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METHODOLOGICAL DEVELOPMENTS IN LANDSCAPE ECOLOGY AND RELATED FIELDS (Y WIERSMA AND J HOLLISTER, SECTION EDITORS)

Why We Need to Invest in Large-Scale, Long-Term Monitoring Programs in Landscape Ecology and Conservation Biology

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Abstract

Purpose of Review Large-scale and/or long-term monitoring has many important roles in landscape ecology and conservation biology. We explore some of these roles in this review. We also briefly discuss some of the key design issues that need to be considered when developing long-term, large-scale monitoring to ensure it is effective.

Recent Findings Much has been written on the importance of ecological monitoring, but the record on monitoring in landscape ecology and conservation remains generally poor. For populations of many species and for many environmental management interventions, monitoring is rarely done, or done well. This review outlines some of the reasons it is critical to invest in well-designed, implemented, and maintained monitoring. New ways of using monitoring data, such as in environmental accounting and mandated environmental reporting, might provide avenues for garnering greater support for monitoring programs in the future.

Summary We discuss seven of the most important roles of monitoring in landscape ecology and conservation biology. These are (1) documenting responses to environmental change, (2) answering key ecological questions, (3) testing existing ecological theory and developing new theory, (4) quantifying the effectiveness of management interventions, (5) informing environmental prediction systems, (6) engaging citizen scientists and the general public, and (7) contributing data and other insights to environmental initiatives. We illustrate these key roles with examples, drawn from existing large-scale, long-term work in a range of environments in Australia. We argue that some of these functions can only be realized if a monitoring program is well designed, implemented, and maintained.

Keywords Ecological monitoring · Monitoring design · Biodiversity · Management interventions · Management effectiveness · Environmental accounting and reporting

Introduction

The disciplines of landscape ecology and conservation biology are characterized by vast literatures, with much written on the importance of ecological monitoring [1–3, 4•, 5]. In this paper, we briefly outline some of the key reasons why it is critical to invest in long-term, large-scale monitoring in both landscape ecology and conservation biology and provide brief examples to illustrate these values. Our examples draw on our own large-scale, long-term programs throughout eastern Australia, but many of the broader lessons from these case studies are applicable to monitoring in many other jurisdictions around the world. We also briefly touch on some of the key design issues that need to be considered in long-term, large-scale monitoring to ensure it is effective.

Background—Two Simple Definitions

The definition of what constitutes large-scale and long-term can be complex and fraught. For example, much large-scale monitoring corresponds to landscape-level monitoring, where a landscape is defined from a human perspective (and

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typically covers thousands of hectares) [6] rather than the perspective of an organism of interest (e.g., a beetle versus a raptor; see [7]). In this paper, for simplicity, we consider large-scale monitoring to be at a landscape level (from a human perspective) that corresponds to areas spanning hundreds to thousands of hectares.

Whether a monitoring program is long-term is sometimes considered to be relative to the generation time of the organism of interest (see [8••]). However, for some long-lived species like trees, this would mean that only programs persisting for longer than 500 years could be considered long-term. Conversely, for rapidly reproducing organisms such as microbes, monitoring longer than a day could be considered long-term. Again, to make our discussion tractable, we have chosen a simple definition and consider a long-term monitoring program to be one that exceeds 10 years in duration. We acknowledge that the landscape spatial scale and decadal temporal scale employed in this article typically relate to vertebrate populations in terrestrial ecosystems. However, many of the general underlying principles that underpin this paper also will relate more broadly to monitoring programs for other groups and in systems other than terrestrial environments.

Background—Why Is Large-Scale, Long-Term Monitoring in Landscape Ecology and Conservation Biology So Rare?

The literature on the importance of long-term monitoring is vast—innumerable scientific articles, dozens of books, and even entire journals have been dedicated to this topic. Yet, despite this, large-scale, long-term monitoring programs are comparatively rare. There are many reasons for their rarity (reviewed by [8••]). These include (among many others) (1) a lack of appetite by government agencies and environmental management groups to fund them; (2) a concern held by some groups (such as industry advocates) that the findings from monitoring programs might expose environmental problems that will be costly to fix or which may curtail their operations; (3) that funding bodies are obsessed with new discoveries and so-called innovation with the repeated measurements needed in long-term monitoring seen as boring and routine; (4) the perspective held by some scientists that monitoring is not science nor research; (5) the demands for a dedicated champion for monitoring projects and whom is prepared to dedicate a prolonged part of their career to gathering data on, and assembling the funding for, work in a particular area or across a given ecosystem; (6) the perception by staff in some agencies that monitoring is too expensive and represents a poor level of return on investment, with the replacement of on-the-ground people with methods such as remote-sensing making the costs of monitoring more tractable (although not necessarily very effective); and (7) a lack of communication and outreach by some people involved in monitoring to gather a constituency of supporters to advocate for such programs monitoring. Of course, some of the key points made in the remainder of this article demonstrate that establishing and maintaining long-term monitoring programs can be incredibly challenging.

Background—Why Does Monitoring Often Need to Be Large-Scale and Long-Term?

Many Key Processes Occur at Landscape Scales

Large-scale monitoring is often required, in part because some key ecological processes occur at landscape scales or larger. For example, forest and other land clearing often occurs at large spatial scales [9, 10] and can have profound impacts on biodiversity and ecological processes over extensive areas [11, 12]. Quantifying spatial patterns of biodiversity occurrence like beta-diversity and its relationships to spatial patterns of vegetation cover also can demand large-scale monitoring [13]. Edge effects from changes in land cover can propagate over extensive areas [14] and their impacts can demand monitoring at correspondingly large scales. Similarly, the effects of natural disturbances such as wildfires and human restoration efforts like revegetation schemes can occur over large areas and documenting their impacts (both negative and positive) can demand large-scale monitoring programs. Moreover, species responses at small spatial scales can be influenced by many factors that operate at larger scales and hence multi-scaled monitoring programs that include large-scale data collection can be important for understanding the drivers of species responses and ecological processes [15]. For example, the effects of the condition of entire watersheds on stream health, aquatic biodiversity, and other environmental factors have been well documented in seminal long-term, large-scale studies (e.g., [16, 17]).

Many Key Processes and Responses to Them Manifest Over Long Time Scales

The impacts of some key ecological processes, and responses to them, can unfold over prolonged periods of time. Long-term monitoring can be critical to quantify these responses [18, 19••] because short-term studies (such as snapshot cross-sectional investigations) can fail to detect them. Responses of biodiversity to restoration efforts is an example [20] because many years can be required for revegetated areas to become established and provide suitable habitat for some species [21, 22]. Post-fire recovery in vegetation and associated biota is another process that can take prolonged periods for key patterns to manifest [23] and may continue to change through time with successional dynamics [24]. Indeed, time is often a key variable with large effect sizes in analyses of the factors influencing biodiversity in landscapes undergoing environmental change. For instance, we have implemented a long-term study (now spanning 24 years) that has aimed to document the changes in biodiversity within woodland patches as the surrounding landscape (covering an area of ~ 20,000 ha) is subject to exotic tree plantation establishment. Many of the most marked changes in biota occurred after more than a decade, in part, associated with canopy closure in stands of plantation trees [25]. Therefore, time since plantation establishment was a dominant explanatory variable in models for the vast majority of taxa (e.g., 57 of the 80 species of birds in the study) [25]. Similarly, the establishment of the plantation itself has only relatively recently begun influencing the bird fauna of woodland patches on adjacent farmland (where there are no plantations) [25]—an effect that was not apparent in the first decade of monitoring. In another example, species responses to the emergence of threatening processes can be dynamic. For example, following the introduction of chytrid fungus into Australia in the late 1970s, some frog species declined rapidly and then recovered, while the decline of other species took decades to become apparent [26]. Long-term monitoring is crucial to documenting such variable and dynamic species responses to threats like invasive species and informing conservation actions.

Why Invest in Large-Scale, Long-Term Monitoring?

There are many reasons to invest in large-scale, long-term monitoring programs and we briefly touch on a subset of the ones we deem most important below. Some of these are inter-related, but to limit repetition, we restrict commentary to the topic where a given reason is most salient.

Documenting Responses to Environmental Change

Large-scale, long-term monitoring is often essential for documenting the response of biodiversity and key ecological processes to environmental change. This can be important for a host of reasons. For example, it can highlight which species or indeed entire ecosystems are declining and need conservation action [27, 28]. This can, in turn, indicate the level of investment that might be needed to rectify environmental and conservation management problems (e.g., [29•]). As an example, we have maintained an ongoing 24+-year program of monitoring temperate woodland birds in agriculture-dominated landscapes of inland south-eastern Australia. Data from the work have helped identify which species of birds have increased and decreased over time [30] and how species are responding to temporal changes in the amount of woodland vegetation in the landscape that has resulted from replanting programs and natural regeneration [31]. The data have also been instrumental in quantifying how different species have responded over the past two decades to the interacting effects of woodland vegetation type (plantings versus regrowth versus old growth), long-term climate, and short-term weather [32]. Such kinds of data are important to help segregate the effects of fluctuations in weather (from droughts to floods) from spatio-temporal changes in landscape cover as well as determine how such factors interact to influence bird occurrence, including in regions with marked differences in long-term climate (hot and dry versus cool and wet) [32].

Answering Key Ecological Questions

Robust answers to key ecological questions often require data from long-term, large-scale monitoring programs. These can include developing an accurate picture of the range and population size of species both in space and in time through documenting patterns of long-term occurrence and persistence. This can be challenging when there are temporal and spatial differences in environmental conditions and drivers of population variability throughout a species' range. Sometimes key ecological questions are relatively simple (albeit not always easy to answer), but nevertheless important for resource and conservation management. For example, a key question in the management of the native forests of the Australian State of Victoria is: Are populations of the critically endangered Leadbeater's Possum increasing or decreasing? Leadbeater's Possum (*Gymnobelideus leadbeateri*) (Fig. 1) is one of the faunal emblems of Victoria and its distribution overlaps extensively with areas that are heavily cut for timber and pulpwood [33]. Detections of the species have increased markedly in the past decade, but is this a function of a considerable increase in survey effort (as part of newly mandated pre-logging surveys) or does it reflect a true increase in the abundance of the species? To answer the question about long-term changes in the species' occurrence, data from monitoring occurrence at more than 160 permanent field sites were collected between 1997 and 2018 across large parts of the known distribution of Leadbeater's Possum [34]. The data show that levels of site occupancy have more than halved in the past two decades—declining from approximately 12% of survey sites in 1997 to approximately 5% 20 years later. Data on forest structure and landscape composition allied with species surveys showed that the drivers of decline in site occupancy were a loss in the abundance of large old hollow-bearing trees where the species nests, and the amount of logging in the landscape surrounding long-term monitoring sites [34] (Fig. 2). This example highlights several important factors. First, it illustrates a clear decline

Fig. 1 Leadbeater's Possum (photo by David Lindenmayer)

in site occupancy and disentangles such patterns from variations in survey effort across the species' range. Second and perhaps most importantly, the study illustrates not just the pattern of temporal change but also the processes underpinning those changes (in this case, loss of nesting tree hollows and a change in composition of forest landscapes). This is, in turn, critically important for informing management actions such as enhanced protection of targeted areas of forest such as those that supporting hollow-bearing trees.

Testing Existing Ecological Theory and Developing New Theory

Long-term data are critical for robustly testing ecological theory. As an example, there has been much debate in the landscape ecology and conservation biology literature about whether the total amount of habitat or the spatial configuration of that habitat has the greatest impact on biodiversity [35, 36]. We used data gathered over 13 years in a 1.8 m-ha area to test habitat amount versus habitat configuration theory for birds in fragmented, formerly temperate woodland-dominated landscapes in inland south-eastern Australia [31]. A critical aspect of the work was that monitoring occurred over a prolonged period during which substantial amounts of native vegetation cover were added to the landscape as a result of replanting programs for woodland restoration. These temperate woodlands are relatively slow growing and long-term monitoring was needed to document changes in bird biota resulting from restoration efforts. The results of the work showed that individual bird species responses were overwhelmingly dominated by the amount of native vegetation cover relative to structural connectivity in that cover. The monitoring suggested that restoration efforts for birds might be best focused on increasing overall levels of cover rather than attempting to physically connect existing patches of remnant woodland vegetation (although for less mobile taxa, connectivity may be more important) [31].

Empirical tests of theory using monitoring data can, in turn, be valuable for fostering the development of new theory. For example, insights from analyses of long-term data were used to develop new theory and predictions about biodiversity responses to spatio-temporal changes in patterns of native vegetation cover in agricultural landscapes [37]. In these cases, long-term data can be valuable because of lag times in responses to restoration and, conversely, where extinction debts due to past human disturbances like land clearing can take a long time to manifest [37].

Quantifying the Effectiveness of Management Interventions

Large-scale, long-term monitoring data are essential for quantifying the effectiveness of management interventions, such as those designed to enhance populations of a target species, improve environmental conditions, reduce the

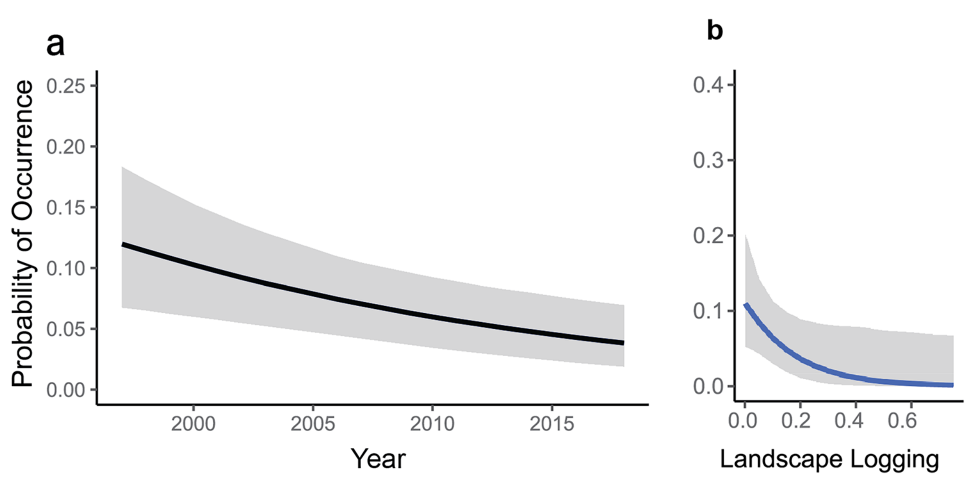

Fig. 2 **a** Temporal decline in site occupancy by Leadbeater's Possum. **b** Influence of the amount of forest logging in the landscape on temporal changes in site occupancy by Leadbeater's Possum (both graphs redrawn from [34])

effects of a threatening process, or all of these outcomes. However, it is extraordinary how infrequently environmental management actions and species responses to them are monitored (e.g., [38, 39, 40•]). This is true in such different fields as agri-environment schemes [41], river restoration [42], and threatened animal and plant species conservation [27, 43, 44]. As an example of targeted monitoring of the effectiveness of a management intervention, a large-scale, long-term monitoring program was employed at Booderee National Park in south-eastern Australia to quantify the outcomes of a major weed control program. This work tracked management outcomes following weed control such as reduced abundance and cover of the invasive plant species, the recovery of native plant species, and the indirect impacts of the treatment protocol on animal species [45, 46]. Analyses of monitoring data revealed that weed control measures were effective, facilitated the recovery of native plant species, and had limited negative impacts on native animals [45, 46]. Indeed, some threatened animal species benefitted significantly from weed removal (e.g., the endangered Eastern Bristlebird; *Dasyornis brachypterus*) [46]. Cost data from implementing the weed control program also revealed that the sequence of treatments employed was cost-effective (as well as being ecologically effective) [45]. In summary, long-term monitoring data can be critical for informed management actions and hence form the basis for evidence-based policy and evidence-based resource and conservation management (sensu [47••]). Highlighting that long-term monitoring programs are cost-effective also can be an important part of ensuring that they are maintained (see below).

Informing Environmental Prediction Systems

Being able to better predict environmental conditions could enhance management of natural resources and biodiversity in the future. Developing environmental prediction systems is a major challenge and long-term data gathered over large spatial scales can be crucial in influencing how accurate (or otherwise) such prediction systems might be. As an example, data have been gathered over 20 + years on the rate of decay and collapse of large old trees in the wet forests of the Central Highlands of Victoria [48] (Fig. 3). These trees are a critical component of the habitat of a range of cavity-dependent species of conservation concern and have a strong influence on patterns of distribution and abundance of these animals [34]. Past monitoring data have been instrumental in developing an environmental prediction system to project future populations of both large old trees and the animal species which depend on them [49]. This, in turn, has helped shape approaches to forest biodiversity conservation, forest restoration programs, and indeed policies for timber resource allocation [50].

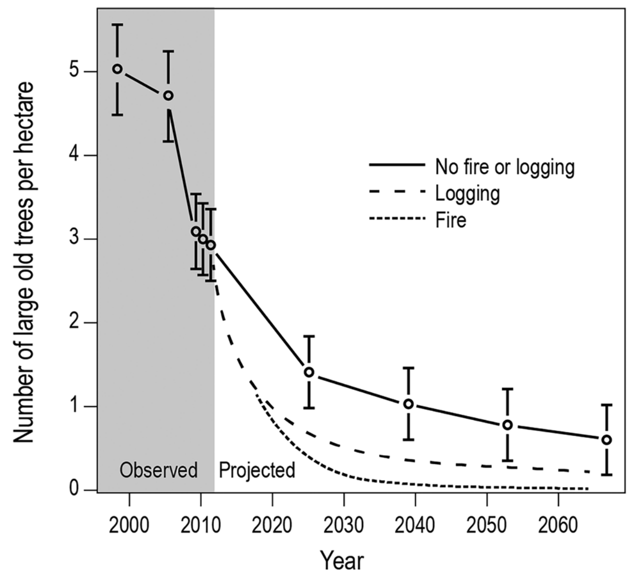

Fig. 3 Projected future changes in large old trees and populations of species closely associated with such trees in the wet forests of Victoria (redrawn from [49])

Simulation models are a widely used kind of environmental prediction system. In a landscape ecology and conservation biology context, programs for Population Viability Analysis (PVA) (sensu [51]) are some of the best-known kinds of simulation models and they are valuable for projecting species probability of persistence, including in response to particular management interventions. Large-scale and/or long-term monitoring data are often critical in these models, particularly if the aim is to generate relative accurate forecasts of population responses [52]. An excellent example of the intimate inter-relationships between monitoring data and its utility for application in PVA comes from recent landscape-scale work aimed at determining what actions will be needed to conserve remaining populations of the highly threatened Regent Honeyeater (*Anthochaera phrygia*) in eastern Australian woodlands [53]. A large-scale monitoring study was implemented to detect individuals of the species throughout eastern Australia [54]. Insights from that work (and other studies) were then used in viability analysis to highlight how quickly the species would be lost in the absence of any conservation action and, conversely, how much population supplementation, competitor control, and vegetation restoration would be required to limit the risks of extinction [53]. In summary, large-scale and/or long-term data can be critical in the application of environmental prediction systems, including the kinds of models routinely used in biodiversity projection like Population Viability Analysis.

Engaging Citizen Scientists and the General Public

Large-scale and/or long-term monitoring programs can often be valuable in providing a platform for engaging citizen scientists and the general public. This can be important for building a constituency of interested people and lead to increased support for science and for conservation programs. A good example is the extensive monitoring program for the iconic but threatened Malleefowl (*Leipoa ocellata*) across many parts of inland semi-arid and rangeland Australia [55]. Here, numerous teams of volunteers assist in field monitoring of nest mounds, screening camera trap footage of nest mounds, entering large amounts of field data, and numerous other key tasks. The monitoring program is part of a true adaptive management study and spans areas exceeding hundreds of thousands of hectares in remote parts of several Australian states [55]. Moreover, the monitoring program has built a large constituency of supporters for the conservation of an iconic threatened species.

Contributing Data and Other Insights to Environmental Initiatives

Data from monitoring programs are essential for use in many kinds of formal environmental reporting. For example, monitoring is mandatory for species listed under the US Endangered Species Act, although the Act currently lacks a comprehensive monitoring policy framework to enable management success (e.g., species recovery) to be fully quantified [39]. Monitoring data are extensively used to report the status of biodiversity and environmental conditions throughout all ecosystems in Switzerland, and are included in regular formal and mandatory environmental reports for that country (e.g., [56•]). Conversely, reporting frameworks without long-term monitoring data can have limited value, as is the case for Australia's State of Environment reports over the past 20 years which are notable for their paucity of robust time series monitoring data on species and ecosystems [57].

Large-scale, long-term monitoring data can be valuable for re-use in many key environmental initiatives and for reporting. For example, long-term monitoring data are critical in the production of environmental and economic accounts like those developed by the United Nations System of Environmental and Economic Accounting framework [58]. Such frameworks provide a robust basis for valuing natural assets and natural capital [59]. As an example, environmental and economic accounting was applied in an extensive forested region in Victoria, south-eastern Australia and included a biodiversity account (in which the number of threatened species increased over the accounting period) as well as a natural asset assessment that showed the value of water from intact forests was 25.5 the economic value of pulpwood cut from wood production forests [60•].

Design Issues in Long-Term and Large-Scale Monitoring Programs

Some of the key roles and values of large-scale long-term monitoring can only be realized if monitoring programs are well designed, implemented, and maintained. A detailed exploration of the many aspects of monitoring design and implementation is beyond the scope of this short review. We refer readers to the substantial (and rapidly expanding) literature on the design of monitoring programs (e.g., [3, 4•, 61–65]). Good design includes consideration of many issues such as (1) framing good questions to be answered and robust hypotheses to be tested. (2) Ensuring the design can actually answer the questions being posed. Particular attention to design may be necessary where multiple drivers underpin environmental change and these drivers can interact (see [66]). (3) Having sufficient power (e.g., enough survey sites) to be confident that the trends identified are real and not an artefact of small sample size [67]. (4) Where there is a management intervention, having a design that encompasses surveys of areas before that intervention occurs, after the intervention, and where there is no intervention (a control). This is sometimes termed a before-after-control-impact (BACI) design [68]. Where a BACI design is not possible to implement (e.g., as it is unethical and dangerous to light a high severity wildfire), other kinds of studies such as quasi-experimental or observational study designs (sensu [69•]) can be used to guide monitoring programs. These studies will often lack some of the design features of true experiments such as true controls and randomized allocation of sites to treatments (see [69•]). On this basis, it is important to be aware of the limitations of these designs, like the reduced potential for inference and assignment of causality. Also, (5) ensuring temporal consistency in data collection methods (such as rigorous field protocols) to ensure that changes in ecosystem condition or population trends in a species are not confounded with measurement protocols [8••].

There is also a need to be mindful of other kinds of confounding in the design of monitoring programs. An example is the confounding which can occur between disturbance and site productivity, with a marked influence on biodiversity. This can manifest in studies of forests, where species may be more abundant in areas of high productivity, but lower where logging occurs. However, logging often occurs in more productive parts of forest landscapes. Logging often occurs in areas with flat terrain, with high inherent levels of soil nutrients and which support rapid rates of tree growth. In contrast, steep and rocky areas with low-nutrient, shallow soils may be spared from timber harvesting. Subsequently, a comparison of monitoring data from logged and unlogged areas may show limited difference in animal abundance between them, but there would likely have been fundamental differences in animal populations between areas even in the absence of logging. Therefore, a conclusion of no logging effects would be naïve and ecologically incorrect as logging of productive areas may have reduced abundance to the same (lower) levels as in unproductive, unlogged forest. Resolution of this problem would require a design that includes all combinations of site types: high productivity logged areas, high productivity unlogged areas, low productivity logged areas, and low productivity unlogged areas.

The importance of good design in large-scale, long-term monitoring programs has sometimes been overlooked. This is especially true more recently as new technologies like satellite imagery and continuous remote data recorders allow for the rapid collection of large datasets with limited human effort and without data collection being guided by good design. While the resulting "big data" from such an approach can be important, large volumes of information do not necessarily correspond to good knowledge and the ability to answer key questions of management and conservation significance [70•]. This was illustrated in the case of large unstructured datasets on Australian birds collected primarily by citizen scientists. Sadly, a lack of consistency in measurement protocols meant the data were not analogous to robust time series data typical of well-designed long-term monitoring programs [70•]. Nevertheless, the collection of big data will continue and we suggest it is critical to align their collection with other kinds of long-term monitoring such as on-the-ground measurements. This can help test the spatial accuracy of, for example, remotely sensed imagery and help correct errors from ground-truthing. There are also entities that cannot be reliably monitored using remotely sensed imagery (such as counts of individual animal species) and tailored on-the-ground monitoring will often be needed for them. Finally, there can be important synergies from multiple kinds of datasets. For example, satellite data on native vegetation cover has been used as a key predictor of long-term patterns of occupancy of temperate woodland patches by native birds in Australian agricultural landscapes. This highlights the value of the integration of time series information from remotely sensed imagery with time-series data on patch occupancy by woodland birds [31].

Key Considerations in Maintaining Large-Scale, Long-Term Monitoring

Appropriate levels of funding for the environment and biodiversity are critical to ensure that robust monitoring programs can be established and then maintained. Many nations clearly underperform in levels of both short-term and the longer-term investment required to support adequate long-term, large-scale monitoring [29•, 71]. Which agencies should be responsible for funding to support long-term monitoring is likely to vary according to the problem being addressed and particular circumstances such as the questions being asked, the species or ecosystem being monitoring, the range of stakeholders involved, and a range of other factors. In some cases, responsibility may lie with governments to the meet the requirements set out under initiatives like national environmental and biodiversity reporting. In other cases, a particular non-government organization may need to maintain a monitoring program such as when a private conservation landholder undertakes an animal reintroduction on their property. In other cases, a suite of funders and monitoring participants may be involved to bring appropriate levels of expertise and sufficient amounts of funding to a monitoring program to maximize the chances of it succeeding.

Some jurisdictions have had some success in securing long-term funding for large-scale monitoring programs, such as the Long Term Ecological Research (LTER) network in the USA, although much of the work under this initiative is focused on co-located long-term research, as opposed to targeted ecosystem and species monitoring. However, LTER networks have been lost in some other locations such as in Australia which lost a raft of long-term monitoring programs in 2017 [72]. In this case, supporting agencies failed to realize that monitoring networks are a critical part of the environmental infrastructure of a nation, just as railways and roads are part of the built infrastructure. We recommend leaders of existing long-term monitoring programs implement strategies for "mothballing" programs in case they are defunded, so that they can be restarted if financial support again becomes available. Good mothballing includes attention to data curation, management, and description so that it is accessible to others in a position to recommence a monitoring program.

It is possible that support for monitoring programs may be more forthcoming if monitoring data are recognized as pivotal to mandatory reporting initiatives, both at international levels (such as the Convention on Biological Diversity) and national and other levels (e.g., the Endangered Species Act in the USA and the State of Environment Reports in Australia). "Article 7 of the Convention on Biological Diversity requires parties to identify and monitor important ecosystems, species and genetic components of biological diversity, as well as processes and activities that have, or are likely to have, significant adverse impacts on biological diversity." In further examples, agricultural sustainability initiatives in Australia's red meat livestock industry such as the Beef Sustainability Framework (https://www.sustainableaustralianbeef.com.au/) and the Sheep Sustainability Framework (https://www.sheepsustainabilityframework.com.au/) have a suite of key biodiversity and ecosystem indicators. Long-term monitoring data, including on-the-ground biodiversity monitoring data, will be essential for these kinds of frameworks to be more than expensive marketing exercises and have any credibility with stakeholders including farmers, environmental groups, and trading partners. In the Australian State of New South Wales, the government has commenced the development of a new scorecard system for its national parks (https://www.environment.nsw.gov.au/topics/parks-reserves-and-protected-areas/park-management/national-park-performance-scorecards). The scorecards aim to document the status of key elements of biodiversity and the condition of target ecosystems within a given national park and will be underpinned by robust long-term, park-wide monitoring programs.

The value of data from monitoring, and hence the value of monitoring per se, also might be better recognized and hence appropriately funded, if they were part of natural capital initiatives such as the framework for the System of Environmental and Economic Accounting [59]. This is because such frameworks allow policy-makers to determine where lies the best return on investment in, and management of, natural capital. As an example, environmental accounts developed for the African nation of Botswana showed that the economic and social value of water for native wildlife (and hence ecotourism) far exceeded the value of water for agriculture and this, in turn, strongly influenced policies on water allocation [59].

Finally, support for long-term monitoring programs might be more likely to be maintained where it can be demonstrated that such efforts are cost-effective and therefore delivering good return on investment. For example, it has been estimated that approximately 10% of the budget of large environmental management initiatives should be dedicated to monitoring in order for it to be possible to determine if such initiatives have been both ecologically effective and cost-effective [8••]. Cost-effectiveness was a fundamental part of the long-term monitoring program designed in part to appraise the weed control program in Booderee National Park in south-eastern Australia. The work focused in the cost-effectiveness and ecologically effectiveness of treatments to both check the spread of invasive plant species like Bitou Bush (*Chrysanthemoides monilifera* subsp. *rotundata*) and have limited impacts on non-target animal species, including species of conservation concern [45, 46].

Concluding Comments

Large-scale, long-term monitoring has many key roles in landscape ecology and conservation biology. Seven of the most important ones are as follows: (1) documenting responses to environmental change; (2) answering key ecological questions; (3) testing existing ecological theory and developing new theory; (4) quantifying the effectiveness of management interventions; (5) informing environmental prediction systems; (6) engaging citizen scientists and the general public; (7) contributing data and other insights to environmental initiatives. Some of these key roles can only be realized if a monitoring program is well designed, implemented, and maintained. Securing long-term funding may be more likely where monitoring data are used in mandatory reporting on environmental conditions or on biodiversity.

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