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Making monitoring meaningful

SCOTT A. FIELD,[1] PATRICK J. O'CONNOR,[2]* ANDREW J. TYRE[3] AND HUGH P. POSSINGHAM[4]

[1]*Department of International and Area Studies, University of California, Berkeley, California,* [3]*School of Natural Resource Sciences, University of Nebraska-Lincoln, Lincoln, Nevada, USA;* [2]*School of Earth and Environmental Sciences, University of Adelaide, Adelaide, SA 5005, Australia (Email: patrick.oconnor@adelaide.edu.au), and* [4]*The Ecology Centre, University of Queensland, St Lucia, Queensland, Australia*

Abstract Conservation monitoring in Australia has assumed increasing importance in recent years, as societal pressure to actively manage environmental problems has risen. More resources than ever before are being channelled to the task of documenting environmental change. Yet the field remains crippled by a pervasive lack of rigour in analysing, reporting and responding to the results of data collected. Millions of dollars are currently being wasted on monitoring programmes that have no realistic chance of detecting changes in the variables of interest. This is partly because detecting change in ecological systems is a genuinely difficult technical and logistical challenge. However, the failure to plan, fund and execute sophisticated analyses of monitoring data and then to use the results to improve monitoring methods, can also be attributed to the failure of professional ecologists, conservation practitioners and bureaucrats to work effectively together. In this paper, we offer constructive advice about how all parties involved can help to change this situation. We use three case studies of recent monitoring projects from our own experience to illustrate ways in which the disconnect between science and bureaucracy can be bridged and some obstacles to collecting and analysing ecologically meaningful data sets can be overcome. We urge a continuing discussion on this issue and hope to stimulate a change in the culture of conservation monitoring in Australia.

Key words: conservation, management, sampling design, statistical analysis, statistical power.

INTRODUCTION

As the science of conservation biology matures, its focus is naturally moving towards applying its newly developed principles to the task of actively managing and restoring landscapes. In this respect, Australia is an intensive laboratory; its temperate woodlands, grasslands and freshwater systems have been massively degraded since European settlement, and tens of millions of dollars each year are now being directed at rehabilitating many regions in its southern agricultural zone. Starting with the Natural Heritage Trust (NHT) in 1997 and continuing with the National Action Plan for Salinity and Water Quality (NAP), more than $3.7 billion of investment from the Australian Government (with approximately equal investment from State Governments) has now been committed to programmes aimed at environmental restoration. This large amount of investment through only a few programmes provides one of the world's most promising opportunities for gathering knowledge about the efficacy of different management strategies and the utility or otherwise of the principles of conservation biology.

Ecological monitoring is an indispensable tool for capitalizing on this opportunity. Without rigorously quantifying the state of a system before and after a management intervention, we are left unable either to defend the decision to intervene, or to assess the efficacy of the action. Therefore, when the dust settles on the current flurry of management activity, we may find ourselves in an invidious position unless we can draw on effective monitoring data to demonstrate what has been achieved through our successes and learned through our failures. This points to the importance of not only implementing conservation management actions, but also purposefully working towards the ability to report on their outcomes. Thus far we have been faced only with the 'what happened to the money?' question. Some years down the track, however, it is likely to be followed by the more difficult, searching enquiry 'what good did it do?'.

If that question were to be asked today, we would have very little to report. The first phase of the NHT devoted scant resources to monitoring, emphasizing a multitude of small-scale uncoordinated on-ground actions, to the near-exclusion of setting up frameworks

*Corresponding author.
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for tracking and assessing the results of those actions. This emphasis has changed somewhat in the NAP and the second phase of the NHT, with the development of the National Natural Resource Management (NRM) Standards and Targets Framework and the National NRM Monitoring and Evaluation Framework providing for increased investment in the evaluation of outcomes from management interventions. However, current monitoring efforts still fall far short of what is required to rigorously document ecological change. If such policy-driven schemes fail to create targeted monitoring designs adequate to the task, the result may actually be worse than not monitoring at all. Not trying to document the effects of management is bad enough; but trying and failing under an expensive and recognizably flawed framework is even worse.

In this paper we argue that this kind of failure in Australian monitoring is a looming problem for the conservation movement, and suggest some strategies by which it can be addressed. We sketch an outline of how monitoring is currently conducted, and identify problems of understanding, coordination and policy at the interface between researchers, conservation managers, bureaucrats and funding bodies. Using examples from our own experience with monitoring programmes in southern Australia, we illustrate ways in which monitoring can be made more robust, cost-efficient and likely to achieve its purpose. Although we focus on Australian examples, the problem is common throughout the rest of the world. Large agri-environment schemes spend billions of dollars in Europe and North America, and recent efforts to document their efficacy have been patchy and produced mixed results (e.g. Kleijn *et al.* 2006). Our point is not that monitoring can be made perfect, for we recognize that ecological monitoring presents genuinely daunting technical challenges. Rather, we argue that the tools and expertise are available to execute it much more effectively than is done at present, and that the natural resource management community will face a crisis of credibility unless its culture changes soon.

WHY MONITORING FAILS

Several authors have recently enumerated the key criteria a monitoring programme must meet if it is to be worthwhile (see Legg and Nagy (2006), boxes 1–3 and references therein). Rather than reproduce a detailed list here, we focus on general problems with monitoring grouped under three broad headings: (i) funding; (ii) objectives; and (iii) sampling design. In what follows, we do not aim to provide a comprehensive discussion of technical details, as entire textbooks have been devoted to the subject and numerous recent reviews have covered the area (Wilson 1996; Thompson 1998; Yoccoz *et al.* 2001; Pollock *et al.* 2002; Williams *et al.* 2002). Rather, we concentrate on a few key practical issues that we consider both critical and under-appreciated in monitoring in Australia, and which should be within the capabilities of practitioners to address as they embark on a monitoring programme.

Funding

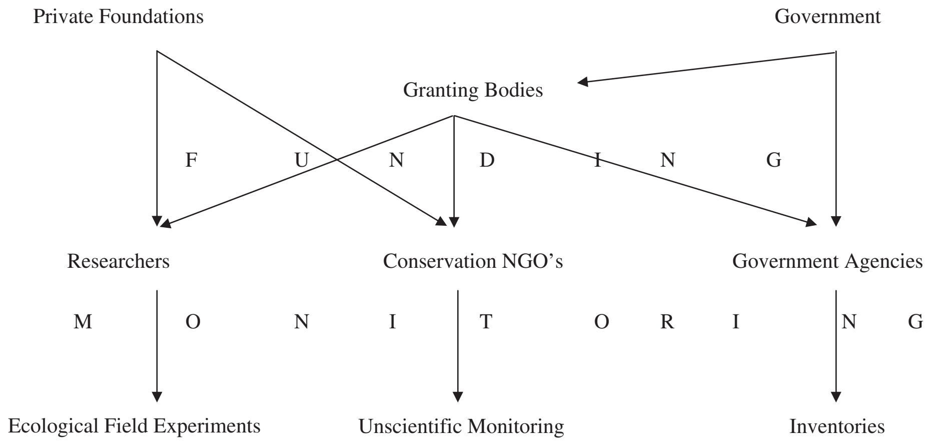
In terms of funding, the commitment needs to be sufficiently long-term to allow a change to be detected over and above the natural temporal fluctuations in the system in question. The time period required will of course vary among study systems, but we would suggest there exist few ecological variables likely to show significant change in less than 5 years, and that 10 years is a sensible minimum target for most ecological monitoring programmes. Note that these time periods can be estimated more rigorously using statistical power calculations based on preliminary data, as discussed and illustrated in the next section.

Objectives

By definition, a monitoring programme cannot possibly succeed without a clear articulation of what success would mean. This entails choosing a suitable variable(s) to represent the change of interest, and specifying what degree of change (effect size, in statistical jargon) would be considered sufficient to trigger a management response.

Sampling design

Having clearly defined the change of interest, the most fundamental requirement of the sampling design is that it should be capable of detecting that change if it actually occurs, that is, that it will yield adequate statistical power. As illustrated below, this entails not only obtaining a sufficient sample size in relation to the variability inherent in the system, but also setting an ecologically appropriate level of power as a target. Another neglected issue in sampling design is that it should be approached with learning and improvement explicitly in mind, that is, it should be experimental and adaptive to the greatest extent possible. Early results should be analysed promptly and, if they point to deficiencies, used to refine the sampling regime so that it becomes progressively more efficient. The early years of data can also be used to predict how the level of statistical power will change over time, and thus estimate the duration over which the monitoring must be maintained in order to yield a meaningful result.



	Ecological Field Experiments	Unscientific Monitoring	Inventories
Funding	Short- to medium-term, often associated with terms of student projects or grants, discontinued after 3-4 years	Short- to medium-term, discontinued due to lack of interest and focus on activities designed to attract and retain volunteers.	Short- to medium-term, often in response to short-lived political pressures. If long-term, unlikely to be sufficiently spatially and temporally replicated for meaningful analysis.
Objectives and Design	Aim to collect information on specific ecological characteristics of target organisms. Adhere to rigorous scientific design, but abundance and distribution usually measured incidentally and thus unlikely to yield high statistical power.	Aim to gather 'snapshot' inventories of particular locations of interest to volunteers, or which support specific campaign objectives. Usually lack rigorous scientific design and produce datasets that are unusable or with low statistical power.	Aim to gather 'snapshot' inventories of particular locations to meet minimum statutory requirements. Usually lack rigorous scientific design and produce datasets that are unusable or have low statistical power.
Data Quality and Uses	Medium to high quality data, but rarely sufficiently long-term to permit demonstration of trends. Held in personal archives, requiring permission and modification before being effectively used.	Poor to medium quality data, unlikely to be systematically archived except by largest and best-funded organizations. Usually used only in support of specific short-term campaign objectives.	Poor to medium quality data, systematically archived but usually inaccessible to outsiders and rarely used for rigorous analysis to support management decisions.

Fig. 1. Schematic representation of approaches to monitoring by different actors in Australia.

Our experience of how monitoring is carried out in Australia reveals numerous ways in which it fails to address these basic requirements (Fig. 1). We identify three broad sectors involved in monitoring: researchers in academic institutions, conservation non-governmental organizations and community groups and government agencies. Funding is disbursed to these groups either from private conservation foundations, or from the government, either directly through government agencies, or indirectly through granting bodies that may provide funds to any of the three groups. Each of the groups has different objectives and constraints in collecting ecological data, but they are all afflicted with the same deficiencies that undermine effective monitoring: failure to secure long-term funding; failure to achieve programme designs that yield high statistical power; and failure to analyse or make available high-quality data that can be used to inform conservation management decisions (Fig. 1).

SOME WAYS TO MAKE MONITORING MORE USEFUL

As mentioned above, there are numerous criteria that have been advanced as essential components of a rigorous monitoring programme. Our aim in this section is not to provide exhaustive technical advice on all criteria; rather we offer three practical examples that illustrate some general principles which, if applied, would go some way towards improving the quality of monitoring data and facilitate its use in decision making.

Trade-off statistical significance in return for statistical power

Obtaining adequate statistical power is the cornerstone of any rigorous monitoring programme, for without it the effect of interest (e.g. population decline, increase in pollution) is likely to pass unnoticed. The question of what is 'adequate' power has traditionally been settled by adherence to the 'five-eighty' convention (Di Stefano 2003), in which statistical significance (Type I error rate, α) is fixed at 5% and statistical power considered adequate if it reaches 80% (Type II error rate, β, of 20%). However, as numerous authors have pointed out (Gray 1990; Peterman 1990; Mapstone 1995; Dayton 2001; Di Stefano 2003; Field *et al.* 2004), this places the 'burden of proof' disproportionately on those trying to demonstrate environmental change. It thus undermines a fundamental aim of ecological monitoring, which is to ensure that real change is detected and acted upon as promptly as possible. Therefore, rather than simply trying (often in vain) to increase power by expanding sample size or reducing variability in the

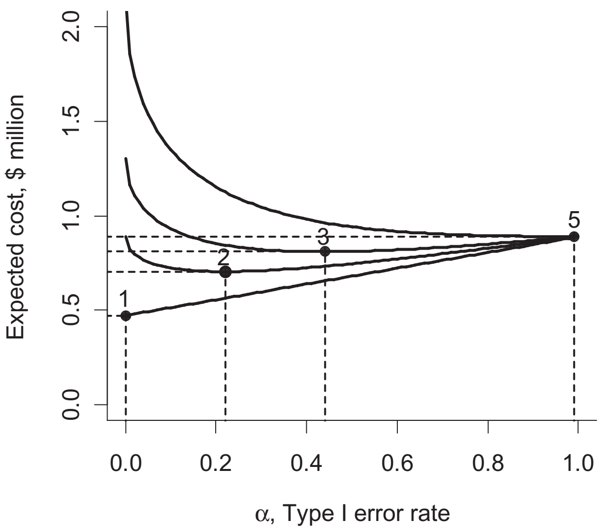


Fig. 2. Expected cost ($ million) of monitoring and management of Coffs Harbour koalas as a function of Type I error rate, α. Intersection of dashed horizontal and vertical lines with curves indicate the expected costs at $\alpha = 0.05$ and at the cost function minimum of $\alpha = 1$.

data, greater power can also be obtained by relaxing the significance level above the conventional 5% level. There is nothing sacred about the 5% significance level; it has no theoretical justification in either statistics or ecology, so abandoning it in order to increase the efficacy of monitoring is entirely legitimate. This message has been around in the scientific literature for decades and it is high time that it be acted upon.

Assuming this is done, the question remains of exactly where levels of significance and power should be set. One straightforward and practical answer is to set the two error rates according to the relative costs of making those errors. This idea was originally put forward by Mapstone (1995), who suggested that the ratio of Type I and Type II errors should equal the ratio of their costs. The notion has recently been elaborated by Field *et al.* (2005a), who derived a cost function that minimized the total cost of the two kinds of errors combined. Although we would argue that the latter formulation is strictly more correct, our analyses suggest that in practice the statistical thresholds derived from either method usually will be quite similar (S. Field *et al.*, unpubl. data 2005).

Analysis of the cost function approach provided three general conclusions about how to balance power and significance (Field *et al.* 2004). First, if the cost of Type II errors is five times or more greater than that of Type I errors, the optimum α level rose to one (Fig. 2); in other words, it simply is not worth monitoring at all, and recovery action should be implemented forthwith. Second, for cost ratios less than 5:1, the optimal α gradually declines towards zero, but for a ratio of 2:1 it is still 0.2, much higher than the conventional 0.05 level (Fig. 2). Third, the stronger the *a priori* expectation that a decline is taking place, the more α should be relaxed, and the greater the cost savings thus obtained (Fig. 2). In sum, for species of high conservation value, there are very few circumstances when conventional statistical thresholds should be used, and some circumstances when money spent on monitoring would simply be better used elsewhere.

Note that using this approach assumes the availability of data on the costs of Type I and Type II errors. In the absence of such information, the most defensible approach is simply to set the two errors equal to one another. This can be achieved using the iterative process described by Mapstone (1995), which involves selecting an arbitrary α, calculating β, then repeatedly changing α and recalculating β until the two are equalized.

Estimate how long would be required to obtain adequate statistical power

Perhaps the most obvious and widely known method of increasing statistical power is simply to increase the sample size. In long-term monitoring studies, this can correspond to extending monitoring over a longer period. We suggest that it can be very useful to all concerned – researchers, managers and funding agencies – to know in advance how rapidly statistical power is likely to increase over time, and thus exactly how long-term an investment will be required in order to achieve the objective of the programme. Therefore, an assessment of the future trajectory of statistical power should be built into the early stages of any monitoring programme.

As an illustration, we calculated the trajectory of statistical power for a number of woodland bird species currently being monitored in the Mt Lofty Ranges, South Australia. Using a simulation method explained in Field *et al.* (2005a), we used the first 5 years of monitoring data to calculate how power would change over the ensuing 5 years. We set our objective as being able to detect a change of conservation status from Least Concern to Vulnerable, as stipulated by the IUCN rule A2 (decline of 30% over 10 years). Species power trajectories varied according to their initial occupancy (proportion of 159 sample sites occupied) and detectability (probability of detecting the species if resident at the site). Statistical significance was set at 0.1 and power was calculated by simulating a linear decline. In the absence of cost data, we aimed to equalize α and β, that is, target $\beta = 0.1$, power = 0.9, as suggested above.

Results showed that despite most species starting with very low power (<0.5), by the tenth year four species had reached the target level of 0.9 (Fig. 3). Moreover, for some of the less prevalent and more

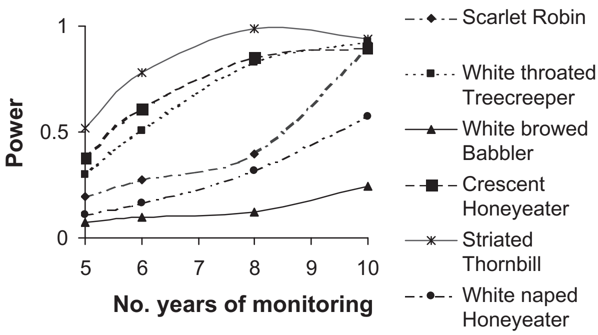


Fig. 3. Statistical power to detect changes in conservation status of varies species of woodland bird in the Mt Lofty Ranges, South Australia, as a function of the time spent monitoring.

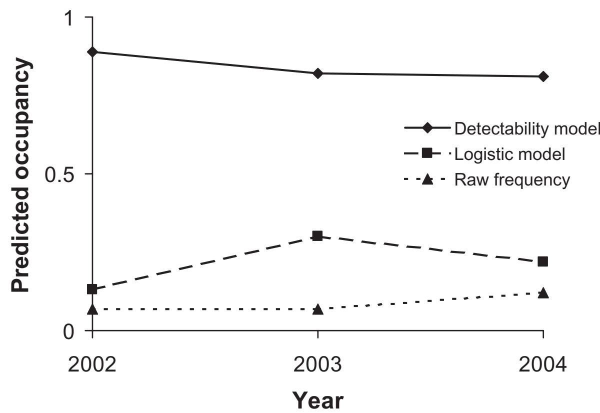


Fig. 4. Fox occupancy levels in the district of Elliston on the Eyre Peninsula, South Australia: (i) raw data (number of observations/total number of km); (ii) predicted occupancy from a standard logistic regression model; and (iii) predicted occupancy from more sophisticated model including variations in detectability.

difficult to detect species, like the scarlet robin and white-naped honeyeater, power started to rise more rapidly as time went by. This underscores the value of combining a long-term commitment with prompt data analysis and projection of power calculations into the future. In the case of the scarlet robin, the dismal power result after 5 years (0.2) or 8 years (0.4), if taken alone, would provide little incentive for further investment in the programme. However, the promise of obtaining a much-improved return for just a few years of continued monitoring could provide a powerful means of leveraging further financial support. It also highlights the fact that some species, like the white-browed babbler, will take so long to properly assess using this method that they might be best evaluated using more intensive targeted surveys.

This analysis clearly demonstrates that up to 5 years of monitoring, there would be little chance of detecting changes of interest and consequently little increased confidence in resultant management decisions. But stopping the monitoring programme at this point, before adequate levels of power have been reached, would unnecessarily waste all the monitoring effort and resources invested up until that point. The ability to forecast future gains in statistical power is crucial to making a sensible decision about whether or not to continue investing in the programme.

Analyse data promptly and use it to refine the monitoring design

Perhaps the most urgently needed cultural change in the approach to monitoring is in the direction of subjecting data to rigorous analysis at the first available opportunity. As in the example above, the results can be used to estimate the *quantity* of data required before meaningful conclusions can be reached, but they can also be used to improve the *quality* of data collected in the future. An explicitly experimental, or adaptive, approach to monitoring can be taken in which successive analyses are used to iteratively improve the power of the data set.

For example, Field *et al.* (2005b) analysed data from the initial 3 years of a fox control programme on the Eyre Peninsula, South Australia. By applying an occupancy model that accounted for detectability, they obtained tentative evidence for a population decline, which was not at all evident from simple analysis methods typically used by practitioners such as plotting the raw data, or logistic regression (Fig. 4). Furthermore, the patterns of detectability obtained suggested that power might be improved by consolidating survey effort in certain areas (away from roadside vegetation) and times of year (the non-cropping season). Theoretical analyses suggest that in cases such as this, where detectability is extremely low (<18%), large numbers of repeat visits are necessary in order to optimize statistical power (Field *et al.* 2005a; MacKenzie & Royle 2005). The iterative reorganization of survey effort suggested by the analysis could facilitate such an increase in survey efficiency, a critical issue when budgets are tight, as in most monitoring studies.

CONCLUSION

In this paper we have argued that a more rigorous approach to ecological monitoring in Australia is urgently needed, outlined some reasons why the current system is inadequate, and suggested some ways in which the field can be improved. We have deliberately avoided a 'laundry list' of technical 'dos' and 'don'ts' in monitoring, as we think the technical requirements are basically available and it is more a cultural change that is required. In particular, forming the habits of promptly, rigorously analysing data and using the results to both leverage further funding and inform future sampling are critical. The illusion of productivity created by the accumulation of essentially useless data has passed as acceptable up to date, but we expect that it will not remain unchallenged indefinitely.

A common objection to the kinds of suggestions we have made here is that they are impractical, because of the high degree of technical difficulty of the analysis methods. While we agree that the models we have used in our examples may exceed the capacities of those usually carrying out the monitoring, we firmly reject this as a reason for continuing to apply simple, less informative methods to monitoring data. Ecological monitoring presents an array of genuinely difficult analytical challenges, and progress toward making it more meaningful will only be made by confronting these challenges head-on. This is not to say that all conservation managers and field researchers must become experts in quantitative analysis. As Witmer (2005) points out, managers are already faced with a formidable set of logistical challenges in simply setting up a programme and keeping the data flowing. Often armed with no more than a working knowledge of undergraduate statistics, it is indeed unreasonable to expect them to stay abreast of the most advanced techniques in quantitative ecology, let alone to apply them to their data sets at regular intervals.

Instead, what we advocate is the explicit cultivation of more collaborative relationships among researchers, conservation managers and bureaucrats. At present these three groups, who are all crucial to the success of monitoring, work in largely separate professional worlds, strive towards different goals and are rewarded in different currencies. Researchers are under constant pressure to develop novel ideas and convert them into technical publications that are unlikely to be read or comprehended by managers and bureaucrats. Managers are typically swamped by the logistical concerns of designing and implementing programmes and don't have the luxury of spending the long hours delving into the fine details of analysis, let alone the communication of discoveries. Bureaucrats must respond to the capricious demands of their political masters, including the management of project funding and reporting processes, which may have little or nothing to do with sound ecological analysis. Under this organizational framework, those whose cooperation is most critical to making monitoring work are largely cut off from one another's ideas, opinions, goals and terminologies. Amidst this culture of insularity, opportunities for ecologically meaningful monitoring continually slip between the cracks.

In our opinion, building the collaborative relationships necessary for effective monitoring requires the emergence of a new breed of environmental professional capable of bridging the gaps described above. What is required is individuals with a sound grasp of the critical components of effective monitoring, the ability to identify in which sectors of the professional community the relevant skill sets lie, the entrepreneurial wherewithal to initiate projects that bring the different parties together and the diplomatic aplomb to cajole them into collaborating effectively. Such individuals need not be expert quantitative ecologists, but they do need to have conquered the pervasive fear of confronting statistics that tends to paralyse non-specialists and to have mastered the art of extracting practical advice from ivory-tower academics. They need to be cognizant of the logistical constraints besieging managers, but also adept at telling the difference between core project activities and mere displacement behaviour designed to create the illusion of productivity. Finally, they need to be realistic about working within the constraints set by the political pressures of the day, but not afraid to confront timid bureaucrats suffering from a congenital fear of taking responsibility.

Moreover, such monitoring professionals need to be supported by the development of a robust institutional environment that facilitates the difficult work of rigorously documenting environmental change. It is difficult to see the cultural changes we advocate being realized in the absence of dedicated collaborative institutes that act both as a forum for dialogue among monitoring stakeholders on setting appropriate objectives, and a source of expertise and the technical capacities required to achieve them. The formation of such institutes in turn depends on securing a long-term commitment from all those involved in monitoring to work together on a common agenda. Given the current disparities in professional goals and cultures we have outlined, this promises to be no small task. But unless and until it happens, the critical task of monitoring will continue to be the largely disjointed, sporadic and ineffectual activity that it is today. Investing the substantial human and financial resources required to get collaborative centres off the ground would be the surest sign that decision makers were serious about addressing the problem.

In closing, we believe that the issue of how to achieve meaningful ecological monitoring can no longer be swept under the carpet. A vigorous dialogue among researchers, conservation groups and government agencies is needed. How to reach the goal of properly funding, designing and analysing ecological monitoring studies is a difficult question requiring sustained attention, input and a commitment to mutual understanding from all parties involved. It will require a significant change in the culture and institutional design of environmental management in Australia, aimed at creating a new generation of crossdisciplinary professionals capable of harnessing the best information and analysis that science, government, business and the community have to offer.

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