**Manuscript 1: Expert elicitation of salamanders**

**Title:**

* Predicting salamander occurrence when data is lacking using expert opinion

**Journal:**

* Conservation evidence (Making amphibian conservation more effective; Meredith et al. 2016)
* Conservation biology (martin et al. 2012, Addison et al. 2015)

**Introduction:**

* Expert knowledge is widely used in conservation b/c of the complexity of problems, relative lack of empirical data and imminent nature of decisions.
* This knowledge typically takes the form of mental models without explicit consideration of biases (i.e., experts are called on to express opinions in a qualitative and non-transparent way). In fields where there is extensive expert knowledge, yet little published data, the use of expert information as priors for ecological models is a cost-effective way of making more confident predictions about the effect of management on biodiversity.
* Increasing use of expert elicitation methods to help inform conservation decisions (identify important hypothesis and parameter uncertainties to resolve). Probabilistic framework that accounts for uncertainty (confidence) of multiple experts.
* Examples of expert elicitation used to parameterize models that inform management decisions (from Martin et al. 2012):
  + Johnson et al. 2010 – use to parameterize Bayesian network to evaluate population viability of cheetahs (X experts)
  + Runge et al. 2011 – use to identify alternative hypotheses and uncertainties affecting mgt of whooping cranes (X experts)
  + O’Neill et al. 2008 – used to quantify trends and range of effects of climate change on polar bears (10 experts)
  + Martin et al. 2005 and Kuhnert et al. 2005 – used to evaluate effects of livestock grazing intensity on austrialian woodland birds in Bayesian GLM (20 experts)
  + Smith et al. 2011 – Bayesian networks
* Examples from Charney 2012:
  + Expert opinion is increasingly used to parameterize models in the absence of data and as Bayesian priors to supplement sparse data (Yamada et al., 2003; Martin et al., 2005; Denham and Mengersen, 2007; Griffiths et al., 2007; Mac Nally, 2007; O’Neill et al., 2008; Low Choy et al., 2009; O’Leary et al., 2009; Murray et al., 2009; James et al., 2010). Yet, when lacking data, expert opin- ion does not necessarily offer an improvement (Cox, 2000; Pearce et al., 2001; Seoane et al., 2005).
* Canessa: Where empirical measures of the required parameters for a situation of interest are not available, expert judgment can help develop plausible estimates that most effectively inform decisions (Speirs-Bridge et al. 2010; Martin et al. 2012). Such methods can prove especially valuable in the management of threatened species, where the need to make urgent decisions leaves little time for the collection of further information.
* An expert is someone who has substantial information on a particular topic that is not widely known by others and who is offered deferred to for their knowledge and interpretation.
* Expert-elicitation (in general) is composed of 5 steps:
  + Deciding how information will be used (purpose and motivation)
  + Determining what to elicit (and identifying experts; creating a statistical model)
  + Designing elicitation process
  + Performing elicitation
  + Translating elicited information into quantitative statements that be used in ecological models (to ultimately help make decisions).
* Additional important steps:
  + How to work with multiple experts
  + How to combine multiple judgments (treat as equal or weights, average or ranges)
  + Minimizing bias in elicited information
  + Verifying accuracy of expert information
* Limited information about amphibians (salamanders) region-wide and are in decline – call for experts to aid in identifying parameters to be used in both predictive and decision models to evaluate range of outcomes of conservation actions.
  + Do predictions from experts vary from publications? (maybe compare in analysis or compare in discussion)
  + Publications have to make lots of assumptions, we hope experts are considering these assumption and relaxing them, thus providing a more realistic understanding of drivers of occurrence.
* Objective:
  + Conduct expert elicitation for Plethedontide (stream obligate for at least some stage of life-history?): Desmognathus, Gyrinophilus, and Eurycea
  + Specifically, G. porphyriticus; spring salamander, D. fuscus; dusky salamander, and E. bislineata; two-lined salamander
  + These species occur across the northeastern streams (i.e., relevant for NECSC) and are known to co-occur in streams with fishes (brook trout; cite), an important predictor/competitor affecting salamander populations.
  + Use insights from experts to build predictive co-occurrence models under climate change (Hocking et al. forecasting paper), and evaluate land-protections strategies (Kate et al. optimization paper).
  + Questions:
    1. How much do expert opinions agree with field-observations (do we have any? – see publication list that we’ll be sending to experts)
    2. How variable are expert opinions (mean and confidence)? Where is the disagreement?
    3. Which uncertainties are driving forecasts of occurrence (sensitivity analysis; tornado diagram)?

**Methods:**

*What to elicit?*

* Stats (mean and confidence): participants provide optimistic and pessimistic consequence estimates to represent 90% credible bounds (reflecting 3-point or 4-point elicitation approach (Speirs-Bridge et al. 2010)).
* Match scale of actions with scales for response (catchment-level actions = occupancy of salamanders).
* Should we elicit multi-state abundance responses (not occupancy) (0, low, medium, some, lots)?
* List of variables (Table 1):
  + Baseline/overall average state (intercept)
  + Catchment-level effects
  + Upstream-level effects
  + Buffer-level effects
  + Upland-level effects
  + Regional-conditional effects (hierarchical; hyper parameter; intercept or slope interaction?)
  + Species (hyper-parameter; affecting slopes/betas)
  + Additional spatial autocorrelation?
  + Temperature effects (mean summer variability, maximum, annual average)
  + Streamflow metric (mean summer variability, maximum, minimum, annual average)
  + Interspecific effects

Table 1. List of variables to elicit (also see BBN).

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Description | Unit | Interpretation |
| Baseline occupancy |  | Probability (0 to 1) | Probability of any catchment, on average, being occupied (intercept) |
| Local Catchment Forest cover | The percent forest cover with a catchment influence occupancy of salamanders | 1 unit increase in forest cover (i.e., X acres randomly throughout the catchment) |  |
| Upstream Catchment Forest Cover |  |  |  |
| Local Forest Buffer |  |  |  |
| Upstream Catchment Forest Buffer |  |  |  |
| Stream Temperature |  |  |  |
| Fish Presence |  |  |  |
| Network Position |  |  |  |
| Local Catchment Wetland Cover |  |  |  |
| Upstream Catchment Wetland Cover |  |  |  |
| Conditional on region/province? (n= | Which responses are conditional on region | Appalachian Plateaus, Valley and Ridge Province, Blue Ridge Province, Piedmont Province, Coastal Plain, New England, Adirondack Province, Interior Low Plateaus | The effects of another variable varies depending on which province your in (due to underlying geology, ground-water connectivity, and other unexplained factors) |

*Salamander model:*

s = species

1 = G. porphyriticus spring salamander

2 = D. fuscus dusky salamander

3 = E. bislineata two-lined

i = catchment

occupied[s,i]~beta(p(occupancy[s,i]))

p(occupancy[s,i]) ~ gamma(mean.pocc[s,i], precision[s,i])

mean.pocc [s,i] <- B0[s] + B1[s,i] + B2[s,i] + B3[s,i]

B0[s] = grand.mean.pocc[s]

B0[s] <-

B0[0,s] +

B0[1,s]\*physiographic province[coastal plain] +

B0[2,s]\*physiographic province[piedmont] +

B0[3,s]\*physiographic province[valley and ridge] +

B0[4,s]\*physiographic province[new england] +

B0[5-8,s]\*physiographic province[other 4 provinces in table 1]

B0[1-8,s]~normal(mean,confidence.90perc)

Elicitation question (4 point confidence; Speirs-Bridge et al. 2010):

1. Realistically, what is your most likely estimate for probability of occupancy in a coastal catchment?
2. Realistically, what do you think the lowest value could be?
3. Realistically, what do you think the highest value could be?
4. How confident are you that the interval you gave (lowest to highest) will capture the true value (please enter a number between 0 and 100% confident)?

Martin et al. 2005 (Eco Apps) only elicited the mean, and calculated the mean and precision using mean values across experts (did not elicit lowest, highest and confidence).

B1[s,i] = effect of upstream catchments[s]

B1[s] <-

B1[0,s] +

B1[1,s]\*upstream.totalforest +

B1[2,s]\*upstream.bufferforest +

B1[3,s]\*upstream.totalwetland

B2[s,i] = effect of local catchments[s]

B2[s] <-

B2[0,s] +

B2[1,s]\*local.totalforest +

B2[2,s]\*local.bufferforest +

B2[3,s]\*local.totalwetland

Example BBN for elicitation of variables (see Ban et al. 2015)

- identify important conditional probabilities

*Elicitation process (to manage bias):*

* Method: email survey, telephone interview, face-to-face interview, group meeting?
* Use a pre-defined elicitation program? http://www.expertsinuncertainty.net/Software/tabid/4149/Default.aspx
* Experts Identified:
  + Criteria – use snowball method question? Ask: Who would you go to for expert judgments on salamander ecology for these three species? Why?
  + Years of direct research on salamanders
  + Number of publications involving salamanders
  + Area of expertise
    - General salamander ecology (more than x publications?)
    - Plethedontide specialist (more than x publications?)
    - Desmognathus expert (more than x publications?)
    - Gyrinophilus expert (more than x publications?)
    - Eurycea expertise (more than x publications?)
    - Landscape effects on salamanders (more than x publications?)
    - Predation-fish effects on salamanders (more than x publications?)

Table 2. List of salamander experts for consideration:

|  |  |  |  |
| --- | --- | --- | --- |
| Last, First | Affiliation | Contact | Area of expertise |
| Adams, Dean |  |  |  |
| Adams, Mike | USGS |  |  |
| Apodoca, JJ |  |  |  |
| Baily, Larissa | Colorado State |  |  |
| Barrett, Kyle | Clemson |  |  |
| Beachy, Chris |  |  |  |
| Bonett, Ron |  |  |  |
| Bruce, Dick |  |  |  |
| Calhoun, Aram |  |  |  |
| Camp, Carola |  |  |  |
| Cecala, Kristen |  |  |  |
| David, Robert |  |  |  |
| Earl, Julia |  |  |  |
| Fields, Will | USGS |  |  |
| Gorman, Tom |  |  |  |
| Graham, Sean |  |  |  |
| Grant, Evan | USGS |  |  |
| Greenwald, Katie |  |  |  |
| Harper, Elizabeth |  |  |  |
| Highton, Dick |  |  |  |
| Hill, Pierson |  |  |  |
| Hocking, Dan | USGS |  |  |
| Homyack, Jessica |  |  |  |
| Houck, Lynne |  |  |  |
| Hunter, Malcom |  |  |  |
| Jaeger, Bob |  |  |  |
| Kozak, Ken |  |  |  |
| Kroll, AJ |  |  |  |
| Lips, Karen |  |  |  |
| Lowe, Winsor |  |  |  |
| Maerz, John | UGA |  |  |
| Mendelson, Joe |  |  |  |
| Milanovich, Joe |  |  |  |
| Miller, David | Penn State |  |  |
| Muths, Erin | USGS |  |  |
| O’Connell, Katie |  |  |  |
| Patrick, David |  |  |  |
| Pauley, Tom |  |  |  |
| Peterman, Bill |  |  |  |
| Pierson, Todd |  |  |  |
| Rissler, Leslie |  |  |  |
| Scott, David |  |  |  |
| Steen, David | Auburn |  |  |
| Stuart, X |  |  |  |
| Sutton, Bill |  |  |  |
| Tilley, Stephen |  |  |  |
| Titus, Valorie |  |  |  |
| Trauth, Stan |  |  |  |
| Wake, David |  |  |  |
| Walls, Susan |  |  |  |
| Welsh, Hartwell |  |  |  |

* Experts will draw on their own expertise, scientific publications and management agency reports (we created a list of relevant documents and provided to experts; Table 1).

Table 3. List of relevant literature provided to experts:

|  |  |  |
| --- | --- | --- |
| Paper | Species | Variables |
|  |  | Baseline states (intercepts) |
|  |  | Catchment-level effects |
|  |  | Upstream-level effects |
|  |  | Buffer-level effects |
|  |  | Upland-level effects |
|  |  | Regional-differences |
|  |  | Additional spatial autocorrelation? |
|  |  | Climate-effects (temperature and flow) |
|  |  | Interspecific effects (with trout) |

*Suggested References Papers:*

Non-forest impacts (urban, agriculture):

Barrett, K. & Price, S. J. Urbanization and stream salamanders: a review, conservation options, and research needs. *Freshw. Sci.* **33,** 927–940 (2014).

Grant, E. H. C., Green, L. E. & Lowe, W. H. Salamander occupancy in headwater stream networks. *Freshw. Biol.* **54,** 1370–1378 (2009). Summary: Eurycea complex mean occupancy = 0.99 (0.03 SE) branched streams, 0.90(0.07 SE) unbranched streams. Two regions: National Capitol Region (3 national park units surrounded by urban) and VA (3 units surrounded by forest; Shenandoah National Park and George Washing and Jefferson National Forest) sites. Lower occupancy in NCR than VA.

Price, S. J., R. A. Browne, and M. E. Dorcas. 2012a. Evaluating the effects of urbanisation on salamander abundances using a before-after control-impact design. Freshwater Biology 57: 193–203.

Price, S. J., K. K. Cecala, R. A. Browne, and M. E. Dorcas. 2011. Effects of urbanization on occupancy of stream salamanders. Conservation Biology 27:547–555.

Price, S. J., M. E. Dorcas, A. L. Gallant, R. W. Klaver, and J. D. Willson. 2006. Three decades of urbanization: estimating the impact of land cover change on stream salamander pop- ulations. Biological Conservation 133:436–441.

Climate-niche models:

Sutton, W. *et al.* Predicted Changes in Climatic Niche and Climate Refugia of Conservation Priority Salamander Species in the Northeastern United States. *Forests* **6,** 1–26 (2014).

Milanovich, J. R., Peterman, W. E., Nibbelink, N. P. & Maerz, J. C. Projected Loss of a Salamander Diversity Hotspot as a Consequence of Projected Global Climate Change. *PLoS One* **5,** e12189 (2010).

Streamflow impacts:

Price, S. J., R. A. Browne, and M. E. Dorcas. 2012b. Resistance and resilience of a stream salamander to supraseasonal drought. Herpetologica 68:312–323.

Fish-salamander studies:

Barr, G. & Babbitt, K. Effects of biotic and abiotic factors on the distribution and abundance of larval two-lined salamanders ( Eurycea bislineata ) across spatial scales. *Oecologia* **133,** 176–185 (2002).

Lowe, W. H., Nislow, K. H. & Bolger, D. T. Stage-Specific and Interactive Effects of Sedimentation and Trout on a Headwater Stream Salamander. **14,** 164–172 (2004).

*Analysis*

* Comparisons of means and confidence across experts
* Weighted averages (various methods for combining experts?)
* Use to make simple salamander only-predictions (which uncertainties matter most?)

**Results**

* Number of experts
* Comparisons across experts (what was consistent and what wasn’t)
* Weighted averages across experts
* Which uncertainties influenced occupancy predictions the most?
* New hypothesis/insights from experts

**Discussion**

**Literature**

Ban, S. S., Pressey, R. L. & Graham, N. A. J. Assessing the Effectiveness of Local Management of Coral Reefs Using Expert Opinion and Spatial Bayesian Modeling. *PLoS One* **10,** e0135465 (2015).

Charney, N. D. Evaluating expert opinion and spatial scale in an amphibian model. *Ecol. Modell.* **242,** 37–45 (2012).

James, A., Choy, S.L., Mengersen, K., 2010. Elicitator: an expert elicitation tool for regression in ecology. Environmental Modelling & Software 25, 129–145

Low Choy, S., O’Leary, R. & Mengersen, K. Elicitation by Design in Ecology : Using Expert Opinion to Inform Priors for Bayesian Statistical Models. *Ecology* **90,** 265–277 (2016).

Kuhnert, P. M., Martin, T. G. & Griffiths, S. P. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecol. Lett. **13,** 900–14 (2010).

Martin, T. G., Kuhnert, P. M., Mengersen, K. & Possingham, H. P. Power of Expert Opinion in Ecological Models Using Bayesian Methods : Impact of Grazing on Birds. Ecol. Appl. 15, 266–280 (2005).

Martin, T. G. et al. Eliciting Expert Knowledge in Conservation Science. Conserv. Biol. **26,** 29–38 (2012).

Kuhnert, P. M., Martin, T. G. & Griffiths, S. P. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecol. Lett. **13,** 900–14 (2010).

Speirs-Bridge, A. et al. Reducing overconfidence in the interval judgments of experts. Risk Anal. **30,** 512–23 (2010).

Runge, M. C., Converse, S. J. & Lyons, J. E. Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. Biol. Conserv. **144,** 1214–1223 (2011).