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Ranking biodiversity risk factors using expert groups – treating linguistic uncertainty and documenting epistemic uncertainty

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Abstract

Sound planning is vital to ensure effective management of biodiversity, particularly where there is a high risk that management goals may not be achieved. This is the case at Toolibin Lake, an internationally recognised wetland, where changed hydrology as a result of agricultural development has detrimentally affected the quality and quantity of water entering the lake. Although management actions have slowed or halted degradation of the lake’s biological assets, goals have not been fully achieved and management is under review. To rank the hydrological risk factors threatening the lake’s biota as a foundation for more detailed planning, a structured elicitation process was used with an expert, cross-disciplinary group. Techniques used were explicitly aimed at minimising and documenting uncertainty. These included calibration questions to assess the accuracy of experts, and tightly specified goals and terms to minimise vagueness, ambiguity and redundancy. Surface water salinity, groundwater salinity and drought were the only factors identified as having a high probability of causing goal failure. Importantly, the majority of risk factors were evaluated as having a low probability of causing goal failure, enabling these factors to be rapidly eliminated from short-term consideration. The experts, acting anonymously when estimating probabilities, varied considerably in the assessment of one risk. This underlines the importance of rigorous processes to identify knowledge gaps and assess the likelihood that proposed management will be successful. The elicitation process provided low cost, rapid assessment of large numbers of risk factors with explicit assessment of uncertainty.

Keywords: Elicitation, expert, Ramsar, hydrology, risk assessment, uncertainty.
1. Introduction

Resources must be wisely allocated through effective planning and priority setting to achieve goals for biodiversity management (Joseph et al., 2009). Sound planning is particularly crucial where important biological assets are highly threatened, resources are limited, and goal failure is thus a distinct possibility. Here, we define a goal as “the desired outcome of management constrained in both space and time” (Wallace, 2012, page 4). Biological management goals are frequently stated in terms of biotic composition – for example, conserving the existing biota or biodiversity of a specific area for a stated planning period, as in this case study for Toolibin Lake. Thus, failure to achieve a goal stated in specific terms within a planning period constitutes goal failure.

Conservation goals are often difficult to achieve in the south-west of Western Australia where extensive replacement of native perennial vegetation with annual crops and pastures has significantly altered hydrological processes. Processes associated with altered hydrology that threaten native taxa include rising saline groundwater, secondary salinisation of soils and surface waters, nutrient enrichment, and altered acidity/alkalinity concentrations (Horwitz et al., 2008). Under these circumstances, and given both the high cost of managing salinity (Sparks et al., 2006) and lack of knowledge concerning catchment processes and biota (Wallace et al., 2011), management goals that aim to retain the existing composition of biota in valley floors and associated wetlands are ambitious and the potential for goal failure is high. This is underlined by the continued decline of wetland biota in the south-west of Western Australia (Clarke et al., 2011). Under such demanding circumstances it is essential to assess the likelihood of achieving management goals – there is generally little point expending resources on management where success is highly unlikely. Rather, alternatives such as changing the goal of management, re-allocating resources, or undertaking further research should be considered (Wallace, 2012).
Although there are cases, such as the Everglades in Florida, where management planning is based on detailed science and associated numerical models (see, for example, The Everglades Foundation, 2011), in many places, including the agricultural landscapes of southern Australia, there is much less information and management is based on some combination of expert opinion and existing data (Walshe and Massenbauer, 2008; Jones et al., 2009; Pannell et al., 2012). Burgman (2005) has noted that where decisions concerning operational management must be made in the context of inadequate knowledge and quantitative modelling is impractical, the use of expert analysis is warranted. However, in relation to using expert elicitation, Martin et al. (2012, page 35) state that “formal methods for eliciting and combining judgments only recently have been adopted and tested for application to conservation science and practice.” One aim of this paper is to provide an applied case study of expert elicitation in planning the operational management of biological assets.

The work described below is consistent with the biodiversity planning framework described by Wallace (2012). This framework explicitly links the human values driving planning and management with goal formulation, description of biological assets, evaluation of key ecosystem processes (risk factors), and assessment of management feasibility. In this paper we focus on the first of three points required to determine management feasibility once goals and biological assets of management interest have been determined. These points are:

• determine the key ecosystem processes (or key risk factors) that should be managed to ensure a high probability of goal achievement (in the case of Toolibin Lake, the assessment assumed that current management practices were maintained, and that no additional management was implemented);

• for key processes or factors, undertake investigations and numeric modelling sufficient to describe additional management actions necessary for success; and
• combine information from the first two points with other data to complete a feasibility analysis and decide whether to proceed with management.

To address the first point when planning the management of Toolibin Lake, we applied an expert elicitation process to generate a risk analysis based on subjective judgement. Experts from different scientific disciplines, operational managers and planners were involved to lay the foundation for a fully cohesive process involving all technical experts. Work reported in this paper will provide the basis for further analyses addressing the second and third dot points above.

When using experts, the uncertainty associated with expert opinion should be explicitly evaluated (Burgman et al., 1999) so that appropriate levels of confidence, which may differ according to the goals of each study, are attached to analyses used in decision-making. In this case study, one aim was to reduce and explicitly document uncertainty through the use of the Threat Elicitation process developed by the Australian Centre for Excellence in Risk Analysis (ACERA, 2010), which involves discussion and knowledge exchange amongst experts.

Such threat elicitation processes are largely aimed at reducing and documenting epistemic (knowledge) uncertainty, which relates to incomplete knowledge concerning the state of a system (Regan et al., 2002; Burgman, 2005). For example, the sharing of information and ideas amongst a cross-disciplinary group of experts can be expected to increase overall knowledge of natural variation and improve understanding of interacting processes, thus reducing uncertainty. Increased knowledge of a system can also enhance subjective judgement, or at least ensure the related uncertainties are well documented.
It is also important to deal with linguistic uncertainty, which arises because language is inexact leading to issues such as vagueness, context dependence, ambiguity and underspecificity (Regan et al., 2002; Burgman, 2005). For example, where definitions of terms are unclear, or there is ambiguity concerning the allocation of factors within classification systems, one or more types of linguistic uncertainty will occur. A number of techniques may be used to minimise linguistic uncertainty (Speirs-Bridge et al., 2010; Patrick and Damon-Randall, 2008).

In this case study, the planning approach outlined by Wallace (2012) was applied to reduce linguistic uncertainty by ensuring that goals are fully specified, terms clearly defined, and ambiguity and redundancy in classification of risks avoided.

Using an expert analysis of the risks to biota at Toolibin Lake arising from hydrological processes, the objectives of this paper are to: evaluate key risk factors; qualitatively assess the usefulness of methods applied to minimise linguistic uncertainty; and evaluate the contribution of expert elicitation, including measures of uncertainty, to management planning. The results of this study will directly contribute to a revised management plan for Toolibin Lake and its biota, and provide a case study of applied elicitation.

2. Methods

2.1 Study system

Toolibin Lake (approximately 300 ha) is an ephemeral, fresh to brackish wetland in south-west Western Australia. It is approximately 200 km south-east of Perth within the inland agricultural region and is the last significant representative of a once common wetland community. The lake bed has large areas covered by two tree species, most commonly *Casuarina obesa*, and to a lesser extent *Melaleuca strobophylla*, nationally listed as a Threatened Ecological
Community. Fifty species of waterbirds have been recorded visiting the lake and, of these, 25 species have been observed breeding. The lake is listed as a Wetland of International Importance under the Ramsar Convention.

The biological assets of the lake are severely threatened by altered hydrology, particularly increasingly saline surface water inflows and rising, highly saline groundwater. Inflow diversion, groundwater pumping and catchment works are being implemented to halt degradation of the biological assets. A new plan is being drafted to reassess the actions required to achieve the goal, and to evaluate management feasibility of proposed actions. This risk analysis was undertaken as part of this planning process. Ultimately, all risk factors will be analysed for Toolibin Lake. However, as altered hydrology is considered most likely to result in goal failure, it was selected for detailed work as reported here.

2.2 Reducing linguistic uncertainty

To reduce linguistic uncertainty when working with the expert group, the assessment task was tightly specified by the authors in consultation with some of the experts involved in the elicitation. The risk analysis was linked to a spatially and temporally defined management goal, as these bounds are critical to effectively specify the evaluation task (Wallace, 2006). Also, any vague or ambiguous terms were either rigorously defined or removed to minimise uncertainty. The risk analysis was couched in terms of probability of goal failure arising from each risk factor. Given that risk of goal failure cannot be entirely avoided, this approach emphasises to decision-makers the importance of considering the level of risk they are willing to accept.

For Toolibin Lake, the management goal is: “to maintain the taxonomic composition of biota identified in current species lists from Toolibin Lake over the next 25 years”. This specifies
what needs to be conserved and the temporal period, but, as noted, the spatial scale is also important. In discussion with workshop participants, Toolibin Lake was defined as the lake bed in addition to the shoreline occupied by *Casuarina obesa* and *Melaleuca* species. These riparian trees were included in the assessment as they occur on the lake bed, and their spatial distribution is tightly coupled with hydrological processes in the area. This definition ensured that the physical boundary of the analysis was unambiguous. The temporal scale was selected as it was considered short enough for experts to comprehend the likely consequences of change, and long enough for change to be possible and management actions to have an impact.

The number and range of biological assets encompassed by the goal are complex. Therefore, to ensure experts considered the same set of assets when making their assessments, indicator species were identified including plants and invertebrates (Table 1). Indicators were obtained from several experts prior to the workshop, and were sent to all participants for comment and formal agreement at the workshop. Indicators were selected on the basis that they would be the most sensitive to the factors considered and thus indicative of the persistence of other species within the ecosystem. To further reduce any ambiguity concerning the meaning of goal failure, the question addressed by experts for Toolibin was interpreted as: What is the probability of any one species becoming extinct at the Lake within 25 years? The scope of estimation was simplified by confining the goal to the recorded species richness, rather than some minimum bound on abundance for each species present at the lake.

There are a range of issues relating to clarity in threat classifications (e.g., Balmford et al., 2009; Salafsky et al., 2009). Given that unclear boundaries in classifications may lead to double-counting and related issues (Wallace, 2012), the analysis was couched in terms of risk factors that directly affect biota and thus the achievement of the management goal. Thus, the
risk factors evaluated were the stresses that directly impinge on the capacity of native organisms to survive and reproduce (e.g., predation, salinity, drought, disease).

Prior to the risk analysis workshop, a list of all potential risk factors that could arise from altered hydrology was developed by the facilitators based on Wallace (2012, see Table 4). This list was assessed by two experts and missing items or suggested alterations were incorporated (Table 2). As these experts were also participants in the risk analysis workshop, the only additional information they received prior to the workshop was the spatial and temporal scale of the study and the list of potential key factors associated with altered hydrology.

2.3 Risk analysis

Ten experts in the biology, hydrology and operational management of Toolibin Lake attended the elicitation workshop. Presentations regarding management goals for Toolibin Lake, as defined above, as well as definitions of spatial and temporal scales and an explanation of risk analysis were undertaken prior to the elicitation.

The 4-step ‘Threat Elicitation’ used for the risk analysis was developed at ACERA and has been shown to reduce overconfidence in expert estimates (Speirs-Bridge et al., 2010), while allowing the estimation of uncertainty. Calibration questions were provided prior to the elicitation to allow the calculation of weights for different subjects and groups of participants. These questions were based on plants, birds, invertebrates, groundwater, rainfall and transpiration, and were specifically selected because the answers were unlikely to be precisely known (i.e. an estimate with higher and lower bounds was required). For example, the first calibration question was: What proportion of the total number of plant species, including introduced plants, in Toolibin lake and reserves (Dulbing + Toolibin) do plants of the Family Myrtaceae comprise?
217  ■ What is your lowest estimate of the proportion?

218  ■ What is your highest estimate of the proportion?

219  ■ What is your best estimate?

220  ■ What is your level of confidence that the true value lies in the range you have provided? (0-100%)?

222  (See Appendix for full calibration question list)

223

224  Risk analysis questions were constructed based on key factors (Table 2) and all questions were of the same format to ensure comparability of results for the prioritisation of risks. Elicitation questions were of the structure: “With current management strategies in place, what is your lowest estimate of the probability that [key factor] will cause species loss (i.e. goal failure) at Toolibin Lake over the next 25 years?” (Step 1). This question was repeated separately for highest (Step 2) and best estimates (Step 3). Participants were also asked “What is your level of confidence that the true value lies in the range you have provided?” (Step 4) following the probability questions. This final question was modified from the original documented in Speirs-Bridge et al. (2010) as experts found the original wording difficult to understand. Initial anonymous responses were collected by the authors and compiled in graphical form for display to the group. This was undertaken to encourage and stimulate discussion regarding similarities or differences. Each participant could then choose to provide modified (second) estimates for all four steps. The final estimates were also made anonymously.

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238  2.4  Data analysis

239  2.4.1  Calibration: Confidence, hit rates and accuracy
All intervals estimated by workshop participants were arcsine transformed which shifted extreme estimates further away from the mean to aid statistical analysis using a normal distribution (Speirs-Bridge et al., 2010). This type of transformation is generally used when the distribution of data points is skewed and bounded by zero and one, as is often the case with proportions and probabilities, and when there are a large number of values close to one or close to zero (Sokal and Rohlf, 1981), as in this study. Following this step, 83% confidence intervals, whereby the true value should lie within the interval in five of six estimates provided by an expert, were derived using the methods of Speirs-Bridge et al. (2010). Hit rates were assessed, where a ‘hit’ was an interval containing the true value. Percent over- and under-confidence was determined using the number of calibration questions for which a ‘hit’ was obtained. The derived 83% confidence intervals (calculated from participants’ own confidence levels) were used in this comparison and a perfectly calibrated participant would have provided intervals containing the true value in five from six questions. While a larger number of calibration questions would have been preferable, the number was limited to six due to time constraints for undertaking the analysis.

Weighting expert opinion according to calibration performance has been commonly reported in the literature (Cooke, 1991; Goosens et al., 1996). In this study, weights for probabilities provided during the elicitation were based on calibration question hit rates and over- or under-confidence for each participant. To normalise the calibration weights, the raw weight was divided by the average from all participants. Estimated probabilities were weighted to ensure responses from better calibrated individuals had greater influence than those from less well-calibrated individuals.

2.4.2 Elicitation
For each factor (Table 2), experts were first asked whether the probability of species loss was very low (<0.05, a definition accepted by the experts present during the evaluation). If there was consensus that the probability was very low, the full risk analysis was not undertaken for that factor. A probability of 0.05 was selected as the cut-off for inclusion in the risk analysis as management intervention would be unlikely to be implemented for these factors in comparison to any higher risk factors (> 0.05). Following the determination of a very low probability of goal failure, an estimate for the actual probability of species loss was determined by the group as a whole and the reasoning recorded. If consensus was not achieved, the full elicitation was undertaken.

During the elicitation, some participants chose not to provide second estimates following discussion. No participants provided second estimates for surface water salinity. When second estimates were provided, a qualitative assessment of differences between the first and second unweighted estimates and variances was undertaken. The ranking of the three factors with the highest probability of causing goal failure was also compared using weighted and unweighted estimates.

In the one case of divergent views amongst two groups of participants, the average weight associated with participants in each group was used to identify the view with the highest weight. These analyses were not undertaken for key factors where there was no clear indication of divergent views, as opposed to simple differences between individuals.

3. Results

3.1 Calibration: Confidence, hit rates and accuracy

The average hit-and-miss calibration using the 80% derived confidence intervals was 65% (i.e. average 15% overconfidence). Four of the ten participants provided intervals that were
perfectly calibrated to the 83% confidence interval (83% hit rate) with five out of six intervals containing the true value. One participant had a hit rate of four from six and were 17% overconfident, while two participants had a hit rate of 3 from 6 (33% overconfidence) and a further two participants had a low hit rate of 1 from 6 (66% overconfidence). Only one participant provided intervals that contained the true value for all six questions. This participant was underconfident (17%) in their responses. Normalising the hit rates from the calibration questions provided the final weights for each participant (Table 3).

3.2 Elicitation results

The majority of key factors assessed during the workshop were determined to be unlikely to cause any species loss (Table 4). Most were allocated expert probabilities of causing goal failure of less than 0.05 during the workshop. The remainder were analysed using the full elicitation process.

Using expert estimates weighted according to calibration performance, the risk analysis identified surface water salinity as the key factor with the highest probability of causing species loss at Toolibin Lake (Best estimate: 0.411, 83% CI: 0.235 – 0.619). The second highest probability was obtained for a lack of water (Best estimate: 0.336, 83% CI: 0.154 – 0.559) followed by ground water salinity (Best estimate: 0.282, 83% CI: 0.133 – 0.454). The same ranking was found when using weighted or unweighted estimates.

There was a clear separation of participants into two groups for the probability of goal failure due to a lack of water (Table 4, Fig. 1). The average best estimates for the different groups were 0.548 (Group A) and 0.202 (Group B). The lower estimate of Group B arose due to the possibility (identified during the workshop) that species are able to cope with a lack of water,
as observed in the severe drought of 2010 (Table 4). Linking each participant with their
assigned weight was undertaken with the aim of determining the more probable stream of
thought, however, the average weight of participants was 0.099 for Group A and 0.102 for
Group B. As the average weight of both groups was almost equal, the average best estimate
from all participants as reported previously was deemed to be appropriate to allow a ‘middle
of the road’ approach by operational managers.

When second estimates were provided, the average best estimates were reduced. For
example, the weighted mean best estimate for the probability of species loss due to ground
water salinity was initially 0.342 and was reduced to 0.282 following discussion. The weighted
mean best estimate for a lack of water (0.419) was also reduced following discussion (0.336).
Variance between unweighted best estimates was reduced in the second estimates for
groundwater salinity (initial: 0.025, secondary: 0.021) and lack of water (initial: 0.046,
secondary: 0.038).

4. Discussion

The study showed that the elicitation technique is a low-cost means of assessing risks to goal
achievement. The expert group dealt with multiple factors efficiently and, crucially,
determined that the majority of factors have a very low probability of causing goal failure. This
is a critical step in early planning, particularly where management resources are limited.
Following this assessment, planners and managers could be confident that, given current
knowledge, low risk factors could be ignored in the short-term allowing a focus on the key
factors considered to have the greatest probability of causing goal failure. It must be noted,
however, that managers and planners should regularly re-assess all potential risk factors to
minimise unexpected impacts and account for changes in knowledge arising from new information.

The risk analysis identified surface water and groundwater salinity as two of the three key factors with a high probability of causing species loss, and thus goal failure, at Toolibin Lake. Increasingly saline surface water or rising, saline groundwaters may result in mortality and ultimately the loss of species. For example, whether from groundwater or surface waters, the infiltration of highly saline water into the root zones of plants may cause widespread mortality. A lack of water (drought) was also identified as having a high probability of causing goal failure and there is evidence that the survival of mature trees and seedlings is increasingly dependent, given decreasing inflow events, on a declining incident, annual rainfall (Ogden and Froend, 2002; Pitman et al., 2004). The results concerning drought revealed substantially different views of this risk. One view was that current management (diversion of highly saline water) plus increased frequency of dry years was likely to cause the loss of species from Toolibin Lake. The other view was that after the extreme drought of 2010, species loss in the next 25 years is unlikely given the biota’s apparent capacity to survive. The generation of risk scores from a discussion aimed at achieving consensus or by immediately averaging scores, as used in the past, would have obscured this important result. The difference in views and the wide ranging estimates indicate there is significant uncertainty concerning the likelihood of goal failure arising from these three key hydrological factors. This underlines that further investigation of key risk factors is essential before a full feasibility analysis may be completed.

Apart from the knowledge outlined above, the elicitation technique provided a number of other benefits. For example, averaging estimates amongst different people, as well as between two responses from the same person, can be beneficial because the estimates are likely to differ in their systematic and random errors and the errors tend to cancel out across all participants (or estimates for a single participant), improving the overall estimate (Herzog and
Hertwig, 2009). Also, the use of structured group discussion ensured all participants were privy to the same information, thereby reducing both linguistic and epistemic uncertainty. Group discussion centred on new information and on those aspects where there was greatest uncertainty and divergent views. This included cross-disciplinary sharing of knowledge which, for example, allowed autoecological knowledge of biota to be combined with what is hydrologically and operationally practical to implement, thus facilitating a more effective assessment. In this context, the identification and consideration of opposing views has been found to improve second estimates (Herzog and Hertwig, 2009) because no two individuals are likely to have the same knowledge and the provision of additional knowledge or counter-arguments allows for the consideration of disconfirming evidence by each participant.

Structuring the mode of questioning into four distinct steps is important here as it should involve the reconsideration of all evidence at each step (question) and therefore brings semi-independent information into the forum. Without semi-independent questioning, overconfidence is generally increased as a result of confirmation bias (Soll and Klayman, 2004).

Finally, steps taken to minimise linguistic uncertainty prior to the elicitation were also particularly valuable, including the specification of the goal for biodiversity in terms of explicit outcomes within spatial and temporal bounds. Similarly, the reduction of assessments to well defined factors that form a logically coherent set that impinge directly on organisms was readily understood by experts and focussed attention on direct stressors.

However, biases may also arise from elicitation processes. Discussion amongst participants during the elicitation process was observed to influence second estimates, and this could be attributed to a ‘halo effect’ (Nisbett and Wilson, 1977). This effect occurs when experts make global assumptions about the knowledge of one expert and adjust their own estimate accordingly. Other biases may arise by attributing higher confidence to the beliefs of confident people regardless of whether they are knowledgeable, or by adjusting beliefs to reflect those...
of people that can influence career progression (ACERA, 2010). However, the elicitation process was specifically designed to reduce the effects of these potential biases, for example, through the use of anonymous estimation of probabilities. In addition, the willingness of experts to participate in the discussion may have reduced the impact of a halo effect by facilitating reasoned arguments and identifying alternative points of view. The authors made every attempt to ensure participants understood that all opinions were valid and should be considered equally by the group. Consequently, it is likely that modifications during the second round of estimates reflected improved certainty of knowledge arising from the discussion. This was illustrated by the significant reduction in estimates produced following discussion of the probability of species loss due to a lack of water (drought). A follow-up elicitation would be valuable to clarify this point and determine if, similar to groundwater salinity and a lack of water, the estimate for surface water salinity declined with second estimates.

Focussing on how the elicitation process might be improved in future, one issue is the use of calibration questions. These are rarely used in environmental assessments utilising expert opinion, and this has been attributed to the lack of evidence showing their benefit (Walker et al., 2003). Calibration questions may also be problematic if the questions are not specifically structured to reflect the experts’ knowledge, thus resulting in higher weight being attributed to participants with a lesser knowledge of the system or with skewed beliefs (Burgman et al., 2011). However, Burgman et al. (2011) also suggested that facilitators have a mandate to use calibration questions to eliminate sources of uncertainty while ensuring that the scope of questions relate directly to the knowledge being elicited. The weights calculated here from the calibration questions were assumed to be appropriate because, although general, they directly related to knowledge required for effective elicitation. Although there was no difference between the ranking of weighted and unweighted key factors, the use of weights did reduce the variance for estimates in two of the three key factors identified, thereby providing greater
overall precision. The divergence of views highlighted for a lack of water did indicate the need for additional research as noted above. Overall, the use of calibration questions at least provides a measure of whether experts are sufficiently knowledgeable to assess risk, and their responses may then be used as a basis for comparison with other expert groups.

The elicitation method could be improved in a number of ways. Discussion of the trade-off between accuracy and bias (Yaniv and Foster, 1997) may have resulted in fewer extreme intervals and improved participant weightings. Also, better explanation and use of practice questions may have increased the understanding of the process, thus preventing the exclusion of participants from the final analysis. One participant suggested that, despite group agreement concerning the goal being assessed, they were subconsciously considering the magnitude of expected impacts and not solely the probability of goal failure as defined. This type of response was identified by Slovic (1987) where the perception of risk was influenced by the control people felt they had in managing the contributing processes, as well as the desirability of goal achievement. Knowledge of such factors are crucial for interpreting expert data and should be carefully managed in future elicitations. To some extent, this issue would be addressed by defining outcomes in terms of types of taxa, their number and distribution. However, this would require a much more detailed analysis and discussion by experts, and needs to be balanced against the time available for the elicitation process. Time limitations restricted the number of calibration questions used, and while the six questions posed to participants were useful, a longer workshop with more time for calibration questions would be beneficial.

Returning to the objectives set for the paper, the risk analysis has provided a useful evaluation of key hydrological risk factors at Toolibin Lake and is an important step towards a feasibility assessment for practical management in this data-limited situation. The use of expert opinion is a valuable contribution to assessing risk, particularly where there is inadequate knowledge.
In this case study, expert analysis quantified uncertainty and provided a firm platform for planning future investigations and modelling. The methods used to reduce linguistic uncertainty, including a robust planning framework with rigorous goal definition and coherent classification sets, were effective based on the qualitative assessment of the facilitators and comments from experts. Despite these steps, this case study highlighted that for some risk factors there may be substantial disagreement regarding the ability to achieve the management goal. Further investigations and effective quantitative models are critical for robust management decisions, particularly where, as at Toolibin Lake, substantial resources and liabilities are involved with operational actions. Finally, important ancillary benefits from the elicitation process included the sharing of knowledge and increased collective understanding of the issues for achieving management goals for an important biological asset.
Acknowledgments

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evaluate the extinction risk of Atlantic sturgeon (*Acipenser oxyrinchus*). Biol. Conserv. 141, 2906-2911.


Table 1. Categories and indicator species used in the elicitation process as identified by experts. The estimation of probability of goal failure was undertaken for each category of species with these indicator species in mind. Note that some of the environmental limits are expert assessments only and require further scientific confirmation.

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator species</th>
<th>Reason for inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants</td>
<td><em>Casuarina obesa</em></td>
<td>Sensitive to saline groundwater in root zone and soil salinity. Provides habitat for other species. Groundwater must be maintained at 4m below ground level. Flooding of the lake must be limited to 100 days and dry periods &gt;8yr necessary for recruitment. Surface water salinity of &lt;1500 mg/l required for survival (El-Lakany and Luard 1983).</td>
</tr>
<tr>
<td></td>
<td><em>Melaleuca strobophylla</em></td>
<td>Sensitive to saline groundwater in root zone and soil salinity. Provides habitat for other species. Groundwater must be maintained at 8m below ground level. Flooding of the lake must be limited to 100 days and dry periods &gt;8yr necessary for recruitment. Surface water salinity of &lt;1500 mg/l required for survival (Bell 1999).</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Glossophoniidae (leeches)</td>
<td>Highly salt sensitive and recorded at Toolibin Lake in salinities of 2400 mg/L (Doupe and Horwitz 1995) but not at 9400 mg/L (Halse et al. 2000).</td>
</tr>
<tr>
<td></td>
<td>Conchostracans (<em>Cyzicus</em> spp. - clam shrimp)</td>
<td>Very limited salt tolerance, with most species rarely occurring in salinities &gt;1000-2000 mg/L. <em>Cyzicus</em> conchostracans have been recorded upstream from Toolibin Lake, at salinities of 3500 mg/L (Doupe and Horwitz 1995) but there are no confirmed records of conchostracans in Toolibin Lake. Conchostracans are present in nearby Lake Bryde when it is fresh, but not when the lake is saline, which suggests that they could return to Toolibin.</td>
</tr>
<tr>
<td></td>
<td><em>Bennelongia ‘australis’</em> (ostracod)</td>
<td>Salt-sensitive and common in temporary freshwater wetlands. 93% (from 294 records) of <em>Bennelongia</em> records (and 90% of <em>Bennelongia ‘australis’</em> records) are from salinities &lt;5000 mg/L. Present at Toolibin in 1992 at 2400 mg/L and in 1994 at 10000 mg/L, but absent in 1998 at 9400 mg/L.</td>
</tr>
</tbody>
</table>
Table 2. Risk factors that may be affected by altered hydrology at Toolibin Lake over the next 25 years. Examples of each risk factor that may arise from altered hydrology are provided.

<table>
<thead>
<tr>
<th>Category of factor</th>
<th>Key factor</th>
<th>Generic example (associated with altered hydrology)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources</td>
<td>• Food</td>
<td>• Mortality following waterlogging and death of trees that provide food</td>
</tr>
<tr>
<td></td>
<td>• Oxygen</td>
<td>• Juvenile plant death following deprivation of $O_2$ during inundation and waterlogging.</td>
</tr>
<tr>
<td></td>
<td>• Light (photosynthesis)</td>
<td>• Adult or juvenile plant death following deprivation of light from turbid water</td>
</tr>
<tr>
<td></td>
<td>• Water</td>
<td>• Inadequate fresh water availability (drought) leads to death</td>
</tr>
<tr>
<td>Disease/competition etc.</td>
<td>• Disease</td>
<td>• Surface water transports diseased plants into the system causing plant death</td>
</tr>
<tr>
<td></td>
<td>• Toxic species</td>
<td>• Death of animal through consumption of toxins</td>
</tr>
<tr>
<td></td>
<td>• Predation</td>
<td>• Death of birds due to predation following reduced availability of roosting habitat (due to death of trees)</td>
</tr>
<tr>
<td>Physical and Chemical factors</td>
<td>• Salinity</td>
<td>• Evaporation, saline inflow, and rising groundwater cause salt toxicity in macroinvertebrates.</td>
</tr>
<tr>
<td></td>
<td>– Surface water</td>
<td>• Increased contaminants through catchment run-off into lake causes death of organisms</td>
</tr>
<tr>
<td></td>
<td>– Groundwater</td>
<td>• Nutrient input through run-off causing toxicity</td>
</tr>
<tr>
<td></td>
<td>• Contaminants</td>
<td>• Damage to trees causing death</td>
</tr>
<tr>
<td></td>
<td>– Acidity/alkalinity</td>
<td>• Nutrient input through run-off causing toxicity</td>
</tr>
<tr>
<td></td>
<td>– Pesticides</td>
<td>• Damage to trees causing death</td>
</tr>
<tr>
<td></td>
<td>– Heavy metals</td>
<td>• Nutrient input through run-off causing toxicity</td>
</tr>
<tr>
<td></td>
<td>• Nutrients (N, P)</td>
<td>• Reduced availability of mates due to death or movement to more favourable areas</td>
</tr>
<tr>
<td></td>
<td>• Physical damage from flooding (water velocity)</td>
<td>• Reduced genetic diversity following death or movement resulting in lower</td>
</tr>
<tr>
<td>Reproduction</td>
<td>• Lack of mates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Genetic diversity</td>
<td></td>
</tr>
<tr>
<td>Lack of nesting habitat</td>
<td>Reproductive success and survival</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td>Reduced availability of nesting habitat due to inundation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 3. Level of over- or under-confidence, raw and normalised weights by participant code.

<table>
<thead>
<tr>
<th>Participant code</th>
<th>Over- or under-confidence</th>
<th>Raw weight</th>
<th>Normalised weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17% underconfident</td>
<td>0.83</td>
<td>0.1084</td>
</tr>
<tr>
<td>B, D, E, J</td>
<td>NA, Perfectly calibrated</td>
<td>1.00</td>
<td>0.1309</td>
</tr>
<tr>
<td>C</td>
<td>17% overconfident</td>
<td>0.83</td>
<td>0.1084</td>
</tr>
<tr>
<td>F, H</td>
<td>33% overconfidence</td>
<td>0.67</td>
<td>0.0877</td>
</tr>
<tr>
<td>G, I</td>
<td>66% overconfident</td>
<td>0.33</td>
<td>0.0445</td>
</tr>
</tbody>
</table>
Table 4. Workshop participant estimates of the probability that altered hydrology will, through impacts on key factors, cause goal failure (species extinction from the wetland). Participants’ assumptions and reasons underlying their estimates were also recorded. High probability factors were assessed in more detail using the full risk analysis process.

<table>
<thead>
<tr>
<th>Key factor</th>
<th>Probability of species loss</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticides/herbicides</td>
<td>&lt; 0.05</td>
<td>Application levels on farmland may occasionally be high but entry through run-off predicted to be low.</td>
</tr>
<tr>
<td>Acidity/alkalinity</td>
<td>&lt; 0.05</td>
<td>Some carbonates exist in groundwater but levels not expected to cause significant change in acidity/alkalinity.</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>&lt; 0.05</td>
<td>Heavy metal presence and toxicity is highly correlated with acidity/alkalinity. Therefore, risk rated at the same level.</td>
</tr>
<tr>
<td>Nitrogen toxicity</td>
<td>&lt; 0.01</td>
<td>There are no substantial inputs from external sources.</td>
</tr>
<tr>
<td>Phosphorus toxicity</td>
<td>&lt; 0.01</td>
<td>There are no substantial inputs from external sources.</td>
</tr>
<tr>
<td>Physical damage</td>
<td>&lt; 0.01</td>
<td>Current management practices determine inflow levels under usual rainfall levels within the catchment ensuring that physical damage should not occur. Significant flood events that may cause physical damage leading to species loss have not been recorded.</td>
</tr>
<tr>
<td>Food</td>
<td>&lt; 0.01</td>
<td>Extreme circumstances are necessary for hydrology to alter food resources causing species loss.</td>
</tr>
<tr>
<td>Oxygen</td>
<td>&lt; 0.05</td>
<td>Prolonged flooding is unlikely to cause the complete removal of a plant species due to oxygen deprivation. Although Melaleuca strobophylla is relatively susceptible to anoxic conditions, species loss would require years of continuous flooding.</td>
</tr>
<tr>
<td>Light</td>
<td>&lt; 0.01</td>
<td>Inundation by turbid water is unlikely to occur for periods long enough to cause species loss.</td>
</tr>
<tr>
<td>Disease</td>
<td>&lt; 0.05</td>
<td>Most watercourses in WA have been found to have at least one type of Phytophthora within them but some are simply involved in nutrient cycling (i.e. do not cause plant death). As yet no Phytophthora spp have been found at Toolibin Lake so species loss is thought to be unlikely at this stage.</td>
</tr>
<tr>
<td>Toxins</td>
<td>&lt; 0.02</td>
<td>Only one cyanobacteria/Botulinum spp event poisoned substantial numbers of waterbirds at Toolibin Lake in the last 30 years, however, there have been no records of species loss there or elsewhere in the south-west of Western Australia.</td>
</tr>
<tr>
<td>Predation/grazing</td>
<td>&lt; 0.01</td>
<td>Some predation (e.g. by foxes and cats) may increase if inundation of the lake does not occur for a long enough. These predators cannot reach the fledgling birds when water levels are high but shorter hydroperiods mean less time for fledgling birds to learn to fly (i.e., escape from predators). Species loss, as a result of predation is thought to be unlikely.</td>
</tr>
<tr>
<td>Lack of mates</td>
<td>&lt; 0.05</td>
<td>Sexually reproducing species generally have access to mates over a large spatial scale so lack of mates unlikely to cause species loss.</td>
</tr>
<tr>
<td>Lack of genetic diversity</td>
<td>&lt; 0.05</td>
<td>As above</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>Lack of nesting habitat</td>
<td>&lt; 0.05</td>
<td>Bird species unlikely to stop visiting Toolibin Lake simply due to a lack of nesting habitat (J. Lane, pers. comm.).</td>
</tr>
<tr>
<td>Lack of water</td>
<td>83% CI: 0.154 – 0.559 (best estimate 0.336)</td>
<td>Two divergent views were clearly observable: 1) Current management (water diversion) plus increased frequency of dry years is likely to cause the loss of species from Toolibin Lake. 2) After the extreme drought of 2010, species loss in the next 25 years is unlikely given their apparent capacity to survive and ability to survive in microhabitats.</td>
</tr>
<tr>
<td>Ground water salinity</td>
<td>83% CI: 0.133 – 0.454 (best estimate 0.282)</td>
<td>Rising highly saline groundwaters over an extended period may cause death of trees. However, the species may persist in microhabitats.</td>
</tr>
<tr>
<td>Surface water salinity</td>
<td>83% CI: 0.235 – 0.619 (best estimate 0.411)</td>
<td>Evapoconcentration of salts from surface water can cause elevated soil salinity and reduced water availability due to the osmotic effects in the root zone. Little change would be necessary to see some species loss, however, with current management practices there would need to be a large highly saline flood event for this to occur.</td>
</tr>
</tbody>
</table>
Figure 1. Estimates for the highest, lowest and best probability of change according to expert opinion for second estimates for goal failure due to a lack of water (drought) at Toolibin Lake. A clear separation between the two divergent views (Group A - triangles and Group B - squares) is shown.