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PRACTITIONER'S PERSPECTIVE

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The use and utility of surrogates in biodiversity monitoring programmes

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1 | INTRODUCTION

Monitoring programmes are intended to inform effective biodiversity conservation and management (Legge et al., 2018). Well-designed programmes can establish baseline conditions, determine trends in threatened species populations, quantify the effects of management and provide warning of ecosystem changes (Magurran et al., 2010). For these reasons, biodiversity monitoring underpins the activities of land management agencies world-wide. However, it is not always possible to *directly* monitor key variables at ideal spatio-temporal resolutions, due to resourcing or logistic constraints. For example, direct monitoring of koalas (*Phascolarctos cinereus*) can be cost- and time intensive as koalas are cryptic, occur at low densities and are difficult to reliably observe in dense forest canopies (McAlpine et al., 2006). Where money, time or logistic challenges hamper monitoring efforts, managers may instead measure a surrogate in lieu of the direct variable of interest (Lindenmayer, Pierson, et al., 2015). While the distinction between surrogate and direct measurement can be ambiguous, here we define a biodiversity surrogate as an attribute of an ecosystem that is used as a proxy for another aspect of biodiversity of interest (Lindenmayer, Barton, & Pierson, 2015). For koalas, the presence of faecal pellets on the forest floor is a rapid and reliable surrogate for estimating occupancy over large areas (McAlpine et al., 2006).

Pragmatically, surrogates appear to be a simple 'fix' to the logistic and financial challenges of monitoring complex systems. Surrogates also are a necessity for programmes where the stated goal is conserving biodiversity, as this target is impossible to monitor directly. Once applied in real-world situations, however, surrogates can yield serious challenges because changes in the target of interest must now be inferred, rather than directly observed (Lindenmayer & Likens, 2011). Before surrogates can be confidently integrated into monitoring programmes, a considerable initial investment of resources may be needed to evaluate surrogates and ensure they are fit for purpose.

The logistic and financial advantages of surrogates can be opaque, yet there is surprisingly little research on the practicalities of selecting and applying surrogates in monitoring programmes. In particular, the views of practitioners are lacking from this research. Specifically, there has been little discussion with practitioners about: (a) the extent of surrogate use, (b) how surrogates are used, (c) decisions guiding surrogate use and (d) barriers to using surrogates, as perceived or experienced by practitioners. Answers to these questions can only be answered through discussion with practitioners about how and why they choose surrogates, thus providing direction for research into improving the application of biodiversity surrogates in monitoring programmes.

To explore the utility of surrogates in biodiversity conservation-focused monitoring programmes, we held a workshop in August 2017. This workshop brought together academics, and government and non-government practitioners from Australia and New Zealand. The workshop consisted of a pre-workshop survey, practitioner conceptualizations of monitoring programmes during the workshop and a post-workshop semi-structured phone interview. The event was a collaborative experience where participants shared their understanding of, and experiences in developing and using biodiversity surrogates (see Foster et al., 2019). The workshop yielded real-world perspectives on the use of biodiversity surrogates; perspectives that have largely been lacking in the field of surrogate ecology (Caro, 2010). We note that these perspectives stem from practitioners making decisions about the planning and on-ground monitoring of biodiversity, and that these decisions are at the final end of a decision chain that falls within a broader political and value-driven context defined by institutional managers and government policy. Here, we focus on reporting the perspectives arising from the workshop, to bridge the gap between research and effective practice of surrogacy in biodiversity monitoring and conservation. Through understanding the perceived extent and factors influencing surrogate use in biodiversity monitoring programmes, we identify six problems limiting the identification and implementation of surrogates, and make operationally focused recommendations for improving surrogate use in monitoring programmes.

2 | PERCEIVED EXTENT OF SURROGATE USE IN MONITORING PROGRAMMES

Workshop discussions quickly revealed that, when describing monitoring programmes, practitioners described a number of variables as direct measures that academics perceived as surrogates (Figure 1; see Table S1 for a summary of monitoring variables used across programmes; Sato et al., 2019). Collectively, we identified three factors that appeared to influence these differences in the use of the surrogate term: the degree of exposure to surrogacy concepts; the organizational context shaping the interpretation of monitoring programmes and/or monitoring programme complexity.

First, organizational context and organization-specific terminology appeared to influence conceptualizations of what a surrogate is, and how individuals described target-variable relationships (Problem 1, see Table 1). In ecology, appropriate application of surrogacy-related terminology is an ongoing issue (Hunter et al., 2016; Lindenmayer, Pierson, et al., 2015). Many surrogate-associated terms exist (e.g. umbrella species, indicator species, higher taxon surrogate) and each may have multiple definitions due to terms being used interchangeably (see Caro, 2010). Additionally, conservation organizations use surrogate-related terms that may take on organization-specific meanings in policy documentation aligning with definitions related to management (e.g. performance indictor), ecology (e.g. indicator species) or measures that relate to a management goal (regardless of whether it is a surrogate or not; for example, monitoring indicator). Strong organizational structuring of monitoring programmes using explicit and precisely defined, organization-specific terms can be useful to avoid confusion within organizations. However, it may limit the ability to conceptualize monitoring programmes using general surrogacy concepts. It also may limit the ability of individuals external to the organization to appropriately interpret target-variable relationships within a monitoring programme.

Second, many programmes included complex or ambiguous targets that led to difficulties in appropriately identifying the type of relationship between that target and its associated variable(s) (Problem 2, see Table 1). Complex targets from our workshop contained ambiguous action verbs (e.g. 'restore', 'enhance'), qualifiers (e.g. 'reasonable', 'appropriate') and biodiversity attributes (e.g. 'vegetation quality', 'ecological health'). Such terms sufficiently described targets for experienced staff with intimate knowledge of a programme, as those practitioners had an implicit understanding of the manageable 'sub-targets' that comprise a complex target. However, this implicit knowledge can lead to experienced staff identifying more direct target-variable relationships for complex targets than individuals who do not have complete operational knowledge of a programme. This is because experienced staff may be mapping

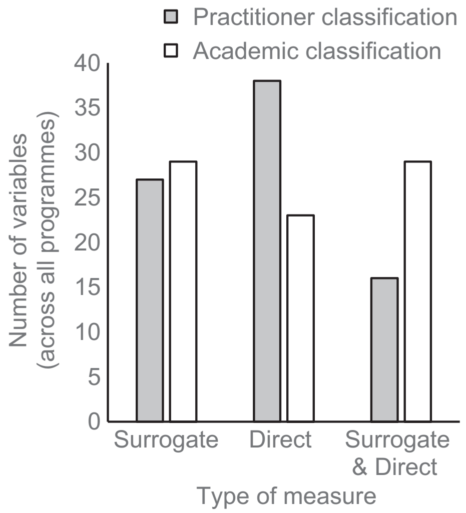

FIGURE 1 Practitioner and academic classifications of monitoring variables as surrogates, direct measures or as both surrogate and direct measures (depending on the associated target), across eight monitoring programmes

TABLE 1 Summary of recommendations to solve six problems associated with the identification and implementation of surrogates in monitoring programmes

Problem	Recommended solution
1. Terminology impeding communication	• Define organization-specific terminology • Provide synonyms for surrogate-related terms • Find consensus on terminology before engaging in deeper conceptual discussions
2. Ambiguous targets	• Use clear and specific language to describe targets • Break complex targets into measurable sub-targets
3. Complex targets informed by multiple variables	• Conceptualize monitoring programme and identify targets informed by multiple variables • Scrutinize the purpose of each variable in the programme • Identify linkages and potential relationships among variables • Identify potential redundancies in monitoring variables • Qualitatively or quantitatively evaluate consequences of removing redundant variables
4. Risk of organizational knowledge loss	• Minimize and/or manage organizational instability • Establish and maintain frameworks to retain and build upon organizational knowledge
5. Insufficient resources for surrogate evaluation	• Prioritize funding for data analysis and surrogate evaluation • Secure staff with a strong background in data analysis to support evaluation tasks • Communicate to planners/policymakers the importance of evaluation to wider policy • Negotiate a commitment to analysis and evaluation prior to embarking on monitoring
6. Planners/policymakers, scientists and land managers working in isolation	• Define the role and identify the accountabilities of scientists, land managers and planners/policymakers with respect to progressing organizational monitoring objectives • Increase the integration of scientist, land manager and planner/policymaker roles (ideally at the outset of monitoring programme design) • Promote and maintain robust communication channels between scientists, land managers and planners/policymakers

monitoring variables against specific (but implicit) sub-targets rather than the documented complex target. For example, experienced staff may identify native grass cover and height as direct variables for a documented target of 'maintaining appropriate grassland condition' because these variables are linked with implicit sub-targets of 'maintaining 60%–80% native grass cover'. However, individuals without knowledge of these sub-targets may identify native grass cover as a surrogate because this variable is assumed to reflect changes in the suite of unmeasured variables that contribute to 'appropriate grassland condition' (e.g. bare ground, sward density).

Third, conceptual clarity regarding surrogates was more difficult to achieve when multiple variables were used to inform a single target (Problem 3, see Table 1). Such situations are unavoidable because multiple variables sometimes need to be tracked to provide a more complete picture of complex or ambiguous targets. For example, a target to 'maintain habitat structural complexity' may be informed by a combination of litter cover, shrub cover and shrub density. Each variable contributes some information for measuring progress towards the target. However, other variables are also likely to contribute to habitat structural complexity (e.g. grass biomass, rock cover, etc.). Therefore, in measuring a subset of variables, surrogacy relationships are assumed; changes in the *measured* variables are assumed to reflect changes in *unmeasured* variables. It is this type of assumption that requires development of conceptual models of the target system, as well as scientific validation to ensure effective use of surrogates in monitoring programmes. It is therefore important to recognize that as targets become more complex, target-variable relationships are more likely to depend on surrogacy, and can become more difficult to accurately verify (Lindenmayer, Pierson, et al., 2015).

3 | FACTORS INFLUENCING THE USE OF SURROGATES IN BIODIVERSITY MONITORING

Through discussion of shared constraints and challenges across the eight monitoring programmes represented at our workshop, we identified seven issues that affected practitioners' decisions when selecting and using monitoring variables. These were: (a) stakeholder communications and expectations, (b) staff and funding capacity, (c) the availability of appropriately trained field staff, (d) long-term retention of corporate knowledge, (e) existing knowledge base in understanding of complex ecosystems, (f) disconnectedness among planners/policymakers, scientists and land managers, and (g) data evaluation capacity.

Some issues identified by practitioners hindered their ability to use surrogates, favouring instead the use of direct measures as monitoring variables. For example, practitioners found it is easier to communicate progress towards targets using direct measures, rather than explaining how a pattern in a surrogate relates to patterns in, and achievement of, the target. Moreover, as the level of the investment committed to achieving a target increased, the greater effort required to monitor direct measures became easier to justify. For example, in Australia, conservation programmes that aim to restore ecosystems through the reintroduction of threatened mammals are resource intensive (e.g. AUD$600 000 to relocate the dibbler, *Parantechinus apicalis*, in Western Australia; Moro, 2003). Given this investment, accurate, high-certainty data about the target (i.e. mammal abundance) are required to evaluate progress towards that target. These data are most likely obtained through direct measurement of populations, justifying the use of resource-intensive surveys, despite a less resource-intense surrogate potentially being available (e.g. scat or track counts).

In contrast, some issues faced by practitioners made surrogates more attractive relative to direct measurement. For example, practitioners highlighted that limited availability of experienced field staff can reduce the quality of data collected and increase the time taken to collect data. Where field staff turnover was high, expertise was limited, or where volunteers and contractors collected field data, practitioners expressed a preference for using surrogates if they were simpler to collect and robust to variable expertise levels. Rather than collecting detailed floristic data, for example, measures of vegetation structural attributes or broad functional groupings (e.g. tree, shrub, herb cover) may be collected that adequately inform improvements in vegetation condition.

Discussion between practitioners and researchers also revealed that knowledge gaps, compounded by loss of knowledge through staff turnover, can limit the identification and validation of potentially cost-saving surrogates (Problems 4 and 5, see Table 1). The organizations at the workshop representing long-term monitoring programmes (i.e. >10 years) with low staff turnover explained they had been able to: (a) develop a good conceptual understanding of the ecosystem being monitored; (b) confidently recognize patterns in targets and associated monitoring variables; and (c) identify and evaluate when monitoring a surrogate instead of a direct measure may be more appropriate. These reflections underscore the importance of well-resourced, stable programmes in allowing organizations to develop a detailed understanding of the focus ecosystem, and in parallel, build a strong conceptual and practical understanding of the role of surrogates in monitoring programmes.

Finally, some practitioners felt that lack of connectedness between scientists, land managers and planners/policymakers in their organizations strongly influenced the selection and use of appropriate surrogates (Problem 6, see Table 1). In most organizations, these roles are occupied by separate individuals who face different challenges and draw on different strengths. Planners and policymakers may be required to monitor certain aspects of biodiversity based on priorities set by higher level political or organizational values (Turnhout, Hisschemöller, & Eijsackers, 2007). However, without frequent, constructive communication between all key stakeholders, political priorities and planner/policymakers' demand for 'seeing' results from investment may end up driving the targets and the types of variables selected for monitoring programmes. In such cases, input-driven variables (e.g. numbers of culled non-native herbivores) may be selected over outcome-driven variables (e.g. changes in vegetation condition) to rapidly show 'results' from investment in pest control where an improvement in vegetation condition is the primary target. However, without explicitly testing the inferred surrogacy relationship between these variables (i.e. if fewer introduced herbivores equates to improvements in vegetation condition), it is challenging for an organization to appropriately track progress or alter management actions to meet a conservation target.

4 | RECOMMENDATIONS

Based on the problems identified above, we describe six broad recommendations for improving the identification and use of surrogates in monitoring programmes (with Table 1 providing a summary of specific recommendations). Our recommendations are not exhaustive and vary in the ease with which they may be implemented by organizations. However, these recommendations reflect practitioner opinion about areas of operational focus with direct bearing on selecting and implementing appropriate surrogates.

4.1 | Define organization-specific terminology

Monitoring agencies, private industry and academic organizations use embedded, organization-specific terminology that can limit incorporation of relevant research into policy documents, inhibit effective communication between practitioners and academics, and lead to inconsistent evaluation of surrogate use in monitoring programmes (Caro, 2010; Hunter et al., 2016). Where practitioners and academics work together to explore surrogacy, they should find consensus on terminology prior to engaging in deeper conceptual discussions.

Additionally, for written documents (e.g. scientific articles, programme documents), definitions of key terms should be clearly stated. Definitions will assist internal and external readers in appropriately interpreting documents (and programmes) which is critical for later reuse of that information (Westgate & Lindenmayer, 2017). Furthermore, key words for documents should contain synonyms (e.g. a scientific article on surrogates should include 'indicator' and 'proxy' as key words) so that relevant information can be found and used by those employing different terminology.

4.2 | Critique and refine targets

Targets that are ambiguous can facilitate values-based communication and provide flexibility (Maxwell et al., 2015), while realistic, clear, specific and measurable targets (Fancy & Bennetts, 2012) facilitate identification of direct and inferred target-variable relationships. Given the utility and differing purpose of both types of targets, it may be that biodiversity monitoring programmes require two sets of targets: one set of overarching, aspirational targets that serve as communication tools; and a second, internally documented set refined from more complex or ambiguous targets that aid robust implementation and evaluation of programme success. The specificity and clarity of ambiguous targets can be improved by modifying language used to describe targets, or by breaking complex targets into measurable 'sub-targets' that contribute to achieving the complex target. For example, 'enhancing ecosystem condition' might be made more specific by focusing on sub-targets of reducing weed occurrence and increasing the abundance of a threatened plant. In situations where modifying ambiguous targets is not feasible, each variable associated with a target should be carefully assessed to identify whether it provides a direct and explicit measure of the target, or whether an inferred relationship is assumed. If an inferred relationship is assumed, scientific validation of that relationship should be prioritized.

4.3 | Scrutinize targets informed by multiple variables

Multiple variables are sometimes required to assess a single target (see Fancy & Bennetts, 2012). These situations may occur because the target is genuinely complex, but they may instead indicate redundancy among monitored variables. Where multiple surrogates inform a single target, efficiencies can be created if variables that serve similar purposes are identified and removed. For example, three surrogate measures of habitat structural complexity (e.g. shrub cover, shrub height, and shrub density) may be redundant if all measures provide similar information for a target related to maintaining reptile habitat structural complexity (i.e. measuring all three variables does not contribute significantly more information about the target when compared with just one variable). If redundant variables are identified in a programme, the surrogacy value of each identified variable can be tested (see Lindenmayer, Pierson, et al., 2015), surrogates that best meet the target can be retained and redundant surrogates can be removed.

For surrogates to save time and money in monitoring programmes, organizations must conceptualize monitoring programmes (i.e. link monitored variables with specific targets they address; Foster et al., 2019); scrutinize the purpose of each variable in the programme; identify potential relationships among variables and assess whether these relationships form the basis for appropriate surrogates; and qualitatively or quantitatively evaluate the consequences of removing redundant variables from the programme.

4.4 | Develop strategies that prevent knowledge loss

Intellectual capital is an asset vital to the functioning and development of an organization. In biodiversity monitoring, knowledge of local ecosystems is a key component of intellectual capital critical to identifying and implementing robust surrogates. However, the retention and generation of intellectual capital in environmental organizations is jeopardized by organizational instability arising from shifting political priorities and short funding cycles (Burbidge et al., 2011). Where maintaining stability is outside the control of an organization, procedures and strategies must be established to document organizational knowledge to help prevent knowledge loss. Workshop participants suggested that scientific advisory panels affiliated with organizations can mitigate knowledge loss arising from staff turnover, provided communication with panels is maintained. Practitioners also suggested that formal documentation of decision-making processes (e.g. reasons for including/excluding variables from programmes, identifying decisions as being informed by monitoring data or expert opinion), field data collection methods and operational/ecological field staff observations that inform organizational knowledge, is required. Formalized journals, online communities or after-action reviews can maintain such knowledge (Liebowitz, 2009).

4.5 | Allocate funding to data analysis and surrogate evaluation

Practitioners identified that, while there is a desire to validate surrogacy relationships in monitoring programmes, analysis and testing of surrogacy is often impeded by funding constraints and a lack of internal statistical expertise. Two organizations represented at the workshop based their selection of surrogate variables on available peer-reviewed scientific literature, while a single organization with greater security in long-term funding actively evaluated surrogate relationships in-house. However, for most organizations, validation of surrogate relationships was not possible as it was a low funding priority. As long as evaluation of surrogacy relationships remains a low-priority funding item, resources may continue to be wasted on collecting data on redundant or poorly performing surrogates. Evaluation of surrogacy relationships is critical to determine the effectiveness of surrogates, and whether their use should be continued (Lindenmayer, Pierson, et al., 2015). Evaluation also informs what a change in a surrogate means for the target, which informs better management. A cultural shift in organizations is required regarding funding prioritization, such that funding is explicitly allocated to surrogate evaluation and staff or external bodies skilled in data analysis to support evaluation of surrogacy relationships (Robinson, Smallbone, & O'Connor, 2012). Moreover, the importance of analysis and evaluation in wider organizational frameworks should be communicated to planners and policymakers, and where possible, commitment of resources to analysis negotiated prior to embarking on (further) monitoring.

4.6 | Facilitate frequent communication between stakeholders

Value-laden decision-making pervades biodiversity monitoring programmes from top-level policy decisions, to planning decisions, to decisions of individual scientists on what to measure to address an objective. As such, the development of monitoring programmes informed by robust surrogates is a combined science-policy process (Turnhout et al., 2007) as different stakeholders value different surrogate 'properties'. Scientists may prioritize use of surrogates with strong ecological relationships to targets; land managers may prioritize surrogates that reduce monitoring costs or have strong social outcomes (e.g. engaging farmers in monitoring programmes using fox baiting programmes where the programme target is to increase native fauna richness); and policymakers may prioritize surrogates aligned with political priorities. In situations where organizational structures result in scientists, land managers and planners or policymakers working in isolation, the value of surrogates to different users can be lost. This can lead to the removal of surrogates from programmes that are valuable to some stakeholders (e.g. surrogates selected for their social outcomes) and may jeopardize the integrity of long-term monitoring programmes, or may have implications for evaluation and inference drawn from monitoring data about conservation actions. Organizational structures should seek to reduce the separation of scientists, land managers and policymakers by promoting and maintaining robust communication channels. Frequent communication will allow the value of different types of surrogates to be conveyed to different parties and a balance can be struck in selecting, retaining and validating surrogates that meet the needs of all stakeholders.

5 | CONCLUSIONS

Despite differences between academic and practitioner perceptions of surrogate use in monitoring programmes, our workshop showed that surrogates are frequently used to assess programme targets. It is critical that organizations undertaking biodiversity monitoring identify if and how their programmes rely on surrogacy (i.e. inferred relationships between variables and targets). This will ensure that surrogacy can be validated where funding and political will permit, and greater confidence can be placed on the information surrogates provide and the management responses they underpin. While, many operational factors limit the testing and selection of appropriate surrogates, our six practitioner-focused recommendations will facilitate current and future identification and use of robust surrogates in monitoring programmes.

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AUTHORS' CONTRIBUTIONS

C.F.S., M.J.W., P.S.B., C.N.F., L.S.O. and D.B.L. conceived the ideas, designed methodology and collected the data; C.F.S. analysed the data and drafted the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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De-identified summary data for this article are available via the Dryad Digital Repository https://doi.org/10.5061/dryad.q8kh0p9 (Sato et al., 2019). The complete dataset from the workshop could not be archived due to confidentiality agreements with workshop participants.

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BIOSKETCH

The authors at The Australian National University have diverse interests in landscape and restoration ecology, ecological synthesis and the theory and application of biodiversity surrogates. Their research is aimed at providing solutions to biodiversity conservation and land management problems.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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