0.4481(\text{day of year} + t/24)))}{1 + \alpha \frac{S_e^\varepsilon H_x^\phi}{H_u^\psi T^\rho}}$$

B



C



**Fig. 3 (left)**

Marine iguana (*Amblyrhynchus cristatus*) haulout depends on solar elevation  $S_e$ , heat index  $H_x$ , and tide height  $T$ .

A. Algebraic model for steady state dynamics of hauled out iguanas on a beach at Isla Fernandina, Galápagos, Ecuador.

B. Hauled out marine iguanas.

C. Model predictions (curve) and observations (circles). See Payne et al. (2015).

**Fig. 4 (right)**

Some animal behaviors are highly determined by abiotic environmental variables; others are influenced relatively little.

From left to right: seabird rest (unpublished data), seabird preen (Henson et al. 2007), seal haulout (Hayward et al. 2005), seabird sleep (Henson et al. 2007), seabird colony attendance (Henson et al. 2007), seabird loafing (Hayward et al. 2009). After Henson and Hayward (2010).

$$(3) \quad N_i(t+1) = N_i(t) + \sum_{j=1}^m p_{ij} f_{ij} - \sum_{j=1}^m p_{ji} f_{ji} \\ = \sum_{j=1}^m p_{ij} f_{ij} + N_i(t) \left( 1 - \sum_{j=1}^m p_{ji} \frac{f_{ji}}{N_i(t)} \right)$$

and the continuous-time equation is

$$(4) \quad \frac{dN_i}{dt} = \sum_{j=1}^m r_{ij} f_{ij} - \sum_{j=1}^m r_{ji} f_{ji}$$

where  $f_{ij} \leq N_j$  is the density of individuals in compartment  $j$  that are eligible to move to compartment

$i$ . If the total population size  $K = \sum_{i=1}^m N_i$  remains constant

on the time scale of the model, we can eliminate one of

the state variables by setting  $N_m = K - \sum_{i=1}^{m-1} N_i$ .

Applying these models to any particular biological

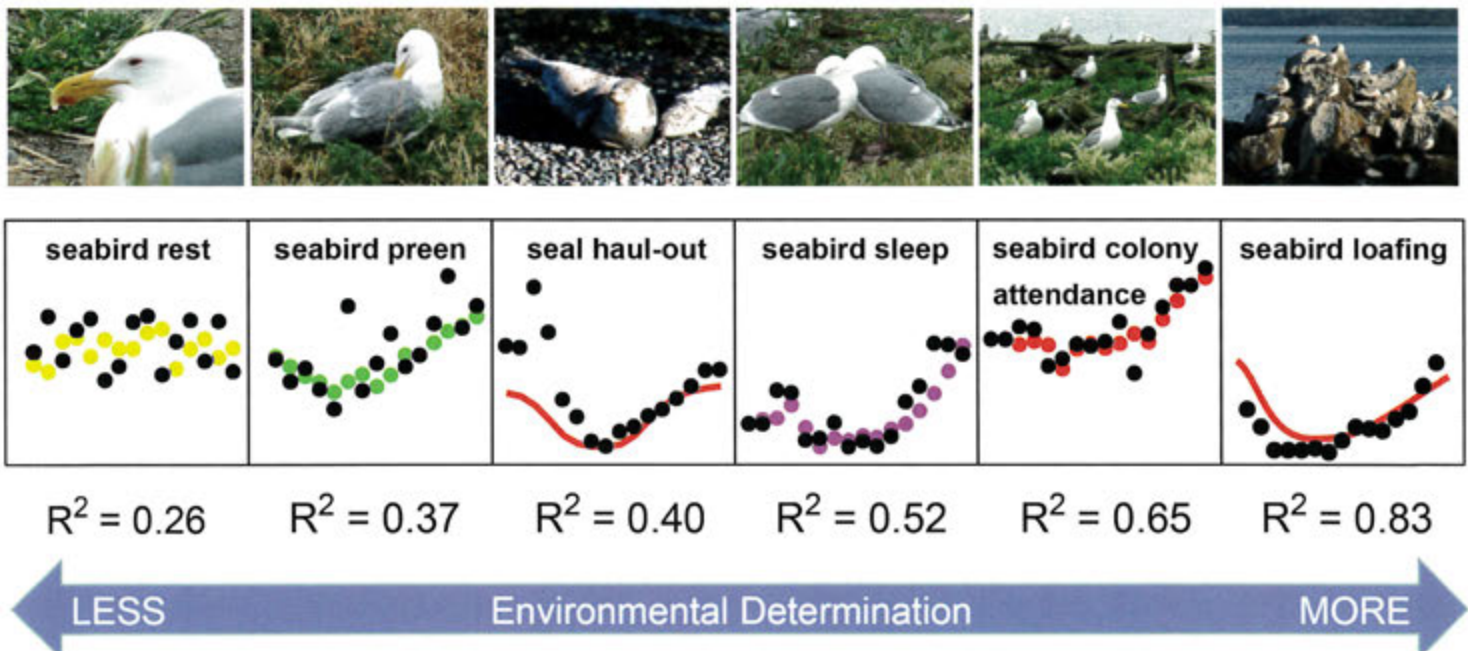
system requires specifying  $f_{ij}$ ,  $p_{ij}$ ,  $r_{ij}$  by means of modeling assumptions. In general, these coefficients are functions of population densities and time, which renders the models nonlinear and nonautonomous.

If the system recovers rapidly after disturbance, the ODEs (4) can be reduced to algebraic models on two time scales, one for disturbance dynamics and one for steady state dynamics (Figs. 2c and 3a ; Henson et al. 2006).

## Data

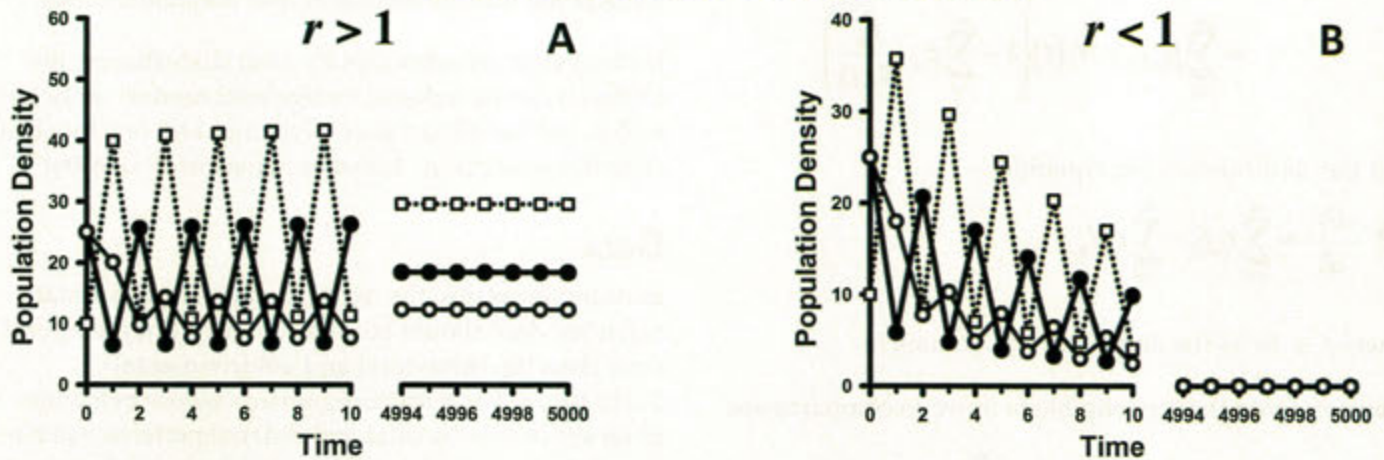
In order to capture the dynamic patterns of animal behavior, data should be collected on a finer temporal scale than the behavioral and environmental fluctuations. For marine organisms whose behaviors often are driven by tidal and diurnal patterns, we have found that hourly data collected over a complete two-week tidal cycle is best. Typically we collect data at the top of each hour for 16 or 17 hours per day for several weeks. This kind of dense data collection requires student assistants and offers many opportunities for student participation in research (Henson and Hayward 2010).

*continued on next page*

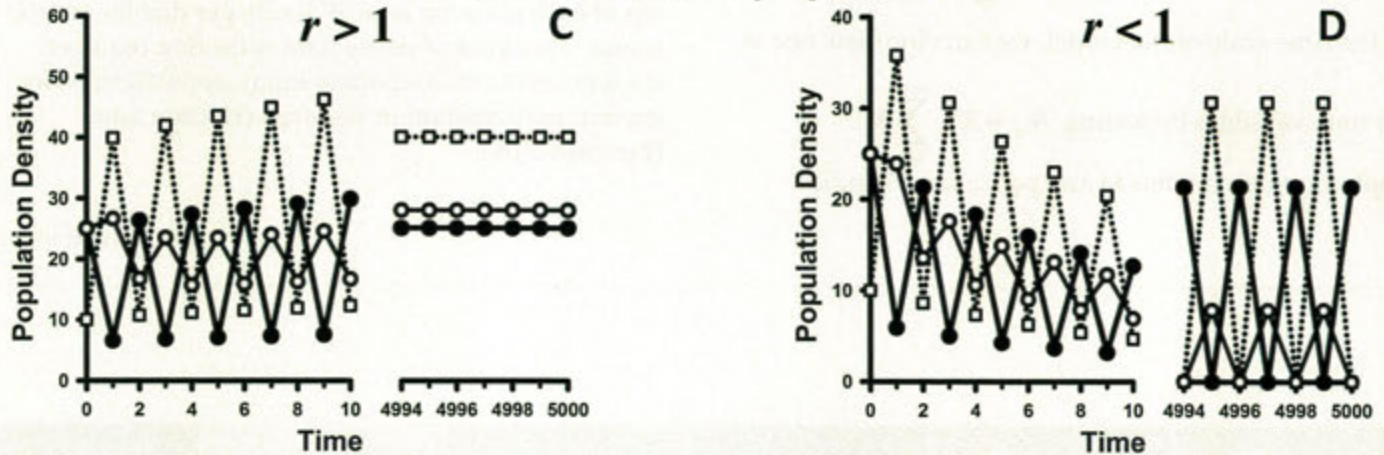




## Non-cannibalistic population



## Cannibalistic population



**Fig. 5**

Sample trajectories of a three stage, discrete time structured population model whose state variables are juveniles (open squares), reproductively active adults (solid circles), and reproductively inactive adults (open circles). Juveniles are victims of cannibalism by both adult classes. The first row of graphs is for a population without cannibalism and placed in two different environments: **A.** healthy ( $r > 1$ ) and **B.** degraded ( $r < 1$ ). Each graph shows a plot of initial transients for 10 time steps separated by a plot of the final attractor for the last 7 of 5,000 time steps. Note in **B** that this non-cannibalistic population goes extinct in the degraded environment. The second row of graphs shows the trajectories that result when

cannibalism is introduced into this population with a sufficient positive benefit to adult survival. Note in **D** that this cannibalistic population does not go extinct in the degraded environment. Also note that the cannibals' attractor is a cycle of period 2 in which the two adult classes are out-of-phase (reproductive synchrony). The explanation for this is that a backward bifurcation at  $r = 1$  has created a strong Allee effect, i.e. the existence of two attractors: a survival 2-cycle and the extinction equilibrium. Initial conditions other than those used in **D** can result in extinction. Graphs taken from Veprauskas and Cushing (2016b).



## Parameterization

Estimating parameters requires a stochastic version of the model that accounts for the noise structure (Cushing et al. 2002). For example, in many of the systems we have studied, stochastic perturbations are largely uncorrelated in the hourly sample times and the stochastic model can be written

$$(5) \quad \varphi(\mathbf{N}(\tau+1)) = \varphi(G(\tau, \mathbf{N}(\tau))) + \mathbf{E}(\tau)$$

where  $\mathbf{N} = (N_1, N_2, \dots, N_m)$  is the vector of state variables,  $\mathbf{E}$  is a vector from a multivariate normal random distribution with variance-covariance matrix  $\Sigma = (\sigma_{ij})$ , and  $G(\tau, \mathbf{N}(\tau))$  is the deterministic prediction at hour  $\tau+1$  based on the state of the system at hour  $\tau$ . Here  $\varphi$  is a variance-stabilizing transformation; the transformations  $\varphi(x) = \ln x$  and  $\varphi(x) = \sqrt{x}$  render environmental and demographic stochasticity, respectively, approximately additive (Cushing et al. 2002).

The one-step conditioned residual error vectors are

$$(6) \quad \rho(\tau+1) = \varphi(\mathbf{n}(\tau+1)) - \varphi(G(\tau, \mathbf{n}(\tau)))$$

where  $\mathbf{n}$  is the vector of observations. The likelihood function, which measures the likelihood that the residuals arose from a joint normal distribution, is a function of the model parameters, and its maximizer is the vector of parameter estimates (Cushing et al. 2002).

## Alternative models and model selection

If models serve as testable hypotheses, then we can pose alternative models as a means to test alternative hypotheses. Information theoretic methods of model selection such as the Akaike Information Criterion (AIC) take into account both the value of the likelihood function and the number of parameters, so that models with more parameters are penalized for over-fitting. This criterion allows one to select the best model from a suite of alternatives (Burnham and Anderson 2010).

## Model validation

A good model not only describes and explains, but also predicts. Validating a model means testing its predictability on an independent data set not used to estimate its parameters. One can validate a model by estimating parameters from a “calibration” data set and computing the goodness-of-fit of the fitted model on that data set, and then comparing that to the goodness-

of-fit on an independent “validation” data set without re-estimating the parameters. Goodness-of-fit can be computed with a generalized  $R^2$  (Cushing et al. 2002). For example, when we developed a model to predict numbers of gulls loafing on a pier,  $R^2 = 0.58$  for the calibration data set and  $R^2 = 0.61$  for the validation data set (Henson et al. 2004); for Galápagos marine iguana haul-out numbers,  $R^2 = 0.77$  for the calibration data set and  $R^2 = 0.80$  for the validation data set (Payne et al. 2015). Close correspondence in goodness-of-fit between calibration and validation data sets, as in these cases, suggests that a model captures the major dynamics of a system.



The most convincing models, of course, are those that make unexpected a priori predictions that are borne out by new experiments. Most seabird biologists, for example, would have predicted that during high tides gulls, which are intertidal feeders, should be loafing near the colony and not away feeding. Our model predictions, however, counterintuitively suggested that during high tides close to tidal nodes (when high tide occurs at midday) gulls should be away feeding — which is exactly what we observed (Fig. 1c, days 142 and 155).

## Proof-of-concept models and evolutionary game theory models

In addition to realistic models that are tied rigorously to data, we also use simplified proof-of-concept models to probe dynamic consequences, sharpen ideas and definitions, and suggest hypotheses.

Currently we are using discrete-time proof-of-concept models to study the effects of rising sea surface temperatures and concomitant resource paucity on

*continued on next page*



the feeding and reproductive strategies of colonial seabirds. The phenomena of interest involve interactions of individuals from different lifecycle stages and behavioral categories (eggs, juveniles, reproductively active and inactive adults, etc.) and therefore require that we build structured matrix models of the form (Caswell 2001)

$$(7) \quad N(t+1) = P(N(t)) N(t)$$

where the (density-dependent) entries of the  $m \times m$  projection matrix  $P$  describe the reproductive, survival, and category transition rates. This matrix is nonnegative (i.e. its entries are nonnegative) and is assumed to be irreducible so that each category of individuals is reachable (through birth or transition processes) from any other category. With regard to population survival, the extinction equilibrium  $N(t) = 0$

and its stability are of fundamental interest. The Linearization Principles says that its stability can be determined by the eigenvalues of the Jacobian at  $0$ , which is the (inherent or density-free) projection matrix  $P(0)$ . Perron-Frobenius theory implies the existence of a positive dominant eigenvalue  $r$ , the inherent population growth rate. The extinction equilibrium loses stability as  $r$  increases through  $1$ , which introduces survival (positive) equilibria through a transcritical bifurcation (Cushing 1998). (Other bifurcation parameters are usually more convenient to use, such as the inherent net reproduction number  $R_0$  or other model-specific parameters.) Our modeling efforts so far have concentrated on the nature of this bifurcation and how it is related to specific biological mechanisms, in particular to adult-on-juvenile cannibalism, reproductive timing, and environmental resource degradation (due to climate and environmental change).

For example, a low dimensional cannibalism model that includes the negative and positive effects on juvenile (victim) and adult (cannibal) survival rates, respectively, and a trade-off between environmental resource availability and cannibalism activity shows that cannibalism can result in a stable survival equilibrium in circumstances under which the absence of cannibalism would lead to extinction (namely, when

environmental resource is low and the positive effect of cannibalism on adult survival is significant enough). Mathematically, this is due to a backward bifurcation at  $r = 1$ , which in turn creates a strong Allee effect and its corresponding survival equilibrium when  $r < 1$  (Cushing et al. 2015). In the absence of cannibalism the bifurcation is forward and  $r < 1$  (a degraded environment) implies extinction.



Another model, designed to explore the effects of reproductive synchrony by adults, has a more complicated bifurcation. Mathematically, this is caused by the imprimitivity of  $P(0)$  ( $r$  is not a *strictly* dominant eigenvalue). The result is the simultaneous bifurcation of periodic cycles at  $r = 1$ , cycles whose adult components are out-of-phase and represent reproductive synchrony. The stability of these cycles is promoted by environmental degradation, the resulting

increase in cannibalism, and an assumed victim (prey) saturation effect of cannibals (predators) (Veprauskas and Cushing 2016b).

These findings support our hypotheses concerning the observed correlations between cannibalism, reproductive synchrony, and climate change (for which mean sea surface temperature is a surrogate) in seabird colonies (Henson et al. 2010, Henson et al. 2011, Hayward et al. 2014).

To explore whether the traits that produce these conclusions are adaptive in an evolutionary sense, we have begun investigations of evolutionary versions of the models using the methodology of evolutionary game theory. This methodology assumes the individual vital rates modeled by the entries in the projection matrix are functions of a vector  $\mathbf{v}$  of phenotypic traits of the individual, subject to Darwinian evolution, as well as the traits of other individuals (which is why “game” appears in the name of this methodology) as represented by the population mean trait vector  $\mathbf{u}$ . Thus,  $\mathbf{P} = \mathbf{P}(\mathbf{N}, \mathbf{v}, \mathbf{u})$ . Evolutionary game theory models population dynamics by

$$(8) \quad N(t+1) = P(N(t), \mathbf{v}, \mathbf{u}(t))|_{\mathbf{v} = \mathbf{u}(t)} N(t)$$





The canonical assumption of Darwinian evolution states that the change in the mean trait  $\mathbf{u}$  is proportional to the fitness gradient (with respect to  $\mathbf{v}$ ). In the multi-trait context this assumption is expressed by the equation

$$(9) \quad \mathbf{u}(t+1) = \mathbf{u}(t) + \mathbf{C} \nabla_{\mathbf{v}} \mathbf{F}(\mathbf{N}(t), \mathbf{v}, \mathbf{u}(t))|_{\mathbf{v} = \mathbf{u}(t)}$$

where  $\mathbf{C}$  is a variance-covariance matrix among the traits. This is often called the Breeder's or Fisher's or Lande's equation. The connection between the population and trait dynamics (together called Darwinian dynamics) is made by relating fitness  $\mathbf{F}$  to the projection matrix  $\mathbf{P}$ . The most commonly adopted definition of fitness is  $\mathbf{F}(\mathbf{N}, \mathbf{v}, \mathbf{u}) = \ln r(\mathbf{N}, \mathbf{v}, \mathbf{u})$ . For these Darwinian dynamic models we have established extensions of the fundamental bifurcation theorems that occur as the extinction equilibrium destabilizes (Veprauskas and Cushing 2016a) and used them (and numerical simulation explorations) to study evolutionary versions of our cannibalism and reproductive synchrony models. For example, by use of this methodology we have shown that cannibalism rates that produce population survival in degraded environments can be

an evolutionary adaptive strategy (evolutionary stability strategy or ESS) (Veprauskas and Cushing 2016b).

## Closing thoughts

The role of the burgeoning human populace as a major planet changer provides a rich field of opportunities for applied mathematicians and ecologists. As we look to the future, a serious problem is the lack of quantitative training for biologists; in many universities, biology majors are no longer required to take calculus. As a consequence, biologists sometimes do not have enough basic mathematical training to collaborate effectively with mathematicians. Mathematicians, on the other hand, often are more interested in finding applications of a particular theorem than in actually addressing a scientific problem with its attendant messiness of data and stochasticity. Never has there been a more opportune time, however, for mathematicians and biologists to work together to solve pressing scientific problems.



## Acknowledgements

We thank the National Science Foundation (DMS 0314512, 0613899, 1022494, 1407040 to S. M. H. and J. L. H.; DMS 1407564 to J. M. C.) and Andrews University (faculty grants 2002–2016) for financial support of our work; Kevin Ryan, Jennifer Brown-Scott, Lorenz Sollmann, and Sue Thomas for permission to work on Protection Island National Wildlife Refuge; Rosario Beach Marine Laboratory for logistical support in Washington State; Galápagos National Park for permission to study marine iguanas; Charles Darwin Foundation for logistical support in the Galápagos Islands; and our many students for field and laboratory assistance.

## References

- Burnham, K. P. and D. R. Anderson (2010). *Model selection and multimodel inference: a practical information-theoretic approach*. Springer, New York, NY.
- Caswell, H. (2001). *Matrix Population Models: Construction, Analysis, and Interpretation*. Sinauer Associates, Sunderland, MA.
- Cowles, J. D., S. M. Henson, J. L. Hayward and M. W. Chacko (2013). A method for predicting harbor seal (*Phoca vitulina*) haulout and monitoring long-term population trends without telemetry. *Natural Resource Modeling* 26(4): 605–627.
- Cushing, J. M. (1998). *An Introduction to Structured Population Dynamics*. Conference Series in Applied Mathematics Vol. 71, SIAM.
- Cushing, J. M., R. F. Costantino, B. Dennis, R. Desharnais and S. M. Henson (2002). *Chaos in Ecology: Experimental Nonlinear Dynamics*. Elsevier Science, New York, NY.
- Cushing, J. M., S. M. Henson and J. L. Hayward (2015). An evolutionary game-theoretic model of cannibalism. *Natural Resource Modeling* 28(4): 497–521.
- Hayward, J. L., S. M. Henson, C. J. Logan, C. R. Parris, M. W. Meyer and B. Dennis (2005). Predicting numbers of hauled-out harbour seals: a mathematical model. *Journal of Applied Ecology* 42(1): 108–117.
- Hayward, J. L., S. M. Henson, R. D. Tkachuck, C. M. Tkachuck, B. G. Payne and C. K. Boothby (2009). Predicting gull/human conflicts with mathematical models: a tool for management. *Natural Resource Modeling* 22(4): 544–563.
- Hayward, J. L., L. M. Weldon, S. M. Henson, L. C. Megna, B. G. Payne and A. E. Moncrieff (2014). Egg cannibalism in a gull colony increases with sea surface temperature. *Condor* 116(1): 62–73.
- Henson, S. M., J. M. Cushing and J. L. Hayward (2011). Socially induced ovulation synchrony and its effect on seabird population dynamics. *Journal of Biological Dynamics* 5(5): 495–516.
- Henson, S. M., B. Dennis, J. L. Hayward, J. M. Cushing and J. G. Galusha (2007a). Predicting the dynamics of animal behaviour in field populations. *Animal Behaviour* 74(1): 103–110.
- Henson, S. M., J. G. Galusha, J. L. Hayward and J. M. Cushing (2007b). Modeling territory attendance and preening behavior in a seabird colony as functions of environmental conditions. *Journal of Biological Dynamics* 1(1): 95–107.
- Henson, S. M. and J. L. Hayward (2010). The mathematics of animal behavior: an interdisciplinary dialogue. *Notices of the American Mathematical Society* 57(10): 1248–1258.
- Henson, S. M., J. L. Hayward, C. M. Burden, C. J. Logan and J. G. Galusha (2004). Predicting dynamics of aggregate loafing behavior in glaucous-winged gulls (*Larus glaucescens*) at a Washington colony. *Auk* 121(2): 380–390.
- Henson, S. M., J. L. Hayward, J. M. Cushing and J. G. Galusha (2010). Socially induced synchronization of every-other-day egg laying in a seabird colony. *Auk* 127(3): 571–580.
- Henson, S. M., J. L. Hayward and S. P. Damania (2006). Identifying environmental determinants of diurnal distribution in marine birds and mammals. *Bulletin of Mathematical Biology* 68(2): 467–482.
- Levin, S. A. (1992). The problem of pattern and scale in ecology. *Ecology* 73(6): 1943–1967.
- Payne, B. G., S. M. Henson, J. L. Hayward, L. C. Megna and S. R. Velastegui Chávez (2015). Environmental constraints on haul-out and foraging dynamics in Galápagos marine iguanas. *Journal of Coupled Systems and Multiscale Dynamics* 3(3): 208–218.
- Veprauskas, A. and J. M. Cushing (2016a). Evolutionary dynamics of a multi-trait semelparous model. *Discrete and Continuous Dynamical Systems Series B* 21(2): 655–676.
- Veprauskas, A. and J. M. Cushing (2016b). A juvenile–adult population model: climate change, cannibalism, reproductive synchrony, and strong Allee effects. *Journal of Biological Dynamics*, DOI: 10.1080/17513758.2015.1131853.
- Waters, C. N., J. Zalasiewicz, C. Summerhayes, A. D. Barnosky, C. Poirier, A. Galuszka, A. Cearreta, M. Edgeworth, E. C. Ellis, M. Ellis, C. Jeandel, R. Leinfelder, J. R. McNeill, D. d. Richter, W. Steffen, J. Syvitski, D. Vidas, M. Waple, M. Williams, A. Zhisheng, J. Grinevald, E. Odada, N. Oreskes and A. P. Wolfe (2016). The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* 351(6269): 137.



# PRESIDENT'S COLUMN

by John Hearne



**A**s I write it is just over three months before our annual conference. The conference organisers, Bob

Fray and Catherine Roberts, have done a superb job so far and there is every indication that this will be another inspirational experience both scientifically and socially. At this conference "The Rollie Lamberson Research Award" will be awarded for the first time. Beautiful medals have been cast for these prestigious awards. There is still time to have your paper considered. Please see our website for more details.

Have you visited our website recently? ([resource modeling.org](http://resource modeling.org)) Thanks to Harry Gorfine for keeping this website up to date. Also thanks to Vanessa Trijoulet and Adam Clark there are frequent posts of scholarship opportunities for both PhD's and Postdocs as well as other useful information.

**The 2017 conference will be held in Barcelona from June 18-21.** This conference will be co-hosted by the Pau Costa Foundation for Fire Ecology and Management. They state for their work: "The objectives are the research in the field of forest fire ecology, the creation of knowledge, tools and techniques for the management of forest fires, and the dissemination of this knowledge to the technical world through training and dissemination

instruments." The conference should provide an opportunity for RMA members to establish new collaborations. Of course, as usual, the conference will welcome all areas of natural resource modelling.

We continue to seek ways to improve the value of your membership of the RMA. We have great conferences, a good journal, informative newsletters, an active website where you can advertise jobs free of charge, and a prestigious Research Award Medal. We welcome any ideas to further our service to you the member.

I look forward to seeing many of you in Flagstaff in June. After Flagstaff we have Barcelona (2017) and we are looking for proposals for 2018.

## Membership in RMA

All members who have supplied an email receive the first renewal notice via email, which includes a link to the online renewal page. The second renewal notice is printed and mailed, the 3rd notice is emailed. This is the link to the main ordering page: [http://ordering.onlinelibrary.wiley.com/membership.asp?ref=1939-7445&doi=10.0111/\(ISSN\)1939-7445](http://ordering.onlinelibrary.wiley.com/membership.asp?ref=1939-7445&doi=10.0111/(ISSN)1939-7445). The link provided in the renewal emails goes directly to the order form for the type of membership and should list the correct rate.

Due to data security guidelines, Wiley no longer includes the credit card payment box on the printed renewal forms, and therefore we encourage the members to renew online or to contact us by phone. Online credit card payments are accepted globally. We do accept VISA, MasterCard and AMEX, but not PayPal.

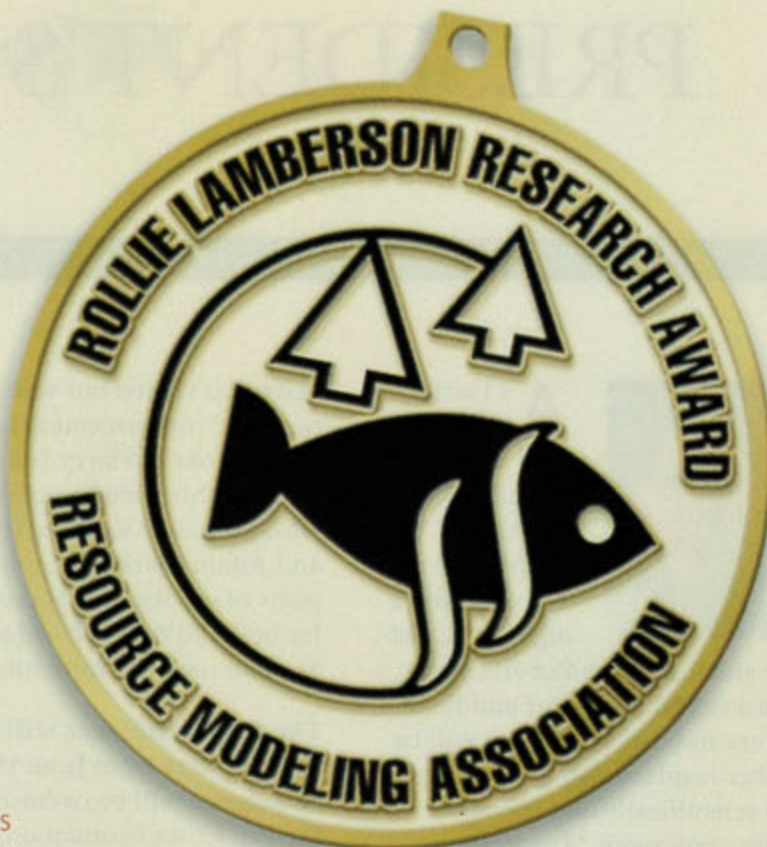
If you have any questions about your membership, feel free to contact Gayle Scaramozza (Membership Services Specialist): Wiley Publishing Global Operations, 350 Main St., Malden, MA, USA; 781.388.8425; [gscaramo@wiley.com](mailto:gscaramo@wiley.com)



# Rollie Lamberson Award

The Resource Modeling Association's annual Rollie Lamberson Award will be announced for the first time at the RMA annual conference in Flagstaff in June 2016. The award is given for the most outstanding paper in natural resource modeling of the previous two years, authored by an RMA member. This new award has been established to recognize the contribution of Professor Roland (Rollie) Lamberson to the growth of the RMA and its journal *Natural Resource Modeling*. Rollie is a founder of the Resource Modeling Association and has served as the founding President and as Executive Secretary, receiving an Award for Distinguished Service from the association in 1991. He has also contributed substantially to the *Natural Resource Modeling* journal, acting as Managing Editor 1985–1991, and editing numerous special issues, and still serves on NRM's Senior Advisory Council.

All papers published in *Natural Resource Modeling* within the past two calendar years, with at least one current RMA member as an author, will automatically be considered for the award. Papers published in other journals by current RMA members may also be nominated for consideration, by submission of an electronic copy of the paper in English along with a nominating letter detailing why the paper merits the Rollie Lamberson Award. These nominated papers should be sent to [editor@resourcemodeling.org](mailto:editor@resourcemodeling.org). The deadline for submitting nominations is May 15, 2016.



The award recipients will be decided by a committee comprising representatives from the RMA board of directors and the editorial board of *Natural Resource Modeling*. The committee members and the RMA president are ineligible for the award. The award-winning paper will be the one most consistent with the RMA's goals of advancing modeling excellence to transcend divides among natural resources disciplines, and will have broad reach and implications for the natural resource modeling community. Detailed criteria for the award can be found at the RMA website [resourcemodeling.org/awards/](http://resourcemodeling.org/awards/)

The authors of the winning paper will each receive the Rollie Lamberson Medal. In addition, one author will be invited to deliver the Rollie Lamberson Award address in a plenary session of the RMA conference, including subsidized attendance at the conference.





## Editor's Column

*by Catherine A. Roberts*  
*Editor of Natural Resource Modeling*

**W**e are pleased to announce the 2016 changes to our society's journal's editorial board for its 29th volume. Carlos Castillo-Chavez has moved to our Senior Advisory Council and will continue his involvement with the journal in this new role. We thank several editors who are moving off the board for new adventures: Peter Baxter, Graciela Ana Canziani, Jon Conrad, James Ianelli, and Maja Schluter. Our editorial board welcomes the following new members:

**Sarah Bekessy**

*Social and Ecological Modeling*  
Royal Melbourne Institute of Technology, Australia

**Luc Doyen**

*Bioeconomic Modeling for Resource Management*  
University of Bordeaux, France

**Julie C. Blackwood**

*Mathematics and Ecological Dynamics*  
Williams College, USA

**Martin Quass**

*Fisheries and Sustainability Economics*  
Kiel University, Germany

**Ignacio Barradas Bribiesca**

*Applied Mathematics in Biology*  
Centro de Investigacion en Matematicas (CIMAT), Mexico

In addition, Athol Whitten (Fisheries Modeling and Management) has changed his affiliation to Mezo Research in Australia. Not only does this new editorial board offer us tremendous expertise in areas where we are seeing increasing paper submissions to the journal, they also extend our international diversity.

Please remember that membership in the Resource Modeling Association includes expedited reviews of manuscripts you submit to our journal. It also includes online access to our journal. If you do not know how to access this, please send an email query to Gayle Scaramozza, Membership Services Specialist, at [gscaramo@wiley.com](mailto:gscaramo@wiley.com).

I look forward to seeing many of you at the 2016 World Conference on Natural Resource Modeling in Flagstaff, Arizona. Two of our editorial board members are among the keynote speakers! As usual, the journal will sponsor prizes for students' talks and posters. Please encourage your students to join us.





Resource Modeling Association  
[resourcemodeling.org](http://resourcemodeling.org)

In 1982 a group of researchers living in the western United States and Canada and working in the intersection of Applied Mathematics, Ecology, Economics, Fisheries and Forestry held a meeting in Arcata, California and decided to form a learned society of like-minded individuals. Thus was the birth of the Resource Modeling Association (RMA). Since then it has grown into an international organization of individuals who are interested in using quantitative methods to study and manage natural resources.

The RMA sponsors a major scholarly journal, *Natural Resource Modeling* published by Wiley, and annual conferences that are held throughout the world. These conferences, which are rather small, emphasize close interaction between senior researchers and those who are beginning their careers. There is an emphasis on social interaction as well as serious scholarly exchanges. These contacts have often led to shared ideas and collaboration. This is an ideal setting for young researchers to present the results of their initial work. These international meetings are usually held at interesting locations where major environmental studies are being conducted.



Summer 2015 RMA Banquet Dinner

The RMA also publishes a biannual newsletter with survey articles and information about happenings of the association and the annual conference. The RMA website [resourcemodeling.org](http://resourcemodeling.org) has a wealth of information about the organization and resource management. The association also sponsors the annual Rollie Lamberson Award for outstanding research papers in the area of resource modeling by authors who are members of the RMA.

The association welcomes all scientists who are interested in using quantitative methods to inform the management of natural resources. When you attend one of the world conferences you will experience many other researchers from around the world who share your interest in and enthusiasm for preserving our resources using mathematical techniques.

### RMA MEMBERSHIP INCLUDES:

- Subscription to the journal *Natural Resource Modeling* (NRM)
- RMA Newsletter
- Reduced registration fee for the annual conference
- Eligibility for the Rollie Lamberson Award
- A 25% discount on all Wiley and Wiley-Blackwell product lines

*The official newsletter of the  
 Resource Modeling Association*

Bob Fray, editor  
[bob.fray@furman.edu](mailto:bob.fray@furman.edu)

Mathematics Department  
 Furman University  
 3300 Poinsett Highway  
 Greenville, South Carolina 29613