Received: 11 September 2021 | Revised: 3 May 2022 | Accepted: 9 May 2022
DOI: 10.1111/csp2.12732

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access
WILEY

Application of qualitative value of information to prioritize uncertainties about eastern black rail population recovery

Abigail J. Lawson[1] | **Kevin Kalasz**[2] | **Michael C. Runge**[1] | **Amy C. Schwarzer**[3] | **Michelle L. Stantial**[1] | **Mark Woodrey**[4] | **James E. Lyons**[1]

[1]U.S. Geological Survey, Eastern Ecological Science Center at the Patuxent Research Refuge, Laurel, Maryland, USA

[2]U.S. Fish and Wildlife Service, Florida Ecological Services Field Office, Gainesville, Florida, USA

[3]Florida Fish and Wildlife Conservation Commission, Gainesville, Florida, USA

[4]Mississippi State University, Coastal Research and Extension Center, Biloxi, Mississippi, USA

Correspondence
Abigail J. Lawson, U.S. Geological Survey, New Mexico Cooperative Fish and Wildlife Research Unit, Department of Fish, Wildlife, and Conservation Ecology, New Mexico State University, 2980 South Espina Street, Knox Hall Room 132, Las Cruces, NM 88003, USA.
Email: ajlawson@nmsu.edu

Present address
Abigail J. Lawson, U.S. Geological Survey, New Mexico Cooperative Fish and Wildlife Research Unit, Department of Fish, Wildlife and Conservation Ecology, Las Cruces, New Mexico, USA

Funding information
U.S. Fish and Wildlife Service, Grant/Award Number: SSP-19-R5-01

Abstract

Natural resource management decisions are often made in the face of uncertainty. The question for the decision maker is whether the uncertainty is an impediment to the decision and, if so, whether it is worth reducing uncertainty before or while implementing actions. Value of information (VoI) methods are decision analytical tools to evaluate the benefit to the decision maker of resolving uncertainty. These methods, however, require quantitative predictions of the outcomes as a function of management alternatives and uncertainty, in which predictions which may not be available at early stages of decision prototyping. Here we describe the first participatory application of a new qualitative approach to VoI in an adaptive management workshop for Atlantic Coast eastern black rail populations. The eastern black rail is a small, cryptic marsh bird that was recently listed as federally threatened, with extremely little demographic data available. Workshop participants developed conceptual models and nine hypotheses related to the effects of habitat management alternatives on black rail demography. Here, we describe the qualitative VoI framework, how it was implemented in the workshop, and the analysis outcomes, and describe the benefits of qualitative VoI in the context of adaptive management and co-production of conservation science.

KEYWORDS

adaptive management, decision analysis, endangered species, marsh birds, structured decision making, value of information

1 | INTRODUCTION

Decision making under uncertainty is a ubiquitous, persistent challenge in natural resource management. Adaptive management and other decision-analytic frameworks explicitly incorporate uncertainty into decision-making processes (Regan et al., 2002; Williams, 2011; Williams et al., 2007). A distinguishing feature of adaptive management is the emphasis on reducing uncertainty while managing, with short-term learning resulting in greater long-term management performance (Walters, 1986). There are often several sources of uncertainty in natural resource management problems, however, and not all of them can be resolved; furthermore, not all of them affect which management action is preferred (Regan et al., 2002; Runge et al., 2011). In such cases, additional tools are required to determine which uncertainties are the most important to resolve based on expected increase in management performance.

Value of information (VoI) analysis is a generic term that encompasses multiple analytical methods to quantify the potential benefits of resolving uncertainty associated with a well-defined decision problem. Among VoI analyses, the expected value of perfect information (EVPI) is a common benchmark, as it quantifies the maximum expected improvement in management performance after obtaining perfect information and resolving all uncertainties (Raiffa & Schlaifer, 1961; Yokota & Thompson, 2004). Simply put, EVPI is the difference between management performance under existing uncertainty and management performance under perfect information. Thus, if managers are likely to select different alternatives when uncertainty is present compared to if it were resolved, and the difference in management performance is large, EVPI will be large. Resolving all uncertainties perfectly is unrealistic, but other VoI metrics can evaluate the relative value of resolving specific uncertainties or obtaining additional imperfect information. The expected value of perfect partial information (EVPXI) measures the value of reducing specific sources of uncertainty and is typically used to rank those different sources based on their ability to improve management outcomes (Felli & Hazen, 1998; Runge et al., 2011). In natural resource management, data are often imperfect, that is, they include sampling error; the expected value of sample information quantifies the expected improvement in performance from obtaining additional (sample) information (Canessa et al., 2015).

VoI is often used to prioritize experiments or research activities that are most likely to reduce uncertainties to which management performance is most sensitive (Bolam et al., 2019; Runge et al., 2011). Applying VoI within an adaptive management framework for imperiled species is particularly powerful when uncertainty about population declines and management responses underscores the need for accelerated, targeted learning and simultaneous management. Unfocused monitoring (i.e., efforts to reduce multiple sources of uncertainty without regard for expected change in management performance) can result in poor returns on monitoring investment, opportunity costs, and delays that could prove costly for imperiled populations (Lyons et al., 2008; Runge, 2011; Runge et al., 2011). For rapidly declining species in which the cause of decline is highly uncertain, simplified tools to identify and prioritize uncertainties with a broad management community could be an effective initial conservation step. After this initial step, investing resources in additional data collection or expert elicitation from specialized species experts to estimate quantitative VoI metrics (e.g., EVPI, EVPXI) could be warranted.

Qualitative value of information (QVoI; Runge et al., n.d.; Rushing et al., 2020) is a new tool that can be used to prioritize uncertainties within a specific management decision context using a simple, rapid scoring framework in lieu of quantitative predictions and other information necessary for EVPI and related measures. In a QVoI analysis, each source of uncertainty is expressed as a scientific hypothesis (with its logical complement considered an implicit null hypothesis). The hypotheses are evaluated independently using three scoring criteria: (1) Magnitude of Uncertainty (hereafter Magnitude), (2) Relevance for Decision Making (hereafter Relevance), and (3) Reducibility. Magnitude refers to the relative support for a particular hypothesis as evidenced by a theoretical foundation and consensus of empirical studies. A low Magnitude score reflects a stronger consensus about the hypothesis and a high score reflects greater uncertainty due to a lack of theory or evidence. Relevance describes the degree to which testing a hypothesis would lead managers to select a different management action, one with a greater probability of achieving management objectives if the hypothesis were true (Rushing et al., 2020). Thus, sources of uncertainty that score low on Relevance are unlikely to influence management decisions, whereas a high score indicates that resolution of the uncertainty will alter the preferred management action and expected outcome. The final scoring criteria, Reducibility, describes the degree to which research and monitoring activities can reduce uncertainty. A low score indicates that the necessary data, technology, or other resources to reduce the uncertainty are limited or not available, whereas a high score indicates that necessary components are readily available and resolving the uncertainty would not be costly or time-consuming (Rushing et al., 2020).

Rushing et al. (2020) defined the product of Magnitude and Relevance scores as the QVoI; Runge et al. (n.d.) show this product is proportional to the quantitative VoI. When evaluating two hypotheses (H_0 and H_1) and two management actions (A and B), VoI is determined by the expected management performance of each action under each hypothesis. Expected performance for action A or B under uncertainty is a weighted average of the two possible outcomes for the action depending on whether H_0 or H_1 is true, with the weights determined by the degree of belief in H_0 or H_1 (i.e., model weights that sum to one). As the degree of belief in H_0 or H_1 approaches zero, the VoI approaches zero; conversely, the VoI increases linearly with model uncertainty and is greatest when the expected management performance of A and B is the same (i.e., at the point of indifference between the two actions; Williams, 2011; Rushing et al., 2020). Note that the point of indifference could occur when the model weights are equal to 0.5, but this is not necessarily the case (Williams, 2011). In QVoI, the Magnitude score reflects the degree of belief in H_0 versus H_1 based on theoretical underpinnings and empirical evidence. A minimum score for Magnitude reflects a high degree of consensus in the literature and other empirical evidence (Score 0 in Table 1) and is synonymous with a high degree of belief (probability near 1.0) in either H_1 or H_0. In contrast, a maximum score for Magnitude (Table 1) reflects high uncertainty due to conflicting or absent empirical evidence and is synonymous with the point of indifference in quantitative VoI, that is, the degree of belief at which VoI is maximized. The Relevance score in QVoI reflects the cost of being wrong (implementing the wrong action) and is proportional to the differences in

TABLE 1 Qualitative value of information (QVoI) scoring rubric for three attributes: Magnitude of Uncertainty (Magnitude), Relevance for Decision Making (Relevance), and Reducibility. This table is adapted from Rushing et al. (2020, table 3) to reflect the low number of studies for black rails (*Laterallus jamaicensis jamaicensis*) and related species (family: *Rallidae*), which affects the scoring criteria for Magnitude

Score	Magnitude	Score	Relevance	Score	Reducibility
0	Firm theoretical foundation and a large number of empirical studies (>3) that support theoretical predictions	0	Preferred management action will be favored regardless of whether hypothesis is true	0	Data necessary to reduce uncertainty does not currently exist and will be prohibitively difficult/expensive to collect given current technologies
1	Firm theoretical foundation with robust empirical support; OR Large number (>3) of consistent empirical studies	1	Reducing uncertainty is predicted to improve management outcomes but range of outcomes will be swamped by natural variability and other uncertainties	1	Data to reduce uncertainty exist but only for a limited taxonomic, geographic, or temporal scope but cannot resolve the specific mechanisms; collection of additional data needed to discriminate among alternative mechanisms will be difficult/expensive or cannot be collected in timeframe relevant to decision
2	Firm theoretical foundation with moderate empirical support; OR Moderate number (2–3) of consistent empirical studies	2	Reducing uncertainty is predicted to improve management outcomes; range of outcomes will be small to moderate compared to natural variability and other uncertainties	2	Data to reduce uncertainty exist but only for a limited taxonomic, geographic, or temporal scope OR data only allow weak inference about mechanisms; collection of additional data needed to discriminate among alternative mechanisms is feasible given current technologies
3	Firm theoretical foundation with no empirical support; OR Small number (<2) of consistent empirical studies	3	Reducing uncertainty is predicted to improve management outcomes and range of outcomes will be same order of magnitude as natural variability and other uncertainties	3	Data to reduce uncertainty exist across a large taxonomic, geographic, or temporal scope AND credible inference can be made from these data
4	Large disagreement between theory and empirical studies; OR No theoretical basis and inconsistent empirical studies	—	—	—	—

management performance between the two actions under each hypothesis (Runge et al., n.d.). If there will be little difference in utility of the two actions, regardless of whether H_0 or H_1 is true, Relevance is low.

We used a QVoI analysis to identify a set of habitat management uncertainties to be addressed within an adaptive management framework for eastern black rail (*Laterallus jamaicensis jamaicensis*; hereafter rail) populations on the Atlantic Coast. The rail is a small, secretive marsh bird that was recently listed as federally threatened under the U.S. Endangered Species Act (ESA; U.S. Fish and Wildlife Service [USFWS], 2020). Rails have experienced a drastic range contraction over the last century due to habitat loss and degradation (McGowan et al., 2020; USFWS, 2018; Watts, 2016). Negative effects of sea level rise and woody vegetation encroachment are well documented (Roach & Barrett, 2015; Tolliver et al., 2019), but substantial uncertainty exists regarding relative importance of habitat suitability factors, which habitat management techniques are most likely to benefit rail populations, and how they can be implemented (e.g., timing, frequency, intensity). The decision makers for habitat management are federal, tribal, state, and non-government landowners. The USFWS plays a coordinating role, as it is tasked with leading the recovery efforts mandated by the ESA. The USFWS Atlantic Coast Joint Venture and the U.S. Geological Survey are leading a distributed network of species and coastal ecosystem experts and managers in collaborative adaptive management to recover rail populations along the Atlantic Coast. Thus, while landowners are the decision makers, members of the adaptive management group are committed to participating in a set of field experiments to accelerate learning and identify optimal habitat management techniques.

Here, we demonstrate the utility of QVoI as a rapid, transparent conservation tool to prioritize uncertainties in an early decision prototyping context, that is, before building the models necessary for traditional quantitative VoI methods. We describe the application and outcomes of a QVoI elicitation conducted during an in-person adaptive management workshop. Lastly, we provide brief guidance on the application of QVoI for participatory settings, such as workshops or other stakeholder events, and discuss its benefits for the co-production of science (Beier et al., 2017).

2 | METHODS

2.1 | Workshop structure and organization

In January 2020, we organized a 2-day workshop in Titusville, Florida, for rail experts and land managers from federal and state governmental agencies, universities, and nongovernmental organizations (Table S1). We identified participants through the USFWS Atlantic Coast Joint Venture's eastern black rail working group (Atlantic Coast Joint Venture [ACJV], 2021), and also relied upon committed participants based in northern Florida (near the workshop location) to recruit additional experts in land management practices of rail habitat.

The workshop's purpose was to complete an adaptive resource management (ARM) rapid prototyping exercise using the PrOACT framework (Gregory et al., 2012; Gregory & Keeney, 2002; Hammond et al., 2002). The PrOACT framework decomposes a decision into smaller parts that include: framing the *Pr*oblem, identifying fundamental *O*bjectives, creating management *A*lternatives, predicting *C*onsequences, and evaluating *T*radeoffs (Gregory & Keeney, 2002). During the workshop, the Problem Framing step focused on defining the problem and the decision maker (i.e., who had the authority to implement a decision), as well as identifying the spatial and temporal boundaries (e.g., determining which habitat types should be included). The Objectives step focused on explicitly stating a clear, quantifiable fundamental objective (what the group hoped to achieve for rails) and how success would be quantified (e.g., abundance, occupancy probability). For the remaining three steps (Alternatives, Consequences, Tradeoffs), the participants separated into breakout groups that were structured according to the four main habitat types identified in the Problem Framing step: (1) Tidal high marsh (THM), which included coastal tidal wetlands (natural or restored); (2) Impounded wetlands (IMP), that is, coastal and inland diked wetlands in which water levels could potentially be manipulated; (3) Inland "elsewhere" wetlands (IEL), noncoastal wetlands outside of Florida (i.e., a variety of types such as wet meadows, farm ponds, sewage treatment ponds, etc.); and (4) inland Florida wetlands (IFL), which include patches of rain-driven wetlands that were originally formed by natural systems, but some of which now have water control structures. With the exception of IFL, the breakout groups were not geographically specific, as the remaining three habitat types could be found in all states within the rail's Atlantic Coast range.

2.2 | Participatory modeling and hypothesis development

Each breakout group followed a two-step process to complete a rapid decision prototype: (1) create a conceptual model of system dynamics and (2) articulate hypotheses based on key uncertainties depicted in the conceptual model. Conceptual modeling was an iterative process in which participants constructed a series of influence diagrams (Howard & Matheson, 2005; chap. 6 in Peterson & Conroy, 2013) that reflected hypothesized habitat-specific relationships between ecological factors affecting rails, chance events, management actions, and the fundamental objective. For each iteration, participants were asked to begin with the fundamental objective and add nodes one-by-one that represented ecological factors or chance events thought to influence the fundamental objective. Nodes added thereafter were thought to have indirect effects on the fundamental objective, in that they influence other factors that have a direct influence on the fundamental objective. In Figure 1, for example, Predation is hypothesized to directly influence Rail Occupancy, whereas Plant Structure (e.g., stem density) has an indirect effect on Rail Occupancy through its influence on Predation, Food, and Nest Sites. As a final step, participants added management actions hypothesized to influence ecological factors. Each breakout group initially created a "full" influence diagram that depicted hypothesized relationships in detail, whereas in the next iteration participants created a "reduced" diagram that reflected only the most essential relationships. Each group presented their reduced influence diagram to the workshop participants in plenary and received feedback, providing the breakout groups a final opportunity to adjust their diagrams.

In the second step, we asked each breakout group to develop a set of hypotheses regarding the relationships between habitat management actions and the fundamental objective, maximize rail occupancy (see Section 3). Each hypothesis was intended to follow a common format that identified a threat to rails, described the demographic mechanism by which the threat affected rails, and proposed a habitat management action that might attenuate or eliminate the threat. For example, prescribed burning (management action) is thought to limit woody plant encroachment (threat) and increase rail occupancy compared to un-burned habitat, because woody plants provide minimal vegetative cover for rails to hide from predators compared to leafy, herbaceous plant species that benefit from fires (mechanism). Each hypothesis was treated as an alternative (H_1) to its logical complement, the implicit null hypothesis (H_0).

2.3 | QVoI elicitation and hypothesis prioritization

Following the breakout group activities, participants met in plenary for training on the QVoI framework and scoring rubric (Table 1; adapted from Rushing et al., 2020). During training, participants were encouraged to ask questions and received scoring clarification from

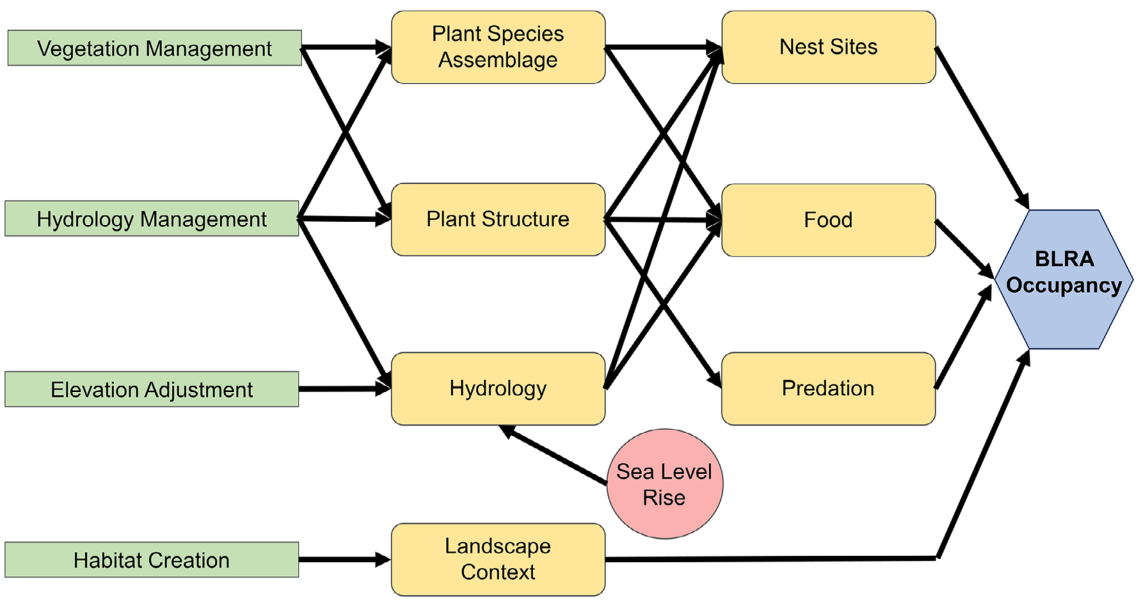

FIGURE 1 Influence diagram for management of Eastern black rails (*Laterallus jamaicensis jamaicensis*, BLRA) in tidal high marsh habitats on the Atlantic Coast. This conceptual model was created by subject matter experts within the Tidal High Marsh breakout group in an adaptive management workshop. The diagram depicts hypothesized relationships between management actions (green rectangles), ecological variables (yellow rounded rectangles), chance events (red circles), and the management objective (blue hexagon). The arrow directionality reflects the hypothesized causal relationship between two nodes. Similar conceptual models for impoundments and inland wetlands are in the Supporting Information (Figures S1–S3).

workshop organizers. Next, each hypothesis was shown one-by-one on a large projection screen and explained by the habitat breakout group members. During the hypothesis presentations, other participants could ask questions to clarify missing or unclear elements (e.g., threat, mechanism, management actions), predictions, or assumptions. After completing the hypothesis clarification, the facilitators asked participants to independently record their scores in the Magnitude, Relevance, and Reducibility categories on a datasheet. All participants scored all hypotheses, not just the ones created by their breakout group. No identifying information was reported except for their habitat breakout group. After the workshop, we computed QVoI for each participant, and then calculated the mean QVoI and Reducibility scores and their SEs across all participants for each hypothesis.

We plotted the mean QVoI and Reducibility scores (±SE) for each hypothesis in two-dimensional space and divided the space into four prioritization categories based on the mean of the minimum and maximum mean scores (Figure 2; Rushing et al., 2020). Thus, we used a "local-scale" to delineate prioritization categories, in which hypotheses are assigned to a category based on their performance relative to other hypotheses in this study. The local scale approach used here contrasts with a "global scale" approach in which hypotheses could be assigned to categories based on the minimum and maximum possible scores (Table 1). The use of a local scale is consistent with other VoI analyses (Runge et al., 2011) because EVPXI, for example, is a function of the specific hypotheses and management responses being evaluated and the cost of implementing the wrong action; all of these elements are specific to the decision context and therefore VoI from one decision context is not meaningful in other decision contexts. Within the prioritization categories, hypotheses that scored high in both QVoI and Reducibility were deemed "Highest Priority," as they were relevant to managers and were associated with high uncertainty that could be readily addressed through research and monitoring. "High-Priority" hypotheses had relatively lower Relevance to managers or lower uncertainty, but that uncertainty could potentially be further reduced through additional research and monitoring. "Medium-Priority" hypotheses had high Relevance to managers but had levels of uncertainty that could not be easily reduced through monitoring and research. Lastly, "Low-Priority" hypotheses were those that had relatively low Magnitude or Relevance (or both) and low Reducibility.

We note that there is flexibility in the designation of quadrants for hypotheses with low QVoI and high Reducibility (classified as High Priority here), versus those with high QVoI and low Reducibility (Medium Priority). Like other tradeoffs in structured decision making, the High versus Medium quadrant designation is a subjective reflection of the values of the decision makers and stakeholders. We opted to prioritize Reducibility due to the urgent need to resolve uncertainties related to both rail ecology and the effects of proposed management techniques for decision makers (USFWS, 2018), and to capitalize on existing willingness of managers to participate in management experiments. With this structure, we placed a premium on the rapid resolution of existing uncertainties (of varying Relevance), as opposed to the resolution of more challenging uncertainties on longer timescales.

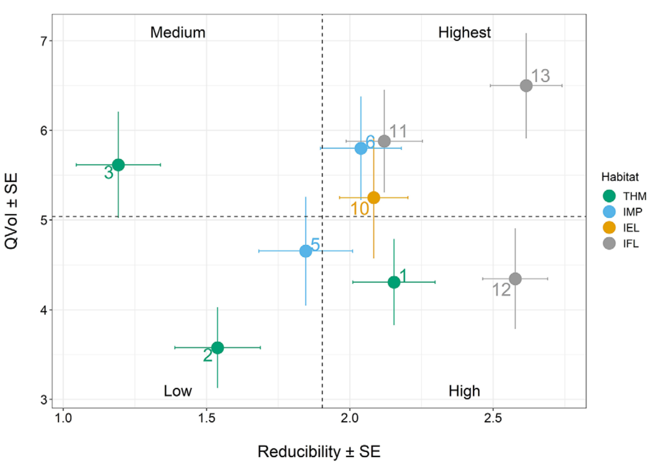

FIGURE 2 Qualitative value of information (QVoI) and reducibility scores for nine alternative hypotheses related to the effects of management actions on Eastern black rail populations on the Atlantic coast. QVoI and Reducibility scores were averaged across voting workshop participants ($n = 26$); error bars reflect the SE. Hypotheses (points) are shown according to the habitat breakout groups: Inland elsewhere (IEL) = gray; inland Florida (IFL) = orange; impoundments (IMP) = blue; and tidal high marsh (THM) = green. The vertical and horizontal dashed lines are the median of the minimum and maximum Reducibility ($x = 1.9$) and QVOI ($y = 5.0$) mean scores, which were used to separate the hypotheses into four prioritization categories: Highest, High, Medium, and Low.

3 | RESULTS

Workshop participants ($n = 30$) framed the problem to focus on identifying and optimizing habitat management techniques that could achieve a single fundamental objective focused on maximizing long-term persistence of black rails on the Atlantic Coast in all four major habitat types. Though "minimizing costs" was proposed as a second fundamental objective, the consensus was that potential experiments could be executed through existing habitat management activities that were already

Conservation Science and Practice
A Journal of the Society for Conservation Biology
Open Access
WILEY

TABLE 2 Hypotheses ($n = 9$) developed by species experts and managers during an adaptive management workshop to test the effects of habitat management actions on Eastern black rail (*Laterallus jamaicensis jamaicensis*; hereafter rail) occupancy probability on the Atlantic Coast. The hypotheses reflected potential options to serve as the basis for a management experiment within the adaptive management framework. Workshop participants created the hypotheses while working in habitat-based breakout groups: Tidal High Marsh (THM); Impoundments (IMP); Inland Wetlands Elsewhere (IEL); and Inland Wetlands Florida (IFL). The first column gives the hypothesis name (bolded) followed by the breakout group in parentheses, general ecological justification, and the decision context (italicized) capturing the critical uncertainty the hypothesis attempts to resolve. Each hypothesis was articulated in the null (H_0) and alternative (H_1) formats. Within the second and third columns, the hypothesis form (H_0 or H_1) is given, followed by the preferred management action (italics) assuming that form is true. The final column contains a prediction based on the H_1 form being true, framed in terms of the fundamental objective: maximizing rail occupancy

Hypothesis name, background, and decision context[a]	H_0 and preferred action if true	H_1 and preferred action if true	H_1 prediction
#1 Single Vegetation Treatment Effects (THM) Mowing, grazing, herbicide, mechanical removal, disking, and prescribed burns may enhance habitat for rails through mechanisms such as limiting the growth of woody vegetation, or releasing nutrients to promote the growth of dense, herbaceous vegetation. Certain vegetation management techniques may be more effective than others in their ability to achieve desired habitat conditions for rails. *Which vegetation management practice is most effective for limiting woody vegetation and maximizing herbaceous vegetation cover?*	There are no differences in the proportion of woody plant cover among marshes treated with different vegetation management techniques. *Use any means available to reduce woody vegetation.*	Different vegetation management techniques produce variation in the proportion of woody plant cover across marshes. *Use the single vegetation management treatment most likely to increase rail occupancy.*	Rail occupancy differs, depending on the vegetation management technique.
#2 Natural versus Altered Hydrology (THM) Tidal high marsh sites subject to water control structures (e.g., stoplogs, flap gates) are less likely to have appropriate hydrology for rails, compared to sites in which the hydrology has been restored to reflect the natural hydrological regime (hydroperiod, average water depth, etc.) in which rail evolved. *Does implementing a natural hydrological regime, through the removal of water control structures or adjusting the way they are used, benefit rail populations?*	There are no differences in rail habitat suitability between tidal high marshes with hydrological regimes that reflect natural conditions compared with those that do not (altered). *Maintain status quo; do not restore natural hydrological regimes in tidal high marshes*	Altered hydrological regimes result in tidal marsh habitat that is less suitable for rails compared to the natural hydrological regimes. *Remove water control structures in tidal high marshes or adjust their use to reflect a natural hydroperiod*	Rail occupancy is predicted to be higher in tidal high marsh sites with natural or free-flowing water inputs (e.g., rivers, creeks), compared to sites subject to water control structures.
#3 Patch Size × Microtopography (THM) Wetland depressions retain water during drought and elevated hummocks provide	There is no difference in rail body condition and survival in small marshes with and without microtopography.	Rail body condition and survival are greater in marshes with microtopography, especially in large marshes.	Large marshes with microtopography are predicted to have higher rail occupancy than sites that lack microtopography, are small, or both.

(Continues)

TABLE 2 (Continued)

Hypothesis name, background, and decision context[a]	H_0 and preferred action if true	H_1 and preferred action if true	H_1 prediction
shallow-water refugia during high water events. Sites with microtopographic variation (depressions and hummocks) provide consistent access to shallow water for foraging opportunities, which is predicted to improve body condition and survival. Wetland patch size could magnify the benefit of microtopography by increasing carrying capacity and further reducing the need to move among patches for resources (e.g., food, mates), and may contain wider variation in elevations for variable weather conditions. *Create microtopography, especially in small marshes, or not*?	*Maintain status quo*; *do not alter microtopography*.	*Add microtopography at small marshes with insufficient depressions and hummocks.*	
#5 Patchy Fire (IMP) Incomplete, patchy burns generate a heterogenous landscape with different vegetation succession stages. Vegetation heterogeneity promotes a greater diversity of rail invertebrate prey items and resiliency to invasive plant species that lack desired vegetation characteristics for rails, compared to homogenous vegetation stands that result from fire suppression or complete burns. *What type of prescribed burn is best? Are patchy, incomplete burns better for rails than complete burns*?	There is no difference in prey diversity and abundance or invasive vegetation species at marshes that receive an incomplete, patchy burn and those that receive a complete burn or fire suppression. *Use any best management practices for prescribed fire*.	Marshes that receive an incomplete, patchy burn have higher prey diversity and abundance, and fewer invasive vegetation species than marshes that receive a complete burn or fire suppression. *Modify best management practices for prescribed fire to increase burn patchiness/ landscape heterogeneity*.	Sites that receive patchy, incomplete prescribed burns will have higher rail occupancy compared to sites in which complete burns, or areas that prescribed burns are not used.
#6 Combined Vegetation Treatment Effects (IMP) Vegetation management techniques are thought to benefit rails through different mechanisms—see "Single Vegetation Treatment Effects" (Hypothesis #1) description. Therefore, applying a combination of vegetation management techniques could be more effective in	There is no difference in herbaceous plant communities at marshes treated with a combination of techniques to control woody vegetation and herbaceous plant communities at marshes treated with a single technique. *Use any single treatment to control woody vegetation*.	Enhanced herbaceous vegetation growth and cover in marshes treated with a combination of vegetation management techniques will provide more cover from predators, compared to sites treated with a single technique. *Use a combination of treatments to control woody vegetation*.	Rail occupancy is predicted to be higher in sites that receive more than one type of vegetation management technique, compared to sites that receive one type of treatment in isolation.

TABLE 2 (Continued)

Hypothesis name, background, and decision context[a]	H_0 and preferred action if true	H_1 and preferred action if true	H_1 prediction
creating desired habitat for rails, compared to a single treatment. *Which vegetation management strategy is best? Reducing uncertainty could result in more combination treatments and less single-treatment management.*			
#10 Water Application (IEL)[b] Year-round water application (irrigation) to slope wetlands could be optimized based on slope, soil type, and natural hydroperiod to produce water depths appropriate for both rails and promote dense herbaceous vegetation structure that rails use for cover. *Can water management at slope wetlands be optimized to benefit rails compared to unregulated hydrology?*	There are no differences in water depth and herbaceous vegetation cover at irrigated and unirrigated slope wetlands. *Status quo. Unregulated (unirrigated) hydrology at slope wetlands.*	Water depth and vegetation cover are more suitable at irrigated slope wetlands than at unirrigated slope wetlands. *Optimized irrigation at slope wetlands.*	Inland wetlands in which water applications are designed to produce water depths year-round are predicted to have higher rail occupancy than inland wetland sites that are naturally fed (i.e., not irrigated), or in which water application is not design to produce depths appropriate for rails.
#11 Microtopography (IFL) See "Patch × Microtopography" (Hypothesis #3).	There is no difference in rail body condition and survival in marshes with and without microtopography. *Maintain status quo; do not alter microtopography.*	Rail body condition and survival are greatest in marshes with microtopography. *Add microtopography at small marshes with insufficient depressions and hummocks.*	Marshes in which microtopography is present are predicted to have higher rail occupancy than sites that lack microtopography.
#12 Fire versus Other (IFL)[b] Prescribed burns that mimic historical disturbance regimes (e.g., lightning strikes) may provide multiple benefits to rail habitat including promoting herbaceous vegetation growth and increasing resistance to woody vegetation encroachment (resilience). Other vegetation management techniques, such as herbicide, grazing, or mechanical removal are thought to provide only a singular benefit such as promoting vegetation growth or directly reducing the presence of woody vegetation that negatively influences rails.	There is no difference in herbaceous plant communities in marshes treated with prescribed fire to control woody vegetation and marshes treated with herbicide. *Use either fire or herbicide interchangeably to control woody vegetation.*	As a result of nutrient cycling and greater productivity, herbaceous plant communities at marshes managed with prescribed fire provide more cover from predators than marshes managed with herbicide. *Use prescribed fire whenever possible.*	Rail occupancy is predicted to be higher at sites with an appropriate fire regime, compared to sites that apply alternative vegetation management techniques (e.g., grazing, herbicide) in lieu of fire.

(Continues)

TABLE 2 (Continued)

Hypothesis name, background, and decision context[a]	H_0 and preferred action if true	H_1 and preferred action if true	H_1 prediction
Which vegetation management practice is best? Reducing uncertainty could result in more prescribed fire, less herbicide, and a better understanding of relative effectiveness of two treatments.			
#13 Woody Threshold (IFL) Historical fire suppression in wetland habitats promoted the invasion of woody plant species that lack the desired vegetation characteristics to provide cover for rails from threats. Rails could potentially avoid woody vegetation if it occurs at low densities or percent cover, though it is expected to negatively affect rails is it becomes too prevalent (unavoidable). *At what percent cover or density does woody vegetation being to negatively affect rail populations? Reducing uncertainty could result in more efficient practices.*	Rail occupancy is the same above and below (TBD) woody vegetation thresholds of stem density and cover. *Reduce woody vegetation on any preferred schedule.*	H_1: Rail occupancy is constant below (TBD) woody vegetation thresholds of density and cover, but declines linearly above woody vegetation thresholds. *Treat woody vegetation just before reaching threshold.* Treat woody vegetation just before reaching thresholds. H_2: Rail occupancy declines linearly with woody vegetation density and cover. *Treat based on acceptable levels determined by decision maker.*	Same as H_1 and H_2 hypotheses.

[a]Hypotheses 4 and 7–9 removed from consideration because they were outside the decision context (Table S2).
[b]Adaptive Resource Management (ARM) hypothesis selected for field experiment development.

budgeted for; the group also expressed a willingness to pursue additional external funding for any experimental activities not budgeted for. The participants selected occupancy probability (MacKenzie et al., 2003) as the metric by which to quantify the success of management alternatives in achieving the fundamental objective. The participants determined that occupancy probability provided the most flexibility for monitoring activities, because it could include monitoring data collected under both occupancy- and abundance-based monitoring frameworks (MacKenzie et al., 2003; Royle, 2004), in which the latter count data could be collapsed into a detection/nondetection format. Congruent with the problem frame and fundamental objective, participants limited management alternatives to optimizing the use of existing methods (e.g., prescribed burns, herbicide, irrigation) in existing habitat rather than intensive habitat creation.

The four habitat-based breakout groups initially generated 13 hypotheses and associated predictions; however, four were removed from consideration because they fell outside the problem frame and were excluded from the analysis (Table S2). Of the nine final hypotheses, three originated from the Tidal High Marsh breakout group ($n = 8$ participants); two from Impoundments ($n = 9$ participants), one from Inland Wetlands Elsewhere ($n = 7$ participants), and three from the Inland Wetlands Florida group ($n = 9$ participants) (Table 2). The QVoI elicitation included scores from only 26 participants because 4 individuals were not present at the time of the elicitation (Table S1).

Magnitude of all hypotheses averaged 2.30 ± 0.11 (SE) on a scale of 0 to 4 (Table 1), in which higher scores indicate greater uncertainty. Participants indicated that the Patch × Microtopography hypothesis (#3) had the greatest uncertainty (2.81 ± 0.18, Table 3), whereas the Fire versus Other hypothesis (#12) had the least uncertainty (1.69 ± 0.19). Relevance to management decisions of all hypotheses averaged 2.20 ± 0.09 on a scale of 0–3 (Tables 1 and 3), in which higher scores indicate that resolution of the hypothesis' uncertainty is likely to influence management decision making. Participants indicated that resolution of the Woody Threshold hypothesis (#13) had the highest Relevance to management decision making (2.65 ± 0.14), whereas the Natural vs. Altered Hydrology hypothesis (#2) had the lowest relevance (1.73 ± 0.16, Table 3). QVoI, the product of Magnitude and Relevance scores, was highest for Woody Threshold hypothesis (#13) and lowest for Natural versus Altered Hydrology hypothesis (#2, Table 3). Reducibility of all hypotheses averaged 2.01 ± 0.15 on a scale of 0–3 (Table 1), in which higher scores indicate that the

TABLE 3 Summary of hypothesis prioritization from an adaptive resource management workshop focused on population recovery of Eastern black rails (*Laterallus jamaicensis jamaicensis*; hereafter black rail) on the Atlantic Coast. Each hypothesis describes a conjecture about the effects of management actions on black rail occupancy. Workshop participants formed breakout groups for four major habitat types: Tidal High Marsh (THM); Impoundments (IMP); Inland Elsewhere (IEL); and Inland Florida (IFL). Origin Group refers to the habitat breakout group from which the hypothesis originated. Workshop participants used a rubric (Table 1) to score the hypotheses in three main attributes: (1) Magnitude; (2) Relevance; and (3) Reducibility. The participants' raw scores were used to derive QVoI (the product of Magnitude and Relevance) for each participant. The raw scores were then averaged across voting workshop participants ($n = 26$) to obtain an overall mean (±SE) for each hypothesis; hence, the product of mean Magnitude and Relevance scores in the table below are not equal to the mean QVoI. The Reducibility and QVoI means were used to assign each hypothesis to a Priority Class (Figure 2). The values in bold indicate the highest scoring or ranked hypotheses in each column

Origin group	Hypothesis name[a]	Magnitude	Relevance	QVoI	Reducibility	Priority class.
THM	#1 Single Vegetation Treatment Effects	2.08 ± 0.17	2.08 ± 0.17	4.31 ± 0.48	2.15 ± 0.14	High
	#2 Natural versus Altered Hydrology	2.19 ± 0.22	1.73 ± 0.16	3.58 ± 0.45	1.54 ± 0.15	Low
	#3 Patch × Microtopography	**2.81 ± 0.18**	2.04 ± 0.16	5.62 ± 0.59	1.19 ± 0.15	Medium
IMP	#5 Patchy Fire	2.15 ± 0.21	2.12 ± 0.19	4.65 ± 0.6	1.85 ± 0.16	Low
	#6 Combined Vegetation Treatment Effects	2.60 ± 0.16	2.15 ± 0.14	5.80 ± 0.58	2.04 ± 0.14	Highest
IEL	#10 Water Application[b]	2.33 ± 0.22	2.21 ± 0.16	5.25 ± 0.68	2.08 ± 0.12	Highest
IFL	#11 Microtopography	2.44 ± 0.16	2.36 ± 0.13	5.88 ± 0.57	2.12 ± 0.13	Highest
	#12 Fire versus Other[b]	1.69 ± 0.19	2.50 ± 0.11	4.35 ± 0.56	2.58 ± 0.11	High
	#13 Woody Threshold	2.42 ± 0.17	**2.65 ± 0.14**	**6.50 ± 0.59**	**2.62 ± 0.12**	Highest

[a]Hypotheses 4 and 7–9 removed from the analysis because they fell outside the problem frame (Table S2).
[b]Adaptive Resource Management (ARM) hypothesis selected for field experiment development.

uncertainty a hypothesis was designed to test was the more readily solvable (i.e., feasible). Woody Threshold had the highest mean Reducibility score (2.62 ± 0.12), whereas Patch × Microtopography (#3) had the lowest (1.19 ± 0.15, Table 3).

We plotted the hypotheses QVoI and Reducibility means in two-dimensional space and used the average of the minimum and maximum scores (QVoI: 5.04, Reducibility: 1.90) to assign each hypothesis to one of four prioritization categories (see Section 2.3). According to our categorization (Figure 2), slightly less than half of the hypotheses ($n = 4$) were designated as "Highest" priority, whereas the High and Low categories each contained two hypotheses, and the Medium category contained one.

4 | DISCUSSION

4.1 | QVoI for developing an adaptive resource management framework for rails

The majority of workshop hypotheses (ca. 66%) were classified as either highest ($n = 4$) or high ($n = 2$) priority. The general clustering of hypotheses in these categories is consistent with two recurring themes expressed by participants. First, rails are poorly studied on the Atlantic Coast (i.e., high Magnitude), particularly in geographic areas or habitat types thought to be potentially important population centers in the future (e.g., inland wetlands, central Florida) given sea level rise trends (Roach & Barrett, 2015; USFWS, 2020, 2018; Watts, 2016). Second, participants also expressed a cautious optimism that habitat management techniques currently used in the rail's Atlantic distribution could be optimized (e.g., adjusted timing, frequency, etc.) to benefit rail populations (indicating a high Relevance) and that management techniques successfully used to boost rail populations in other areas (sensu Huntsinger et al., 2017; Nadeau & Conway, 2015) could be employed on the Atlantic Coast (high potential for Reducibility). Using the prioritization categories as a rough guide, we ultimately selected two hypotheses, one each from the Highest and High categories, to serve as the foundation for management experiments to accelerate learning in an adaptive resource management framework (ARM-hypotheses, hereafter). Next, we discuss the ARM-hypotheses in the context of the rail literature, and how they related to other hypotheses that received substantial support based on the prioritization.

Water Application (#10) was selected as an ARM-hypothesis; it states that water applied to slope wetlands from an external source (e.g., farm pond release, irrigation piping) could be optimized based on physical habitat characteristics such as slope, soil type, and natural hydroperiod to produce water depths that are suitable for rail activities (e.g., foraging, loafing, nesting) and promote dense vegetation structure that rails use for cover (Table 2). The general concept of optimized irrigation for other rail habitat types is supported in the literature, as Nadeau and Conway (2015) demonstrated that optimizing irrigation in impoundments to limit water depths to ≤4 cm increased abundance of California black rails (*Laterallus jamaicensis coturniculus*) in southwestern Arizona by 358%, though vegetation responses were not evaluated. Though it received the lowest QVoI score among the Highest-priority hypotheses, we selected Water Application as an ARM-hypothesis because experts and managers placed a premium on reducing uncertainties in inland wetland habitat types, as they believed they were likely to become increasingly important for eastern rails as existing tidal high marsh and other coastal habitats (e.g., impoundments) are lost to sea level rise (Watts, 2016).

We selected Fire versus Other (#12) as the second ARM-hypothesis, which states that prescribed burns are predicted to provide multiple benefits to rail habitat, whereas other vegetation management techniques such as herbicide, grazing, or mowing are predicted to provide a singular benefit (Table 2). Prescribed burns release nutrients that promote dense, herbaceous vegetation growth used by rails for cover, and increase the resiliency of habitats to woody vegetation encroachment which does not provide cover and is known to negatively influence rail occupancy (Grace et al., 2005; Tolliver et al., 2019).

The Fire versus Other hypothesis received the second-highest Relevance and Reducibility scores and offered several key benefits that justified its inclusion as an ARM-hypothesis, despite being assigned to the High-priority category (rather than Highest). First, emphasis of Fire versus Other hypothesis on comparing vegetation management techniques and their relationship to woody vegetation encroachment provided an opportunity to simultaneously evaluate two additional hypotheses in the Highest-priority category. The Combined Vegetation Treatment Effects (#6) predicted that habitats treated with multiple (combined) treatment types (including prescribed burns) would have higher rail occupancy compared to habitats that received only one type (Table 2). As such, in a Fire versus Other experiment, prescribed burning could be compared against both a separate treatment type ("Other") as well as a combined treatment (Fire + Other). The Woody Threshold hypothesis (#13), which scored the highest in both Relevance and Reducibility (Table 3), could also be tested in the context of Fire versus Other. The Woody Threshold hypothesis stated that rail occupancy is not influenced by woody vegetation cover or density until it crosses an unspecified threshold, beyond which it exhibits a negative effect by limiting herbaceous vegetation used by rail for cover from predators (Table 2). The effects of woody vegetation could be incorporated into the Fire versus Other experimental framework by assigning treatment blocks by starting conditions (e.g., high or low woody vegetation cover) or incorporating woody vegetation as a covariate.

Another key benefit of the Fire versus Other hypothesis is that it appeared to offer a greater reduction in uncertainty (Magnitude) and higher Relevance that was robust to multiple timescales compared to several Highest-priority hypotheses. During the workshop multiple managers expressed concern about climate change potentially limiting the number of days in which they are allowed to burn, meaning that an effective alternative to prescribed burning would need to be identified. Hence, Highest-priority hypotheses studies focused on optimizing existing prescribed fire treatments (e.g., #6 Combined Vegetation Treatments, #13 Woody Threshold) may offer a greater shorter-term reduction in uncertainty, though the knowledge gained may have low Relevance or be considered moot at longer timescales if opportunities for prescribed burns are severely reduced in the future. Lastly, because prescribed fire is not a common management tool at inland slope wetlands, selecting Fire versus Other as the second ARM-hypothesis ensured minimal potential overlap in sites for the Water Application experiment, which will maximize sample sizes for each study.

4.2 | Benefits of QVoI and guidance for future applications

The rapid prototyping and hypothesis prioritization using the QVoI framework was useful to the decision maker and provided four main benefits. First, the primary focus of the workshop was to create a decision prototype that identifies critical uncertainties as the first step in establishing an adaptive management framework for a highly imperiled species with critical uncertainties regarding the causes of decline. The adaptive management framework we are developing shows great promise to serve as a platform for increased communication, coordination of monitoring and experiments, and transparency in decision-making while systematically reducing uncertainty (Cundill & Fabricius, 2009; Sunderland et al., 2009). Second, both the rapid prototyping process and hypothesis prioritization using QVoI were co-produced with a large, diverse community in a participatory setting to promote transparency, trust, and buy-in. For example, the participatory modeling exercise was an approachable way to transparently capture beliefs about system dynamics from experts with varying amounts of modeling expertise, which could be more challenging to implement for a traditional quantitative VoI elicitation. Moreover, the framework we are establishing will be carried out through co-management with a distributed network of collaborators (Djenontin & Meadow, 2018; Johnson et al., 2013; Sunderland et al., 2009).

Third, the hypothesis prioritization using QVoI prompted stakeholders to set priorities in the face of widespread uncertainties. In preparatory discussions with participants, many species experts expressed a ubiquitous sense of uncertainty regarding how habitat management actions could benefit rail populations, with no conception of their relative reducibility. In contrast, after the workshop the participants had a stronger consensus regarding which uncertainties were the most important to pursue among the elicited hypotheses. This may be due, in part, to the participatory model-building in a workshop and simplified nature of QVoI in which the three elicited quantities and output are intuitive and relatively easy to understand, compared to the traditional quantitative form in which quantities like EVPI are calculated by decision analysts and may require multi-attribute utility theory for multiple objective problems. Fourth, specifying research and monitoring priorities through QVoI within the context of an adaptive management framework will close or narrow the “research-implementation gap” (Dubois et al., 2020). Evaluating the benefits (QVoI) and potential costs (Reducibility) of learning through a prioritization framework ensures that monitoring programs are explicitly designed to reduce uncertainties that are important to decision makers, compared to omnibus, unfocused, or uncoordinated monitoring programs in which data are collected with no clear management objective, sometimes at great expense (Lyons et al., 2008; Runge, 2011).

This paper documented the first application of QVoI in a participatory setting. Here we provide some brief guidance on ways to improve the elicitation process, and potentially reduce or eliminate the need for post-workshop clarification. In our instructions to participants, we originally requested that each hypothesis contain three elements: (1) a threat to rails; (2) a description of the demographic mechanism by which the threat acts; and (3) a proposed habitat management action that might attenuate or eliminate the threat. Based on our experience, we recommend that hypotheses be constructed using the format provided in Table 2, consisting of a Background (that includes the three elements), the decision context, as well as succinct statements of the hypothesis' null (H_0) and alternative (H_1) forms and their associated preferred management action and predictions.

Eliciting the hypotheses in this format may help identify potential issues that we encountered in our workshop early-on, such as a decision context outside the agreed-upon problem frame or hypotheses in which the preferred management action is unclear or the same between H_1 and H_0 (Table S2). Early diagnosis of potential problems could give participants an opportunity to refine the hypothesis before it is presented to a larger group, and is also likely to facilitate clearer communication and understanding during the discussion preceding the scoring. Future applications, in which more data are available, could compare prioritization from a QVoI framework with traditional quantitative VoI approaches to provide further insight about the relative benefits of qualitative and quantitative value of information.

Here we described the PrOACT process employed by a workshop focused on establishing of an ARM framework for Atlantic Coast eastern black rails, for which predictive models relevant for decision analysis are not yet available. The workshops successfully used influence diagrams to delineate epistemic uncertainties and generate a set of alternative hypotheses that represented impediments to the selection of optimal management strategies. We then used QVoI, a new decision analysis tool, to prioritize hypotheses to serve as the basis for planned field experiments. This approach was useful for facilitating buy-in from stakeholders and for maximizing the efficiency of limited resources for endangered species recovery. Importantly, we demonstrated that QVoI can be used in a rapid prototyping setting, as opposed to a controlled literature search (Rushing et al., 2020), further improving buy-in. Most importantly, despite time and logistical constraints, we generated a product that was useful to the decision maker, identified critical uncertainties to be reduced through an adaptive management framework for a threatened species, and set the direction for co-produced science (Beier et al., 2017; Wright et al., 2020).

AUTHOR CONTRIBUTIONS

The study was conceived Abigail J. Lawson, Michael C. Runge, Michelle L. Stantial, and James E. Lyons; the workshop was facilitated by Abigail J. Lawson, Kevin Kalasz, Mark Woodrey, and James E. Lyons; Amy C. Schwarzer served as a species expert; Abigail J. Lawson conducted the analyses and wrote the first draft of the manuscript. All authors contributed to revisions and gave final approval for publication.

ACKNOWLEDGMENTS

Funding for this study was provided by the U.S. Fish and Wildlife Service Science Support Partnership Program in collaboration with the U.S. Fish and Wildlife Service and the Atlantic Coast Joint Venture. The authors thank the subject matter experts who attended the adaptive management workshop and contributed expertise and knowledge of black rail ecology and management that made this study possible. The authors thank K. Dunham, M. Lawson, D. Smith, and four anonymous reviewers whose comments improved the quality of this manuscript. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data used in this study are publicly available in the US Geological Survey Science Data Catalog at https://doi.org/10.5066/P9FUQ7VT

ORCID

Abigail J. Lawson https://orcid.org/0000-0002-2799-8750
Michael C. Runge https://orcid.org/0000-0002-8081-536X
Amy C. Schwarzer https://orcid.org/0000-0002-8780-4647
Michelle L. Stantial https://orcid.org/0000-0003-1112-2903
James E. Lyons https://orcid.org/0000-0002-9810-8751

REFERENCES

Atlantic Coast Joint Venture (ACJV). (2021). *Atlantic Coast Joint Venture Structure*. https://acjv.org

Beier, P., Hansen, L. J., Helbrecht, L., & Behar, D. (2017). A how-to guide for coproduction of actionable science. *Conservation Letters*, *10*(3), 288–296. https://doi.org/10.1111/conl.12300

Bolam, F. C., Grainger, M. J., Mengersen, K. L., Stewart, G. B., Sutherland, W. J., Runge, M. C., & McGowan, P. J. K. (2019). Using the value of information to improve conservation decision making. *Biological Reviews*, *94*(2), 629–647. https://doi.org/10.1111/brv.12471

Canessa, S., Guillera-Arroita, G., Lahoz-Monfort, J. J., Southwell, D. M., Armstrong, D. P., Chadès, I., Lacy, R. C., & Converse, S. J. (2015). When do we need more data? A primer on calculating the value of information for applied ecologists. *Methods in Ecology and Evolution*, *6*(10), 1219–1228. https://doi.org/10.1111/2041-210X.12423

Cundill, G., & Fabricius, C. (2009). Monitoring in adaptive co-management: Toward a learning based approach. *Journal of Environmental Management*, *90*(11), 3205–3211. https://doi.org/10.1016/j.jenvman.2009.05.012

Djenontin, I. N. S., & Meadow, A. M. (2018). The art of co-production of knowledge in environmental sciences and management: Lessons from international practice. *Environmental*

Management, *61*(6), 885–903. https://doi.org/10.1007/s00267-018-1028-3

Dubois, N. S., Gomez, A., Carlson, S., & Russell, D. (2020). Bridging the research-implementation gap requires engagement from practitioners. *Conservation Science and Practice*, *2*(1), 1–12. https://doi.org/10.1111/csp2.134

Felli, J. C., & Hazen, G. B. (1998). Sensitivity analysis and the expected value of perfect information. *Medical Decision Making*, *18*(1), 95–109. https://doi.org/10.1177/0272989X9801800117

Grace, J. B., Allain, L. K., Baldwin, H. Q., Billock, a G., Eddleman, W. R., Given, a M., Jeske, C. W., & Moss, R. (2005). *Effects of prescribed fire in the coastal prairies of Texas*. USGS Open File Report 2005-1287, U.S. Departmentof the Interior, Geological Survey, Reston, Virginia.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T. L., & Ohlson, D. (2012). *Structured decision making: A practical guide to environmental management choices*. Wiley-Blackwell.

Gregory, R. S., & Keeney, R. L. (2002). Making smarter environmental decisions. *Journal of the American Water Resources Association*, *38*(6), 1601–1612.

Hammond, J. S., Keeney, R. L., & Raiffa, H. (2002). *Smart choices: A practical guide to making better life decisions*. Broadway Books.

Howard, R. A., & Matheson, J. E. (2005). Influence diagrams. *Decision Analysis*, *2*(3), 127–143. https://doi.org/10.1287/deca.1050.0020

Huntsinger, L., Hruska, T. V., Oviedo, J. L., Shapero, M. W. K., Nader, G. A., Ingram, R. S., & Beissinger, S. R. (2017). Save water or save wildlife? Water use and conservation in the central Sierran foothill oak woodlands of California, USA. *Ecology and Society*, *22*(2), e12. https://doi.org/10.5751/ES-09217-220212

Johnson, F. A., Ken Williams, B., & Nichols, J. D. (2013). Resilience thinking and a decision-analytic approach to conservation: Strange bedfellows or essential partners? *Ecology and Society*, *18*(2), e27. https://doi.org/10.5751/ES-05544-180227

Lyons, J. E., Runge, M. C., Laskowski, H. P., & Kendall, W. L. (2008). Monitoring in the context of structured decision-making and adaptive management. *Journal of Wildlife Management*, *72*(8), 1683–1692. https://doi.org/10.2193/2008-141

MacKenzie, D. I., Nichols, J. D., Hines, J. E., Knutson, M. G., & Franklin, A. B. (2003). Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology*, *84*(8), 2200–2207. https://doi.org/10.1002/cpa.3160360305

McGowan, C. P., Angeli, N. F., Beisler, W. A., Snyder, C., Rankin, N. M., Woodrow, O., Wilson, J. K., Rivenbark, E., Schwarzer, A., Hand, C. E., Anthony, R., Griffin, R. K., Barrett, K., Haverland, A. A., Roach, N. S., Schneider, T., Smith, A. D., Smith, F. M., Tolliver, J. D. M., & Watts, B. D. (2020). Linking monitoring and data analysis to predictions and decisions for the range-wide eastern black rail status assessment. *Endangered Species Research*, *43*, 209–222. https://doi.org/10.3354/esr01063

Nadeau, C. P., & Conway, C. J. (2015). Optimizing water depth for wetland-dependent wildlife could increase wetland restoration success, water efficiency, and water security. *Restoration Ecology*, *23*(3), 292–300. https://doi.org/10.1111/rec.12180

Peterson, J. T., & Conroy, M. J. (2013). Decision making in natural resource management: A structured, adaptive approach. *Wiley-Blackwell.*

Raiffa, H., & Schlaifer, R. (1961). *Applied statistical decision theory*. Harvard University Press.

Regan, H. M., Colyvan, M., & Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications*, *12*(2), 618–628. https://doi.org/10.1890/1051-0761(2002)012[0618:ATATOU]2.0.CO;2

Roach, N. S., & Barrett, K. (2015). Managed habitats increase occupancy of black rails (*Laterallus jamaicensis*) and may buffer impacts from sea level rise. *Wetlands*, *35*(6), 1065–1076. https://doi.org/10.1007/s13157-015-0695-6

Royle, J. A. (2004). N-mixture models for estimating population size from spatially replicated counts. *Biometrics*, *60*(March), 108–115.

Runge, M. C. (2011). An introduction to adaptive management for threatened and endangered species. *Journal of Fish and Wildlife Management*, *2*(2), 220–233. https://doi.org/10.3996/082011-JFWM-045

Runge, M. C., Converse, S. J., & Lyons, J. E. (2011). Which uncertainty? Using expert elicitation and expected value of information to design an adaptive program. *Biological Conservation*, *144*(4), 1214–1223. https://doi.org/10.1016/j.biocon.2010.12.020

Runge, M. C., Rushing, C. S., Rubenstine, M., & Lyons, J. E. (n.d.). *Qualitative value of information*. in preparation.

Rushing, C. S., Rubenstine, M., Lyons, J. E., & Runge, M. C. (2020). Using value of information to prioritize research needs for migratory bird management under climate change: A case study among federal land acquisition in the United States. *Biological Reviews*, *95*, 1109–1130.

Sunderland, T., Sunderland-Groves, J., Shanley, P., & Campbell, B. (2009). Bridging the gap: How can information access and exchange between conservation biologists and field practitioners be improved for better conservation outcomes? *Biotropica*, *41*(5), 549–554. https://doi.org/10.1111/j.1744-7429.2009.00557.x

Tolliver, J. D. M., Moore, A. A., Green, M. C., & Weckerly, F. W. (2019). Coastal Texas black rail population states and survey effort. *Journal of Wildlife Management*, *83*(2), 312–324. https://doi.org/10.1002/jwmg.21589

U.S. Fish and Wildlife Service. (2018). Species status assessment report for the Eastern Black Rail (*Laterallus jamaicensis jamaicensis*), Version 1.2.

U.S. Fish and Wildlife Service. (2020). Endangered and threatened wildlife and plants; threatened species status for the eastern black rail with a Section 4(d) rule; Final Rule. 85 Federal Register 196 (October 8, 2020).

Walters, C. J. (1986). *Adaptive management of renewable resources*. Macmillan.

Watts, B. D. (2016). *Status and distribution of the eastern black rail along the Atlantic and Gulf coasts of North America*. The Center for Conservation Biology Technical Report Series CCBTR-16-09.

Williams, B. K. (2011). Adaptive management of natural resources-framework and issues. *Journal of Environmental Management*, *92*(5), 1346–1353. https://doi.org/10.1016/j.jenvman.2010.10.041

Williams, B. K., Szaro, R. C., & Shapiro, C. D. (2007). *Adpative management: The U.S. Department of the Interior technical guide*. Adaptive Management Working Group.

Wright, A. D., Bernard, R. F., Mosher, B. A., O'Donnell, K. M., Braunagel, T., DiRenzo, G. V., Fleming, J., Shafer, C., Brand, A. B., Zipkin, E. F., & Campbell Grant, E. H. (2020). Moving from decision to action in conservation science. *Biological Conservation*, *249*, 108698. https://doi.org/10.1016/j.biocon.2020.108698

Yokota, F., & Thompson, K. M. (2004). Value of information analysis in environmental health risk management decisions: Past, present, and future. *Risk Analysis*, *24*(3), 635–650. https://doi.org/10.1111/j.0272-4332.2004.00464.x

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Lawson, A. J., Kalasz, K., Runge, M. C., Schwarzer, A. C., Stantial, M. L., Woodrey, M., & Lyons, J. E. (2022). Application of qualitative value of information to prioritize uncertainties about eastern black rail population recovery. *Conservation Science and Practice*, e12732. https://doi.org/10.1111/csp2.12732