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Analysis

Expert Elicitation, Uncertainty, and the Value of Information in Controlling Invasive Species

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ABSTRACT

We illustrate the utility of expert elicitation, explicit recognition of uncertainty, and the value of information for directing management and research efforts for invasive species, using tegu lizards (*Salvator merianae*) in southern Florida as a case study. We posited a post-birth pulse, matrix model in which four age classes of tegus are recognized: hatchlings, 1 year-old, 2 year-olds, and 3+ year-olds. This matrix model was parameterized using a 3-point process to elicit estimates of tegu demographic rates in southern Florida from 10 herpetology experts. We fit statistical distributions for each parameter and for each expert, then drew and pooled a large number of replicate samples from these to form a distribution for each demographic parameter. Using these distributions, as well as the observed correlations among elicited values, we generated a large sample of matrix population models to infer how the tegu population would respond to control efforts. We used the concepts of Pareto efficiency and stochastic dominance to conclude that targeting older age classes at relatively high rates appears to have the best chance of minimizing tegu abundance and control costs. We conclude that expert opinion combined with an explicit consideration of uncertainty can be valuable in conducting an initial assessment of what control strategy, effort, and monetary resources are needed to reduce and eventually eliminate the invader. Scientists, in turn, can use the value of information to focus research in a way that not only increases the efficacy of control, but minimizes costs as well.

1. Introduction

The demography of a species in a novel environment is usually unknown or highly uncertain and this can seriously compromise the control of invasive species, particularly in the early stages of the invasion. Rather than postpone analyses of control actions until more is known, one possible approach is to elicit judgements from experts to form a basis for decision making (Canessa et al., 2015a; Converse et al., 2013; McBride et al., 2012; Runge et al., 2011). This so-called collective wisdom can be an effective method for forming accurate judgements in cases of high uncertainty (Lyon et al., 2015). In the case of invasive species, experts might be those familiar with the species' demography in its native range, those knowledgeable about closely related species, or those engaged in research or management of the invasive species in situ. Although it is common practice to convene a panel of experts and ask them to produce consensus judgements about the values in question, preserving the diversity of opinions among experts is seen as more representative of the actual state of knowledge (Morgan, 2014). Demographic information, whether from expert opinion or empirical data, is then used to parameterize models of the invasive species, which in turn are used to predict how abundance, and perhaps spatial distribution, is likely to change over time in response to dynamic environmental conditions and specific control actions. In most cases these predictions will be highly uncertain, especially if based on expert opinion. Decision analysis that accounts for the probabilistic nature of these predictions is technically straightforward, but it depends critically on understanding the risk attitude of the decision maker (Canessa et al., 2016). For example, some outcomes may be so undesirable that the decision maker may accept a lower net benefit overall if it minimizes the chance of the most undesirable outcomes. There are also decision-making tools for cases of deep uncertainty – those in which possible outcomes lack any (reliable) stochastic structure (Johnson and Williams,

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2015). In either case, demographic models must make predictions about the consequences of control actions in terms that are relevant to the decision maker's objectives. At a minimum, these objectives are likely to include the desire to minimize abundance of the invasive species and the costs of control. Other common objectives include minimizing the impacts of control on non-target species and protecting sites of high value (e.g., conservation reserves) from invasion.

A useful tool for addressing questions about the nature and implications of uncertainty is the expected value of information (VOI) (Canessa et al., 2015b; Clemen, 1996; Runge et al., 2011; Williams et al., 2011; Williams and Johnson, 2015a, 2015b). In particular, the expected value of perfect information (EVPI) expresses the gain in the value expected from optimal management if uncertainty were to be eliminated. Obviously, uncertainty can never be eliminated in resource management problems, but EVPI nonetheless provides a useful heuristic for determining the extent to which uncertainty is relevant to management decisions. EVPI is simply the difference between the objective value expected if there were no uncertainty and the best that could be expected with values that are averaged over uncertain outcomes. Also of potential use in the design of research and management programs is the expected value of partial information, in which the value of eliminating one of multiple sources of uncertainty is assessed. The value of information is often expressed monetarily, but any relevant performance metric will suffice. Expressing VOI in dollars is useful, however, for determining what managers should be willing to spend on monitoring and other data-collection programs designed to reduce uncertainty.

We illustrate the utility of expert elicitation, explicit recognition of uncertainty, and the value of information for directing management and research efforts for an invasive species of lizard in southern Florida. Argentine black and white tegus (*Salvator merianae*) were likely introduced from the pet trade in Miami-Dade County around 2000 (Krysko et al., 2011), and by 2010 were established as a breeding population (Pernas et al., 2012). Tegus are large, long-lived, fecund and omnivorous lizards (Fitzgerald, 1994). As such, they present a growing threat to ecological resources of concern in southern Florida, including the nests of crocodilians (Crocodilia), sea turtles (Chelonioidea), and ground-nesting birds (Mazzotti et al., 2015). While some early detection – rapid response efforts were attempted, it is clear that this population has grown rapidly and the focus has now shifted to containing (or eliminating) the population to prevent expansion into areas of high ecological value, including Everglades National Park (ENP), the Florida Keys, and critical habitat for American crocodiles (*Crocodylus acutus*) at the Turkey Point Nuclear Generating Station near Homestead, Florida.

There have been concerted efforts to control tegus in the natural areas just east of ENP (Southern Glades Wildlife and Environmental Area), but there is concern that these efforts are not meeting the identified management objective of containing the population. Current efforts to address the tegu invasion include trapping, as well as research projects to characterize movements, brumation, reproduction, habitat use, and diet, and to develop more efficient control methods. However, given limited resources, managers need to consider how to optimize the allocation of resources for management and research. To this end, a decision-making workshop was held in August 2015 to help identify management objectives and available actions, to link research and modeling efforts to management needs, and to identify the capacity and constraints of interested parties. This workshop was attended by representatives from various state and federal resource agencies, as well as university scientists. During and following the workshop, we elicited estimates of key demographic parameters of the tegu population in southern Florida from ten experts, who had both general knowledge and field experience with tegus in their native range or in southern Florida. We then considered the experts' uncertainty about these parameters to generate inferences concerning population growth rate and other demographic characteristics of interest. Finally, we used these inferences to examine control strategies intended to minimize tegu abundance and control costs.

2. Methods

2.1. Expert Elicitation

At the workshop, experts were provided the limited information available concerning survival and fecundity of wild tegus in South America (Fitzgerald, 1994). We then used a 3-point process (Soll and Klayman, 2004; Speirs-Bridge et al., 2010) to elicit from each expert their best guess (median) and its 95% confidence interval for tegu demographics in southern Florida. These estimates were collated and then shared with the entire group. The experts were then allowed to revise their estimates if they desired based on discussions within the group. Several months after the workshop, we contacted the experts via email to allow them to revise their estimates again if they wished. We encouraged the experts to draw on any published or unpublished information that they believed to be relevant. Although we encouraged experts to discuss their estimates, we did not use the Delphi process (or its variants), in which experts are encouraged to develop consensus on elicited values (Morgan, 2014). The concern is that such consensus is not based on genuine agreement, but rather is the result of strong group pressure (Woudenberg, 1991). Indeed, we were interested in assessing the full range of experts' opinions about the uncertain parameters (Clemen and Winkler, 1999; Morgan, 2014).

There is an extensive literature on how to combine the diverse opinions of experts (Budescu and Rantilla, 2000; Lyon et al., 2015). A general conclusion from this literature is that some form of averaging is almost always optimal. The most common averaging approaches involve weighting experts equally or weighting experts by the precision of their elicited values. Giving more weight to more precise judgments can give good results (Yaniv and Foster, 1997), but more recent literature indicates that overconfidence tends to predominate in interval judgments (Morgan, 2014; Soll and Klayman, 2004). Several methods have been suggested to reduce overconfidence, including the 3-point elicitation process we used (Soll and Klayman, 2004). Nonetheless, we believed it prudent to weight experts equally because we could not be sure that precision was an accurate reflection of an expert's actual knowledge about the parameter in question. Equal weighting of experts can better account for outlying opinions, is guaranteed to be no less accurate than the typical individual judgments, and has been shown to be surprisingly accurate (Lyon et al., 2015; Morgan, 2014).

Most experts' confidence intervals were asymmetric, and this requires special consideration in aggregating estimates (O'Leary et al., 2015). For each expert and for each parameter, we fit an appropriate statistical distribution to the three elicited values depending on the nature of the demographic parameter. We used a beta distribution for rates that are naturally constrained between zero and one (e.g., survival). We used a log-normal distribution for parameters that were bounded by zero and infinity (e.g., clutch size). Distributions were fit using the rriskDistributions package (Belgorodski et al., 2015) of the open-source computing language R (RCoreTeam, 2016). We then used the fitted distribution for each expert and for each parameter to generate 10,000 samples of the parameter in question. The samples for a given parameter were then pooled across experts (equal weighting of experts) to produce a single discrete distribution for each parameter. We then generated 50,000 complete sets of all parameters by drawing samples from the cumulative distribution functions for the pooled samples. Because considerable correlation existed between some pairs of elicited demographic parameters (see Supplementary Material, Fig. S1), we used a Cholosky decomposition (Morris and Doak, 2002) to preserve this correlation structure. We then confirmed that the marginal distributions of parameters and the correlation matrix were similar to the original data. These 50,000 sets of demographic parameters were then used to draw inference from a population model.