**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)
* Diversity and Distributions ( )

**Overview:** Elicit parameter values and model beliefs from experts for predicting effects of climate, land use, and brook-trout presense on catchment-level occupancy of three stream-salamander species occuring throughout the northeastern US. Use this model to forecast current distributions of salamanders under differnce climate scenarios and compare to exisiting published distributions.

**\* Step 1: build the catchment-level salamander occupancy model**

**\* Step 2: create expert elicitation survey for model parmaeters and beliefs (means only, use 20+ experts to get variance in mean expected values instead of eliciting confidence)**

**\* Step 3: identify salamander experts based on snow-ball or publication criteria**

**\* Step 4: provide a list of literature for experts to consult prior to elicitation**

**\* Step 5: compare expert opinions and host webinar/call if large discrepancys suggesting lack of understanding of the questions (repeat elicitation if needed)**

**\* Step 6: forecast salamander occupancy based on expert elicitation**

**\* Step 7: conduct sensititivly analysis for major uncertainties (hold all constant at the mean and vary one parmaeter at a time)**

**Abstract:**

**Introduction:**

**Why has expert knowledge been in conservation – what’s the problem?**

* 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.
* Use of expert elicitation to consolidate the current state of knowledge is valuable when the status of a species is uncertain, yet there is general recognition that the species is sub- ject to multiple, often synergistic, threats to its persistence in the wild.

**This is well-accepted method and increasing in use:**

* 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.
* The use of expert knowledge is growing as a tool for synthesizing diverse sources of information into a reliable representation of the current state of scientific knowledge, including its uncertainties when elicited with the same level of rigour pro- vided in the collection and use of empirical data.
* When empirical measures are required for evaluating alternative actions, but are not available, expert judgment can help develop plausible estimates that most effectively inform decisions (Speirs-Bridge et al. 2010; Martin et al. 2012). Expert opinions are valuable in the management of threatened species, where the need to make urgent decisions leaves little time for the collection of further information (?).
* Expert elicitation can be conducted within a probabilistic framework, which accounts for uncertainty (confidence) of multiple experts. Also used to parameterize models in the absence of data and as Bayesian priors to supplement sparse data and improve confidence in predictions (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)
* Some chance that expert opinions alone (w/ no data) may not be as useful? Yet, when lacking data, expert opinion does not necessarily offer an improvement (Cox, 2000; Pearce et al., 2001; Seoane et al., 2005).
* 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.

**What do we mean by "expert" - who are the experts?**

* 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 knowledge can be defined as substantive information on a particular topic that is not widely known by others (Martin et al., 2012).
* Experts are distinguished from non-experts by having training or experience with respect to a topic of interest (Fazey et al., 2006).

**What are the steps for expert elicitation?**

* 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

**Why conduct expert elicitation for predicting/forecasting stream salamander occupancy?**

* 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.
* Three common stream salamdaner 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, and are sensitive to buffer and upland forest cover, stream temperature and discharge (and network structure).
* Current data availability:
* Direct threats include:
* Indirect threats include:
* Potentially competing hypotheses?
* Management-relevance (land-protection near buffer or upland?)
* 1. riparian vs. upland land protection is better for instream biota (downstream). Evidence that upland land protection can influence downstream habitat and species occurrence, yet conservation efforts are largely focused on riparian mgt first, then upland (we'll explore this in decision paper)
* 2. fish-interaction is strong or weak (brook trout-salamander interactions)
* 3. species-specific responses (how much do species vary?)
* 4. stream-network impacts on species-responses? some watersheds are more vulnerable than others (i.e., network structure, buffer vs. upland effects?)
* Increasing threat of climate change (temp and flow alterations)
* Range-wide assessments are lacking (studies are patchy in mostly forested landscapes with low forest loss, flow-impacts).
* Knowledge of that status and potential declines is needed to identify mangagement actions that can be implemented to reduce population declines in the future (act now to mitigate climate/land use threats)
* Current data on these species is patchy?
* No consistant monitoring method or field-studies across their range
* Thus they have high levels of uncertainty when extrapolating to even huc 10 (lowest level of mgt), state, or regional scales.
* Significant geographical gaps in estimates and trend in occupancy (need to come up with a list of current studies).
* Need address occupancy, trends, threats and effects of potential land-potection (buffer vs. upland) so that headwater stream mgt actions can be confidently employed to impact local and minimize species declines.
* Also, there are diverse experts opinions on occupancy/threats in various regions.

**Objectives of this elicitation/study:**

* Overall Motivation: To use a structured, expert elicitation methods for species in which empirical data are limited and expert opinions may vary (conflict among experts?), such that effectiveness of alternative mgt strategies may vary.
* 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:
  + How much do expert opinions agree with field-observations (do we have any? – see publication list that we’ll be sending to experts)
  + How variable are expert opinions (mean and confidence)? Where is the disagreement?
  + Which uncertainties are driving forecasts of occurrence (sensitivity analysis; tornado diagram)?
  + Does expert knowledge agree with recent field-observations / occupancy / distribution estimates? (why or why not? do we have any? – see publication list that we’ll be sending to experts for potential comparisons).

**Methods:**

*Identify experts*

* Criteria: published at least one scientific article on at least one focal species*,* collected field data from at least one region of interest (southern, mid-atlantic, northern), and primarily focused on field ecology, natural history, or field experiments (not phylogenetics, physiology, etc).

*Variables 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)?
* Occupancy of a 500-m stream reach (5 x 100).
* List of variables (Table 1):
  + Baseline/overall average state (intercept) – by region (due to variation in stream salamander community richness (500-m reach occurrence ranges from 4 in northeast to 6 in mid-atlantic, to 10 in northeast).
  + Stream size effect
  + Buffer-level effects (30-m percent forest)
  + Upland-level effects (percent forest > 30m buffer)
  + Temperature effects (mean summer variability, maximum, annual average)
  + Streamflow metric (mean summer variability, maximum, minimum, annual average)
  + Fish effects on salamanders
  + Salamander effects on salamanders
  + Network-structure effects (only for author-experts (evan and will? and winsor?))

Table 1. List of variables

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Description | Unit | Interpretation |
| Regional occupancy | Probability of occurrence (0-1) | 0-1 | Overall mean occupancy varies among regions (northeast, mid-atlantic, southern) (due to variation in other stream-salamander co-occurrence) |
| Stream size | Upstream drainage area (km2) | Mean = 2 sq-km  Range = 0.75 – 200 sq-km | Occupancy declines with increasing stream size |
| Stream temperature | Summer mean monthly temperature (C) | Mean = 14O C  Range = 10O – 26O C | Occupancy declines with increasing stream temperatures |
| Upland forest | Percent forested land in the local catchment (non-riparian) | Mean = 100  Range = 0-100% | Occupancy declines with decreasing upland forest cover |
| Riparian forest | Percent forested land in riparian zone (30-m) |  | Occupancy declines with decreasing upland forest cover |
| Streamflow | Summer mean monthly precipitation x drainage area = streamflow index | Normal =  Dry =  Wet = |  |
| Fish Presence |  |  |  |
| Salamander Presence |  |  |  |
| Network Position |  |  |  |

*Salamander model:*

\*functional relationships will be determined by expert knowledge (i.e., expontential decline in occ with stream size, or quadratic relation with stream temp, etc).

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]))

logit (p(occupancy[s,i])) ~ regional.mean[s,i] + stream.size[s,i]\*b1

?grand.mean[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).

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?)
* 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).

*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 (n = 28; Appendix A)
* Comparisons across experts (what was consistent and what wasn’t)
  + Plot of raw values?
  + Plot of mean and sd (assume equal weight)
* 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).

Table 3. List of relevant literature provided to experts:

*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).

Appendix A. List of experts requested to take this survey.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **last** | **first** | **invite** | **email** | **affiliation** | **website** |
| Barr | Garrett | yes | garrettbarr@kings.edu | Department of Biology and the Environmental Program, King's College, Wilkes-Barre, PA 18711, USA | http://staff.kings.edu/garrettbarr/ |
| Barrett | Kyle | yes | rbarre2@clemson.edu | Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634, USA | https://sites.google.com/site/clemsonbarrettlab/home |
| Babbitt | Kim | yes | kbabbitt@unh.edu | Department of Natural Resources & the Environment, University of New Hampshire, Durham, NH 03824, USA | https://colsa.unh.edu/administrator/babbitt |
| Bourne | John | yes | ? |  |  |
| Bruce | Richard | yes | ebruce1563@aol.com | Department of Biology, Western Carolina University, Cullowhee, NC 28723, USA | https://drrichardcbruce.wordpress.com/ |
| Camp | Carlos | ? | ccamp@piedmont.edu | Piedmont College | https://www.researchgate.net/profile/Carlos\_Camp |
| Connette | Grant | ? | ? | Smithsonian Conservation Biology Institute, Smithsonian Institution,Washington, D.C., DC, USA | https://www.researchgate.net/profile/Grant\_Connette/contributions |
| Consentino | Brad | yes | cosentino@hws.edu | Department of Biology, Hobart and William Smith Colleges, Geneva, NY 14456, USA | http://people.hws.edu/cosentino/home.html |
| Crawford | John | yes | joacrawford@lc.edu | National Great Rivers Research and Education Center, East Alton, IL 62024, USA | http://crawfordlab.weebly.com/ |
| Fields | Will | yes | wfields@usgs.gov | USGS |  |
| Grant | Evan | yes | ehgrant@ugsg.gov | USGS |  |
| Hocking | Daniel | yes | djhocking@usgs.gov | USGS | https://danieljhocking.wordpress.com/research/ |
| Lowe | Winsor | yes | winsor.lowe@umontana.edu | Division of Biological Sciences, University of Montana, Missoula, MT 59812, USA | http://hs.umt.edu/dbs/labs/lowe/default.php |
| Moseley | Kurtis | ? | kmoseley@mix.wvu.edu | Division of Forestry and Natural Resources, West Virginia University, Morgantown, WV 26506, USA? | ? |
| Niemiller | Matt | yes | mniemill@illinois.edu | Postdoctoral Research Associate, Illinois Natural History Survey, University of Illinois Urbana-Champaign, Champaign, IL 61820, USA | http://www.speleobiology.com/niemiller/cv/ |
| Osbourne | Mike | ? | osbournms@appstate.edu | Department of Biology, Appalachian State Univeristy, Boone, NC ZIP, USA | https://www.researchgate.net/profile/Michael\_Osbourn |
| Pauley | Tom | yes | pauley@marshall.edu | Department of Biological Sciences, Marshall University, Huntington WV 25755, USA | http://www.marshall.edu/herp/pages/Pauley\_Profile.htm |
| Peterman | Bill | yes | peterman.73@osu.edu | School of Environment and Natural Resources, The Ohio State University, Columbus, OH 43210, USA | http://petermanresearch.weebly.com/dr-bill-peterman.html |
| Petranka | Jim | yes | petranka@ret.unca.edu | Department of Biology, University of North Carolina, Asheville, NC 28804, USA | https://biology.unca.edu/faces/jim-petranka-phd |
| Resetarits | William | yes | wresetar@olemiss.edu | Department of Biology,University of Mississippi, University, MS 38677, USA | http://www.olemiss.edu/resetaritslab/ |
| Richter | Stephen | yes | stephen.richter@eku.edu | Department of Biological Sciences, Eastern Kentucky Unversity, Richmond, KY 40475, USA | http://people.eku.edu/richters/ |
| Rocko | ? | ? | ? | ? | ? |
| Snodgrass | Joel | yes | joels@vt.edu | Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, VA 24061, USA | http://www.fishwild.vt.edu/faculty/snodgrass/index.htm |
| Southerland | Mark | yes | southerlandmar@versar.com | Versar, Inc., ESM Operations, Columbia, MD 21045, USA | https://www.researchgate.net/profile/MT\_Southerland/publications |
| Tilley | Stephen | yes | stilley@smith.edu | Department of Biological Sciences, Smith College, Northampton, MA 01063, USA | http://www.smith.edu/biology/faculty\_tilley.php |
| Willison | JD | yes | willson@srel.edu | Savannah River Ecology Laboratory, Drawer E, Aiken, SC 29802, USA | http://comp.uark.edu/~jwillson/ |