Conservation Biology

Conservation Practice and Policy

Conservation practitioners' understanding of how to manage evolutionary processes

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Abstract: *Both academics and practitioners consider a lack of knowledge about evolutionary theory to be a general barrier to effectively managing genetic diversity. However, it is challenging to judge practitioners' level of understanding and how this influences their management decisions. Knowledge built through experience may be difficult for practitioners to articulate, but could nonetheless result in appropriate management strategies. To date, researchers have assessed only the explicit (formal) knowledge practitioners have of evolutionary concepts. To explore practitioners' understanding of evolutionary concepts, it is necessary to consider how they might apply explicit and implicit knowledge to their management decisions. Using an online survey, we asked Australian practitioners to respond to 2 common management scenarios in which there is strong evidence that managing genetic diversity can improve outcomes: managing small, isolated populations and sourcing seeds for restoration projects. In describing their approach to these scenarios, practitioners demonstrated a stronger understanding of the effective management of genetic diversity than the definitions of the relevant concepts. However, their management of genetic diversity within small populations was closer to best practice than for restoration projects. Moreover, the risks practitioners described in implementing best practice management were more likely to affect their approach to restoration than translocation projects. These findings provide evidence that strategies to build the capacity of practitioners to manage genetic diversity should focus on realistic management scenarios. Given that practitioners recognize the importance of adapting their practices and the strong evidence for the benefits of actively managing genetic diversity, there is hope that better engagement by evolutionary biologists with practitioners could facilitate significant shifts toward evolutionarily enlightened management.*

Keywords: gene flow, inbreeding depression, knowledge exchange, learning by doing, outbreeding depression, restoration, translocation

Entendimiento de los Practicantes de la Conservación sobre Cómo Manejar los Procesos Evolutivos

Resumen: *Tanto los académicos como los practicantes consideran que una falta de conocimiento sobre la teoría evolutiva es una barrera general para el manejo efectivo de la diversidad genética. Sin embargo, es complicado juzgar el nivel de entendimiento de los practicantes y cómo éste influye sobre sus decisiones de manejo. El conocimiento construido por medio de la experiencia puede ser difícil de articular para los practicantes, pero de igual manera podría resultar en estrategias adecuadas de manejo. A la fecha, los investigadores han evaluado solamente el conocimiento explícito (formal) que tienen los practicantes sobre los conceptos evolutivos. Para explorar el entendimiento que tienen los practicantes sobre los conceptos evolutivos es necesario considerar cómo podrían aplicar conocimientos explícitos e implícitos a sus decisiones de manejo. Por medio de una encuesta en línea, le pedimos a practicantes australianos que respondieran a dos escenarios comunes de manejo en los cuales hay fuertes evidencias de que el manejo de la diversidad genética puede mejorar los resultados: el manejo de poblaciones pequeñas y aisladas, y la obtención de semillas para proyectos de restauración. Cuando describieron sus métodos para estos escenarios, los practicantes demostraron tener un entendimiento más completo del manejo efectivo de la diversidad genética que de las definiciones de los conceptos relevantes. Sin embargo, su manejo de la diversidad genética dentro de poblaciones pequeñas estuvo más cerca de la mejor práctica que para los proyectos de restauración. Además,*

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Article impact statement: Better engagement with practitioners could facilitate significant shifts toward evolutionarily enlightened management.

Paper submitted July 26, 2018; revised manuscript accepted January 25, 2019.

DOI: 10.1111/cobi.13306

los riesgos que los practicantes describieron en la implementación del manejo de la mejor práctica tuvieron una mayor probabilidad de afectar a sus estrategias de restauración que a las de reubicación. Estos resultados proporcionan evidencia de que las estrategias para construir la capacidad de los practicantes para manejar la diversidad genética deben enfocarse en escenarios realistas de manejo. Ya que los practicantes reconocen la importancia de adaptar sus prácticas y reconocen la sólida evidencia para los beneficios del manejo activo de la diversidad genética, hay esperanzas de que una mejor colaboración entre los practicantes y los biólogos evolutivos pudiera facilitar cambios significativos hacia un manejo informado evolutivamente.

Palabras Clave: aprender al hacer, depresión endogámica, depresión exogámica, flujo génico, intercambio de conocimiento, restauración, reubicación

摘要: *研究者和保护实践者都认为, 进化理论知识的缺乏常常会阻碍对遗传多样性的有效管理。然而, 判断保护实践者对进化理论的理解程度及其对他们的管理决策的影响却极具挑战。对于保护实践者来说, 通过经验积累的知识可能难以阐述, 但仍然可以指导他们采取合适的管理策略。到目前为止, 研究者只评估过保护实践者关于进化概念的显性知识 (形式知识) 。为探究保护实践者对进化概念的理解, 还应考虑他们如何将显性及隐性知识应用于管理决策。我们通过在线调查, 收集了澳大利亚保护实践者对两种常见管理情景的反应, 在这两种情景 (管理小的隔离种群、追溯恢复计划中引种来源) 中, 均有证据表明管理遗传多样性可以提高保护成效。从实践者对管理这些情景的方法描述中可以看出, 他们对遗传多样性有效管理的理解比对相关概念定义的理解更深刻。然而, 相比于恢复项目, 实践者对小种群遗传多样性的管理方法更接近最佳实践。此外, 他们描述的最佳实践实施中的风险更有可能影响他们对恢复项目的管理方法, 而不是影响迁地保护项目。这些发现证明, 提升保护实践者管理遗传多样性能力的策略应侧重于现实中的管理场景。考虑到保护实践者已经认识到合理调整保护实践的重要性, 且积极管理遗传多样性大有裨益, 我们呼吁进化生物学家应更多地参与保护实践, 以促进保护管理在进化理论应用上的重要转向。***【翻译: 胡怡思; 审校: 聂永刚】**

关键词: 迁地保护, 恢复, 近交衰退, 远交衰退, 基因流, 在实践中学习, 知识交流

Introduction

Using evolutionary theory to inform a range of conservation decisions can help achieve better long-term outcomes when managing threatened species, invasive species and disease, and for restoration and revegetation efforts (Broadhurst et al. 2008; Frankham 2010; Carroll et al. 2014; Smith et al. 2014). Attempts to raise awareness of the need to integrate evolutionary principles and processes (hereafter evolutionary concepts) into existing practices (e.g., Kinnison et al. 2007; Mace & Purvis 2008; Hendry et al. 2011) and the development of decision support tools to facilitate changes to management (e.g., Byrne et al. 2011; Frankham et al. 2011; Weeks et al. 2011) have had little influence on conservation policy (Laikre et al. 2010; Santamaria & Mendez 2012; Cook & Sgrò 2017) and planning (Pierson et al. 2016). Although practitioners (on-the-ground managers and policy makers) recognize the importance of using evolutionary theory to inform management practices (Taylor et al. 2017), this has yet to be translated into management practice (Cook & Sgrò 2018).

Several barriers to better integration of evolutionary theory into conservation practices have been suggested, including limited engagement between practitioners and scientists (Mace & Purvis 2008; Taylor et al. 2017), a lack of resources (Cook & Sgrò 2018), and inadequate knowledge about relevant evolutionary concepts (Ashley et al. 2003; Frankham 2010; Cook & Sgrò 2018). There are concerns that a poor understanding of evolutionary theory among practitioners could lead to misconceptions that overstate the risks of changing practices (Kinnison et al. 2007), such as the risk of outbreeding depression when translocating individuals among populations that have become separated (Weeks et al. 2011; Frankham 2015) or high seedling mortality when sourcing seeds for restoration from outside the local environment (Broadhurst et al. 2008; Sgrò et al. 2011).

Although misconceptions exist about the meaning of relevant evolutionary concepts among practitioners, when asked to define concepts practitioners are more likely to indicate they are unsure about concepts than to demonstrate an incorrect understanding of the concepts (Cook & Sgrò 2019). Many practitioners report having had little formal training in evolutionary biology or genetics during their education (Cook & Sgrò 2019), which could limit their ability to translate theory into practice. However, a lack of formal education in these topics may also make it difficult for practitioners to articulate any implicit (informal) understanding they have of how the concepts apply if they are unfamiliar with the underlying theoretical constructs. For example, a practitioner may understand that connectivity among populations is important to prevent extinction without being able to describe the role that gene flow plays in reducing inbreeding depression. This creates a challenge for assessing practitioners' level of understanding of the relevant evolutionary theories to inform conservation management.

Different types of knowledge are gained in different ways. Explicit (formal) knowledge can be articulated either quantitatively or qualitatively (Fazey et al. 2005), is generally gained through formal education, and is traditionally tested through examinations. However, knowledge can also be implicit (not yet articulated) and tacit (unable to be articulated [e.g., recognizing faces]) (Fazey et al. 2005). These types of knowledge can still reflect a deep understanding built through extensive experience rather than formal education (Fazey et al. 2006). Implicit and tacit knowledge are often built by practitioners in the course of their on-the-job learning. Therefore, only assessing practitioners' explicit knowledge (e.g., by asking managers to define relevant concepts [Cook & Sgrò 2019]); may underestimate their level of understanding and how it influences their management decisions. Likewise, the absence of explicit mention of evolutionary concepts (e.g., Santamaria & Mendez 2012; Cook & Sgrò 2017) or population genetics (e.g., Pierson et al. 2016) in policy and planning documents may not mean practitioners do not have an informal or intuitive understanding of how they should be applied to achieve desired management outcomes.

Assessing the tacit or implicit knowledge of practitioners requires understanding what influences their management decisions. Hence, asking practitioners to apply their understanding to real life management scenarios can be an effective way to elicit their judgments because context can be critical to their decisions (Fazey et al. 2006). Two management issues where evolutionary theory can provide clear conservation benefits relative to current management practices are threatened species management (Weeks et al. 2011; Ralls et al. 2018) and revegetation or restoration projects (Broadhurst et al. 2008; Sgrò et al. 2011). Both these issues have a clear theoretical underpinning (Broadhurst et al. 2008; Weeks et al. 2011). Data related to these management problems demonstrate the benefits of changing commonly used management practices (e.g., Prober et al. 2016; Weeks et al. 2017), and decision-support tools are available to guide management decisions (e.g., Byrne et al. 2011; Frankham et al. 2011; Breed et al. 2013). These are also issues commonly faced by conservation practitioners who manage threatened species and attempt to restore degraded habitat. As such, it may be expected that in their response to practical management scenarios, practitioners could demonstrate their knowledge (tacit, implicit, or explicit) as to how evolutionary concepts might guide management decisions.

To assess whether practitioners can apply evolutionary concepts to their management decisions, we considered 2 scenarios: managing the loss of genetic diversity in threatened species within small, fragmented populations and sourcing seeds for restoration projects. We were also interested in risks that practitioners consider when presented with best practice genetic management for each of the scenarios. We focused our study on Australia because it is a large and diverse continent with relatively complex environmental governance arrangements and a vibrant conservation research community. Australia also has significant environmental challenges (Taylor et al. 2011). For example, extensively cleared and fragmented native ecosystems (Tulloch et al. 2016) create a considerable challenge for threatened species management and restoration efforts. The explicit knowledge of evolutionary theory among Australian practitioners has been assessed (Cook & Sgrò 2019), along with the integration of evolutionary concepts into policy (Cook & Sgrò 2017) and threatened species recovery plans (Pierson et al. 2016). This provides an excellent opportunity to explore whether new approaches to management are being adopted to accommodate evolutionary theory or whether misunderstanding of relevant concepts remains a barrier to better implementation.

Methods

To assess the applied understanding of evolutionary theory within conservation, we developed a questionnaire (Supporting Information) targeting 2 groups of respondents: conservation practitioners in policy or on-the-ground management roles and applied ecologists (academic research scientists) whose research programs focus on management-relevant science.

We sought the views of conservation practitioners from protected area ($n = 8$ state and federal jurisdictions) and natural resource management organizations ($n = 56$ regional bodies). Both groups of practitioners have a role in threatened species management and restoration projects but reflect different scales of management (site-level vs. landscape-scale decisions). Practitioners were identified by contacting senior managers within the relevant organizations across Australia and asking them to distribute a link to the online questionnaire to all relevant staff members.

We also sought to understand the views of research scientists (applied ecologists) whose work is relevant to conservation policy and practice. We targeted applied ecologists because they are involved in generating research and decision-support tools that may inform management practices. In addition, they often directly engage with practitioners about best practice, which provides them with an opportunity to assist practitioners to manage evolutionary processes. Therefore, we were interested in the degree to which these scientists consider the application of evolutionary theory to selecting appropriate management practices. To identify applied ecologists, we searched the online staff profiles from all universities and government research institutes across Australia ($n = 23$). Relevant individuals were identified from the description of their research interests and active research projects ($n = 78$), contacted via email, and invited to participate in the study. Respondents were asked to distribute the survey to relevant members of their research groups, using a snowball sampling approach (Patton 2002). Ethics approval for this project was provided by the Monash University (MUHREC approved project: CF15/774-2015000348).

Questionnaire Development

Two management scenarios were developed to assess respondents' informal understanding of evolutionary theory (Supporting Information). Scenario 1 (translocation) involved the management of a gradually declining, isolated population of a once widespread mammal at risk of extirpation. Respondents were asked what management approaches they would use to support this population and why? They were then informed that individuals from another isolated population were being translocated into the declining population and were asked what potential risks this course of action posed.

Scenario 2 (restoration) involved a project at a site that had been previously cleared, and seeds needed to be sourced from populations where environmental conditions vary. Respondents were asked what they would consider when choosing the location of populations and the individual trees from which to collect seeds? They were then told that seeds had been sourced from multiple populations across a range of environmental conditions and asked how likely their decision to proceed would be influenced by concerns that individuals could flower at different times, mortality rates would be high, and seeds could introduce characteristics that would make future generations less well adapted to local conditions.

Respondents were asked to answer on a 5-point Likert scale (Likert 1932) (from very unlikely to very likely, with an option to select unsure) and to provide a rationale for their choice.

The questionnaire was piloted with 7 individuals (practitioners, scientists, and biology students) who provided feedback on the face validity (an indication of whether the meaning of the questions are clear to respondents [Wainer & Braun 1988]) of the survey tool. Based on their feedback, minor adjustments were made to the questions to improve clarity. The final survey was deployed for 4 months commencing in September 2015.

Data Analyses

A Kruskal-Wallis nonparametric test was used to determine whether there were differences in the risks perceived by respondents of using seeds of mixed provenance. The ordinal likelihood score was used as the response variable. We then used Mann-Whitney nonparametric tests to assess whether practitioners and scientists perceived these risks differently.

Results

A total of 93 individuals responded to at least one of the 2 scenarios (67 practitioners and 26 scientists). Practitioners were evenly split between on-the-ground management (54%) and policy roles (46%) and among site-level (53%) and landscape scale (47%) management. Practitioners had an average of 9.1 years of experience (range 0.5-29 years) and tended to be highly educated (49% bachelor's degree, 43% master's or doctoral degree, and 8% diploma), but often had not studied evolution or genetics during their education (38%). Those who had taken relevant subjects had studied evolutionary biology (22%), genetics (10%), or both (29%). Scientists had bachelor's (19%) or postgraduate degrees (81%), and an average of 10.7 years of experience (range 1-43 years). Most had taken subjects relating to both evolutionary biology and genetics (73%), although some had taken only evolutionary biology (15%) or genetics (8%), or no relevant subjects (4%). Nearly 73% of scientists indicated they spend time engaging with practitioners about how to improve management practices. Practitioners were not asked about whether they spent time engaging with scientists.

Translocation Scenario

Respondents described between 1 and 6 different management approaches they would use to respond to the translocation of a declining mammal scenario (practitioners, $\mu = 2.85$; scientists, $\mu = 2.76$). The most common suggestions were managing threats to the population in situ; conducting research into the reasons for the decline or the population's genetics; translocating individuals from other populations; and increasing connectivity with other populations (Fig. 1 & Supporting Information). The management options considered by practitioners and scientists were similar, although practitioners were more likely to suggest increasing connectivity, whereas scientists were more likely to suggest conducting research, managing threats, and translocating individuals (Fig. 1). Overall, 75% of practitioners suggested augmenting gene flow through translocation (21%), increasing connectivity (29%), or both (25%), relative to 65% of scientists (42% translocate, 8% connect, and 15% both).

Respondents identified a wide range of risks associated with translocating individuals from other populations (range 1-7, $\mu = 2.5$) (Supporting Information). Practitioners were most concerned about the risks of introducing disease into the recipient population. In contrast, scientists were most concerned about the risks of outbreeding depression (Fig. 2), which was often described as concerns about incompatibility or negative consequences of mixing translocated individuals with the existing population (Supporting Information). Overall, outbreeding

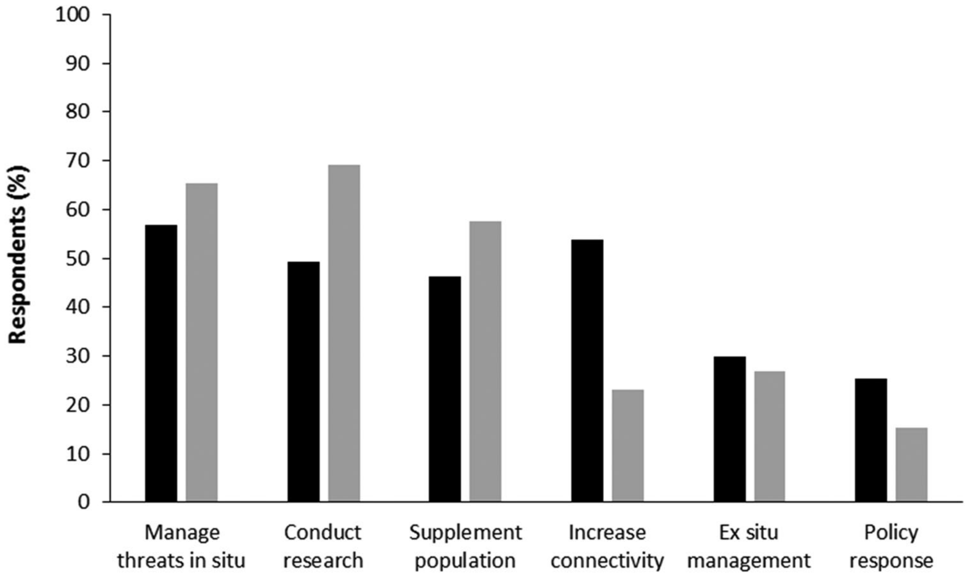

Figure 1. Management approaches suggested by practitioners (black bars, n = *67) and scientists (gray bars,* n = *26) to conserve a small, isolated population in decline. Categories described in Supporting Information.*

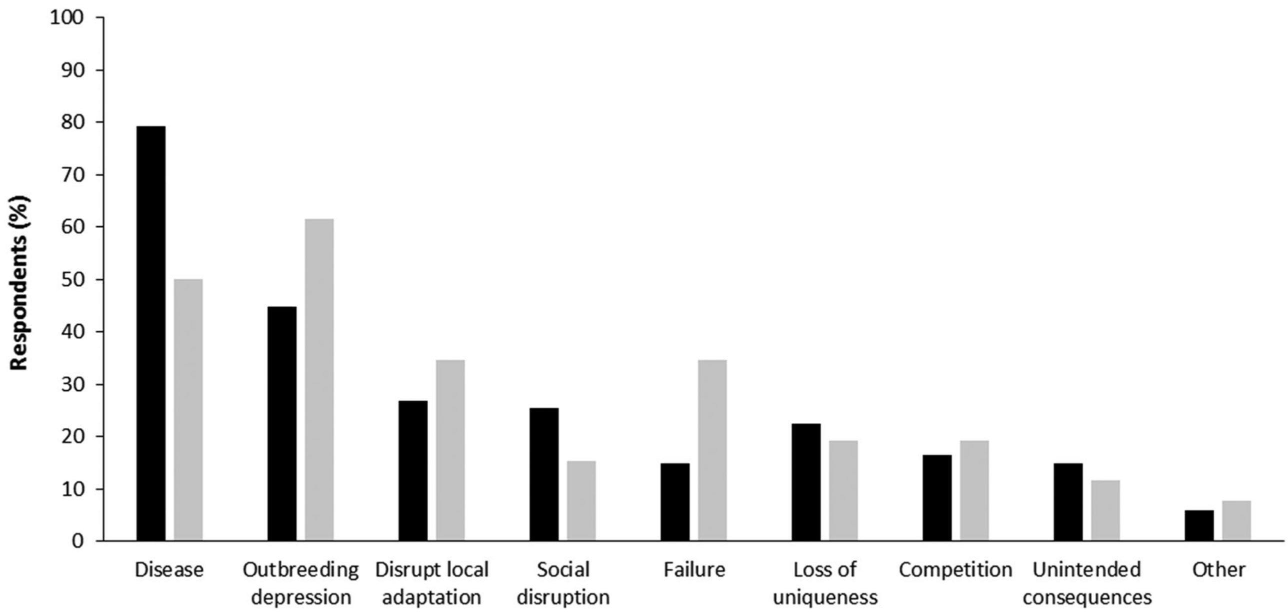

Figure 2. Risks associated with translocating individuals as identified by practitioners (black bars, n = *67) and scientists (gray bars,* n = *26). Categories described in Supporting Information.*

depression was seen as a risk by just over half the respondents and was possibly linked to the next most common concern that translocations may disrupt the local adaptation of the recipient population (Supporting Information).

Restoration Scenario

Eleven respondents indicated they had no expertise in restoration and declined to answer. A total of 82 respondents described a range of factors they would consider when choosing populations and individuals from which to collect seeds for a restoration project (Supporting Information). Most prominent were the need to source seeds from similar environments and to take from multiple individuals to maximize genetic diversity (Fig. 3). Overall, scientists were much more likely to consider the provenance of seeds for restoration (72%) than practitioners (38%). Although in both groups, those who did consider provenance were more likely to suggest mixed provenance (22% of practitioners and 48% of scientists) (Fig. 3) rather than sourcing seeds locally (16% of practitioners and 24% of scientists). Although scientists were more likely to consider sourcing seeds from multiple provenances, practitioners were more likely to focus on not taking too much seeds from any one

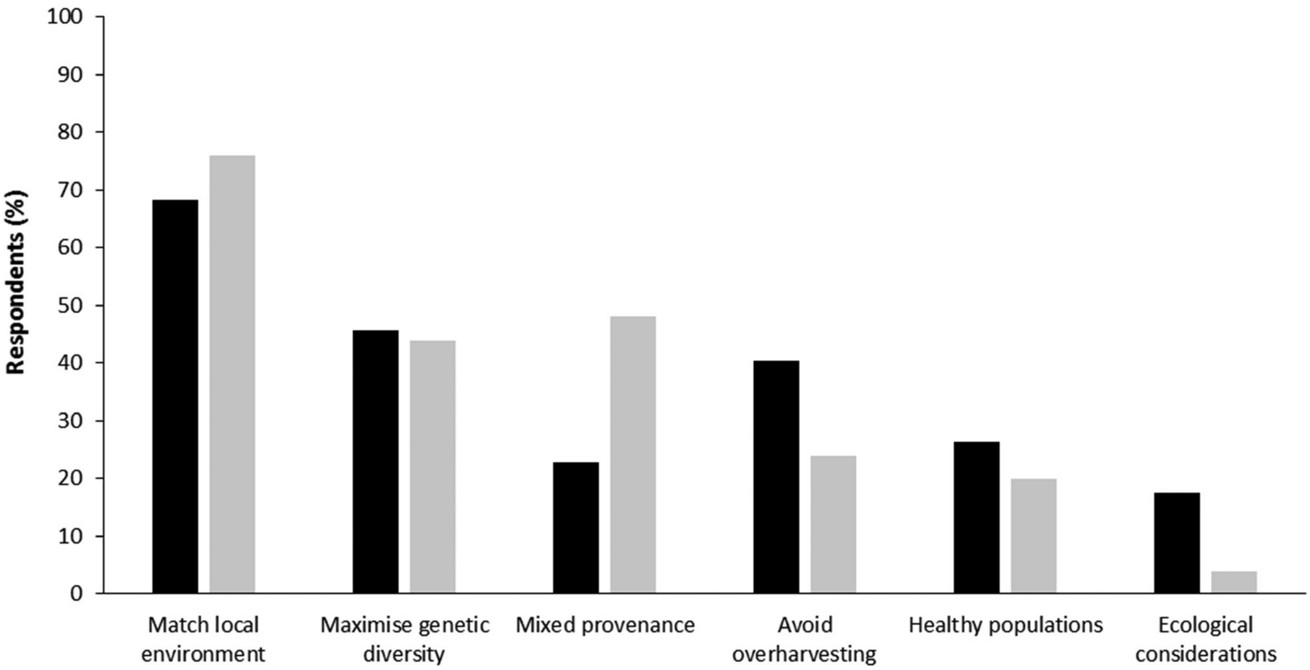

Figure 3. Issues practitioners (black bars, n = 67*) and scientists (gray bars,* n = 26*) consider when deciding from which populations and individuals to source seeds for revegetation. Categories described in Supporting Information.*

individual to avoid negative impacts on source populations (Fig. 3).

Concerns about high mortality rates when using mixed provenance were most likely to make respondents reconsider the restoration project, followed by concerns about a mismatch in flowering time among different provenances (H-statistic = 14.29; df = 2; p = 0.001) (Fig. 4). The loss of local adaptation was unlikely to prevent most respondents from undertaking the project (Fig. 4). There were no significant differences between practitioners and scientists in how they perceived the different risks (phenology: U-statistic = 363.5, df = 1, p = 0.245; mortality: U-statistic = 426.0, df = 1, p = 0.217; adaptation: U-statistic = 437.0, df = 1, p = 0.245) (Fig. 4).

The most commonly provided rationales for why respondents would not proceed with restoration in the mixed provenance scenario centered on their belief that the project would fail and resources would be wasted (52%). When respondents indicated they would still proceed, their explanations focused on the risks being too small to prevent success (52%), that some vegetation at the site would be better than none (24%), or that natural selection would lead to adaptation over time (18%).

Discussion

Our findings suggest that although many practitioners do demonstrate an intuitive understanding of the relevance of evolutionary theory to conservation management, there is still a need to improve their knowledge of evolutionary considerations for management. Based on the alignment between the management activities identified for the different scenarios and best practice guidance from the literature (e.g., Broadhurst et al. 2008; Weeks et al. 2011), practitioners' intuitive understanding of the management of evolutionary processes appears to be better for threatened species management than habitat restoration. However, they are still clearly concerned about assessing and managing the risks associated with what the academic community considers best practice management.

Managing Small, Isolated Populations

Most practitioners appear to have an intuitive understanding that the loss of genetic diversity is detrimental to the survival of small, isolated populations; 75% of practitioners suggested some form of augmented gene flow (supplementation or increased connectivity) (Fig. 1). This is a positive result, given practitioners often struggle to define gene flow (i.e., 35% demonstrate at least a basic understanding [Cook & Sgrò 2019]), and those working in translocation report a lack of knowledge to be a barrier to the genetic management of populations (Taylor et al. 2017). The need to augment gene flow was generally considered by practitioners as part of a broader ecological management strategy that involved mitigating the threats (Fig. 1). This suggests practitioners recognize that restoring gene flow alone may not be successful if the other

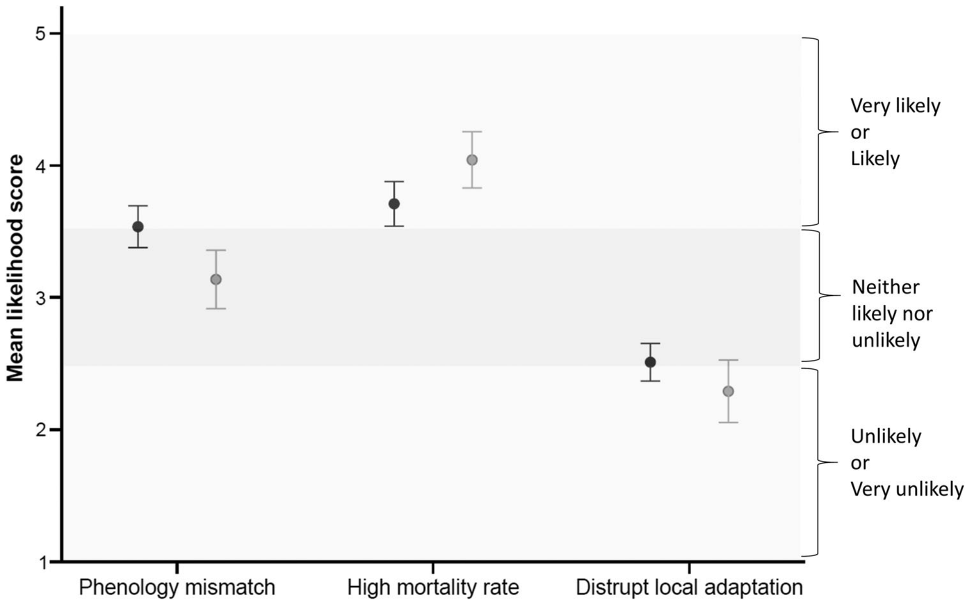

Figure 4. Mean likelihood (SE) that practitioners (black circles) and scientists (gray circles) may decide not to proceed with revegetation with seeds of mixed provenance because of concerns about mismatch in phenology, high mortality rate, or reduced local adaptation.

drivers of population decline are not addressed (Love Stowell et al. 2017). Likewise, the combined strategy suggests awareness that once populations become small enough, abatement of external threats may not be enough to prevent local extinction (Hutchings et al. 2012).

When augmenting gene flow, practitioners were more likely to suggest increasing connectivity among populations, whereas scientists more often suggested supplementing the population through translocations (Fig. 1). Increasing connectivity among populations can offer a longer-term solution to managing inbreeding depression and genetic drift in small, isolated populations (Hedrick 1995), but this is not always possible within fragmented landscapes. If strategies to increase connectivity require habitat restoration, then gene flow may not be restored quickly enough to benefit the declining population. Encouragingly, a quarter of practitioners suggested the need to manage both short-term (i.e., supplementing the population) and long-term gene flow (i.e., increasing connectivity) to ensure the viability (adaptive potential) of the population. The small number of scientists suggesting this combined strategy may reflect their acceptance that active management of gene flow will increasingly need to be ongoing where connectivity cannot be restored to fragmented populations (Love Stowell et al. 2017).

Despite most practitioners being open to the use of augmented gene flow, they were concerned about multiple risks associated with this strategy (Fig. 2). This may partly explain why many respondents said they would commission population genetics research. Guidelines for genetic rescue suggest first establishing evidence of significant inbreeding depression before embarking on translocations (Weeks et al. 2017) and use of population genetics to identify donor populations based on genetic structure (Hedrick & Fredrickson 2010). An understanding of the population genetic structure of potential donor and recipient populations may also help allay concerns about outbreeding depression (Frankham et al. 2011, Supporting Information, Fig. 2), which are often cited as a barrier to practitioners attempting translocations (Frankham 2010; Weeks et al. 2011). These concerns persist despite empirical evidence that strong genetic structure among populations alone is not necessarily a good predictor of outbreeding depression (Weeks et al. 2017).

A common concern for both groups was the introduction of diseases to the recipient population via translocation (Fig. 2). Although disease risk has been acknowledged by advocates of genetic rescue (Hendry et al. 2011; Love Stowell et al. 2017), guidance about how to estimate and minimize this risk is generic (e.g., generally low risk but depends on species [Weeks et al. 2011]) or largely absent (e.g., have a cautionary translocation plan [Hedrick & Fredrickson 2010]). Therefore, more specific guidance for practitioners about estimating and managing disease risk when translocating individuals may facilitate wider application of augmented gene flow.

A number of other risks were also mentioned by respondents (Fig. 2). Many of these risks have been discussed in the literature, such as concerns about taxonomic integrity (Love Stowell et al. 2017), disrupting local adaptation (Hendry et al. 2011), and upsetting social structures (Hedrick & Fredrickson 2010). It is challenging to assess the risk of translocation to taxonomic integrity when there is no consensus about how a species should be defined (Frankham 2010). Similarly, there is conflicting advice about the optimal rates of gene flow needed to avoid disrupting local adaptation (Cook & Sgrò 2017). However, lessons from successful genetic rescue have generated suggestions for minimizing social disruption (e.g., introduce individuals to unoccupied territories or as social groups [Hedrick & Fredrickson 2010]). Although a small number of respondents were concerned about these risks (Fig. 2), many still suggested augmented gene flow as an appropriate management strategy (Fig. 1).

Restoring Native Vegetation

When undertaking restoration, ensuring seeds are sourced from sites with similar environmental conditions was a prominent consideration for both practitioners and scientists (Fig. 3). Concerns around matching environmental conditions to prevent high seedling mortality or phenology mismatches may relate to ecological (e.g., niche) and evolutionary considerations (e.g., local adaptation). However, the only study we are aware of that has assessed the long-term outcomes of mixed provenance suggests that concerns are exaggerated. Prober et al. (2016) demonstrated >80% survival of seeds sourced from sites 90 km apart with a 360-m difference in elevation. The same research shows that the performance of the nonlocal provenance was significantly better in the long term; after 35 years, the survival rate was higher for nonlocal than local seeds (Prober et al. 2016). Such studies are critical to addressing practitioners' concerns regarding high levels of mortality of nonlocal seeds (Fig. 4) and to demonstrating that prioritizing lower initial mortality may compromise the long-term success of restoration efforts.

Despite many different decision-support tools (e.g., Byrne et al. 2011; Breed et al. 2013) and provenancing strategies (e.g., Sgrò et al. 2011; Prober et al. 2015) being Available, less than 40% of practitioners mentioned the need to consider the provenance of seeds (Fig. 3), local or otherwise. The dominance of the local-is-best paradigm for restoration (Broadhurst et al. 2008) was not prominent in our sample (16% of practitioners and 24% of scientists explicitly mentioned sourcing seeds locally). However, the attention given to matching local environmental conditions (Fig. 3) and the significant concern about high mortality when using mixed provenance (Fig. 4) suggests provenance may have been an implicit concern. There was little reference to genetic diversity within the mixed provenance scenario, although 40% of practitioners mentioned that maximizing genetic diversity would be a consideration in selecting seeds (Fig. 3). These practitioners suggested they would select seeds from multiple individual trees to increase genetic diversity, an approach that fails to consider that the genetic diversity of seeds taken from a single population may be low (Sgrò et al. 2011). Likewise, there was little consideration of selecting seeds that might perform well under future climate scenarios (e.g., Breed et al. 2013; Prober et al. 2015). Nevertheless, the recognition that maximizing genetic diversity was important suggested that practitioners may be receptive to the benefits of mixed provenancing strategies for climate adaptation if their concerns about high levels of mortality can be addressed.

Implications

Understanding how practitioners perceive best practice evolutionary management as it relates to problems they regularly address is important for identifying factors that are hindering progress. This understanding can also inform approaches that build practitioner capacity for evolutionarily enlightened management. There are initiatives to help support knowledge exchange between experts and practitioners, such as knowledge brokers within restoration focused nongovernmental organizations and the development of a practitioner-focused genetic management textbook. Nevertheless, limited understanding is not the only barrier to better integration of evolutionary theory (Taylor et al. 2017; Cook & Sgrò 2018). Practitioners often report a lack of resources as a significant impediment to greater integration of evolutionary theory into management (Taylor et al. 2017; Cook & Sgrò 2018), which may still prevent change even if concerns about risks are allayed. Nevertheless, if practitioners have a good understanding of the importance of managing the loss of genetic diversity, funding for genetic management may be prioritized.

Another challenge practitioners cite to changing practice is the focus on short-term rather than long-term management outcomes (Cook & Sgrò 2018). Concerns about initial mortality rates when using mixed provenance in restoration support this pattern (Fig. 4) and conflict with the evidence for better long-term outcomes (Prober et al. 2016). Changing this culture will require policies that prioritize long-term outcomes and increasing the emphasis on managing genetic diversity. These changes will be essential for practitioners to try alternative management strategies in spite of the perceived risks. Growing evidence that practitioners are willing to adapt their management practices (Taylor et al. 2017; Cook & Sgrò 2018) and that better conservation outcomes can be achieved (e.g., Prober et al. 2016; Weeks et al. 2017) suggest that improving practitioners' understanding of the relevant concepts could enable major progress to be made. Given their expertise, evolutionary biologists and conservation geneticists are well placed to support practitioners to make the necessary changes to improve management practices.

Acknowledgments

We thank R. Valkan for assistance with data collection, and D. Coates and A. Weeks for valuable discussion during the development of this research. C.M.S. was supported by an ARC Future Fellowship and C.N.C. by an ARC Discovery Early Career Researcher Award.

Supporting Information

Details of management scenarios (Appendix S1), description of management approaches for translocation scenario suggested by respondents (Appendix S2), description of risks identified by respondents as being associated with translocating individuals (Appendix S3), and description of issues respondents would consider when sourcing seeds for revegetation (Appendix S4) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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