Forest Monitoring

Bridging the gap between data capture and decision-making

A survey of forest managers

prepared for the New South Wales Natural Resources Commission

by Terry Walshe, Kelly de Bie, Libby Rumpff, and Brendan Wintle.

School of Biosciences

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EXECUTIVE SUMMARY

The headline findings of the survey described in this report are:

- Formal adaptive management is broadly supported among NSW forest managers, but also poses the greatest number of challenges in its implementation.
- Status and trend monitoring poses relatively few problems in implementation, but provides a weak basis for bridging the gap between data capture and decision-making.
- Irrespective of what approach to monitoring and decision making is adopted, there is general concern that resourcing and organisational commitment to long term monitoring may be inadequate.

The report concludes with a set of recommendations for consideration by the Forest Monitoring and Improvement Program Steering Committee to better bridging the gap between data capture and decision-making. Specifically:

1. Improvements that could be undertaken in the short term (next 12 months) to promote better use of data in decision-making:

    1.1. Align different monitoring approaches to different decision settings and embark on pilot applications of evidence-based decision support (see Box 1 for a suggested starting point).

    1.2. Co-invest in measures to overcome technical barriers and difficulties. Specifically, recruit competent quantitative modellers with a solid understanding of forest management and if possible, make their skills available across organisations.

    1.3. Establish administrative mechanisms to encourage long term resourcing of monitoring.

2. Improvements that will require a longer-term commitment:

    2.1. Introduce decision thresholds *into status and trend* and *adaptive management applications* incrementally, via co-ordinated and continuous review of monitoring data and structured debate and discussion of values and trade-offs.

    2.2. Initiate long term monitoring of society's views of values and trade-offs as a basis for broadening and informing debate around trade-offs and their implications for evidence-based decision-making. The focus of this monitoring effort would be informed by the subset of applications identified in recommendation 2.1.

BACKGROUND

This report describes outcomes of a survey designed to identify opportunities to improve how existing NSW agency monitoring, evaluation and research data programs can better inform adaptive forest management and decision making for ecologically sustainable forest management. Its focus is determining what can be done to improve prospects for bridging the gap between data capture and adaptive decision-making.

Within the Program Framework of the NSW Forest Monitoring and Improvement Program (FMIP) this project sits under *Aim 4 Employ cost-effective mechanisms*, directly addressing the deliverable, *identify opportunities to improve how existing NSW agency monitoring, evaluation and research data programs can better inform adaptive forest management in NSW*.[1]

APPROACH

Prior to the survey, a review of adaptive management in natural resource management settings was undertaken.

REVIEW

Formal adaptive management is not easy. There are very few examples of successful implementation, to the considerable frustration of scientists. Despite much enthusiasm about the idea, by far the most common form of monitoring is status and trend or non-targeted monitoring, where the motivations for data acquisition are vague and any analysis or review of the data are not formally embedded in organisational decision-making.

The challenges of implementing formal adaptive management and the deficiencies of non-targeted monitoring can lead to a bleak assessment: the purported benefits of monitoring are wildly overstated. This assessment is not shared by the authors of the review. Nor do we believe that a blanket insistence on overcoming the difficulties of implementing adaptive management is the answer. Our guess is that organisations are best served by carefully assessing the merits of different approaches to evidence-based decision-making. There will be settings where formal adaptive management is worth the fuss. And there will be other circumstances where the rigour and formalism of adaptive management may be out of place, and other ways of bringing evidence to the decision-making table may be a better fit. Our review seeks to inform those deliberations.

There is much potential for improvement, including those related to institutional arrangements, design and implementation, data management, and resourcing. We believe that with sufficient resourcing and organizational commitment, many of the technical challenges involved in design and implementation and data management can be overcome. Recent workshops held to progress the Forest Monitoring and Improvement Program indicate considerable technical capacity within and across agencies and organizations in NSW forest management. While these workshops focused on design elements for status and trend monitoring, it was noted more than once that there was a 'tension' between status and trend monitoring and monitoring for adaptive management. The review explores this tension and provides a basis for thinking about where adaptive management might be appropriate

[1] NSW Natural Resources Commission (2019). NSW Forest Monitoring and Improvement Program. Program Framework 2019 – 2024. ISBN: 978 1 925204 43 8

and where alternative approaches might be a better fit. It may be that status and trend is enough in some circumstances. Perhaps there are settings where *any* monitoring effort is a waste of resources. And perhaps, there are instances where formal adaptive management is worth pursuing.

The full review is available at Appendix 1.

SURVEY

The content of the review offered insights into why the explicit linking of data capture and decision-making via adaptive management can be difficult. It also sketched a coarse typology of different approaches to monitoring as a basis for subsequent exploration in the survey (Table 1).

The survey itself included two phases – (a) an online survey, and (b) a follow-up interview.

The online survey focussed on barriers and difficulties encountered in each of the different approaches to use of monitoring data to inform organisational decision-making. The interview phase focussed on improvements for better use of monitoring into the future, including how barriers and difficulties might be overcome. The questions posed in the online survey and interview are provided at Appendices 2 and 3, respectively.

In total, invitations to participate were sent to 41 staff across the following eight organisations:

- NSW Department of Primary Industries
- NSW Department of Planning, Industry and Environment
- NSW National Parks and Wildlife Service
- NSW Environment Protection Authority
- Forestry Corporation NSW
- NSW Crown Lands
- NSW Local Land Services
- Aboriginal Affairs NSW

Table 1. A coarse typology of alternative approaches to monitoring*.

Approach	Description
Formal adaptive management	Changes to management are made as evidence from monitoring accumulates. These changes have been pre-determined through a formal structured decision-making exercise. Thresholds for change are switch points in the merit of alternative actions or strategies based on probability weighted consequences and value-based positions on trade-offs.
Stakeholder driven	Targets or thresholds are set for key values and indicators based on some sense of what would be considered acceptable performance among stakeholders. It is unclear whether or not targets are feasible. Remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Model driven	Targets or thresholds are set for key values and indicators based on predictive modelling linking management and outcomes. Although success is not guaranteed, targets are considered feasible because they are set within the bounds of model uncertainty. Again, remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Status and trend	A set of indicators representing important values are monitored over time. No thresholds or targets are specified. Periodic reporting of monitoring results may or may not lead to changes in management.
No monitoring	No explicit attempt to learn about the performance of management through monitoring. Any change in management is based on piecemeal or anecdotal evidence.

*Note that the typology described in Table A7 of Appendix 1 is slightly different to that presented here. We sought to simplify the description of alternative approaches to make it more accessible to survey respondents who were unlikely to have the time to consider the full detail of the review and its content.

ONLINE SURVEY

The online survey comprised three parts. In Part A we asked about potential operational barriers to adopting each of the five approaches. In Part B we asked about knowledge gaps that might limit application of evidence-based decision making, irrespective of what approach is taken. Part C was an open-ended question, simply asking if there is anything at all participants wished to add. See Appendix 2 for details.

Of the pool of 41 invitees[2], we received 27 full responses to the online survey, a participation rate of 66%. Responses were anonymous so we are unable to report on participation across the eight organisations.

Results are presented below.

[2] The same pool of invitees was also used in the interview phase.

PART A

For each of the five different approaches to monitoring, Part A asked participants to rate a set of pre-identified difficulties or barriers. Respondents were also able to self-identify other barriers or difficulties. These self-identified factors are listed below Figures 1 – 5.

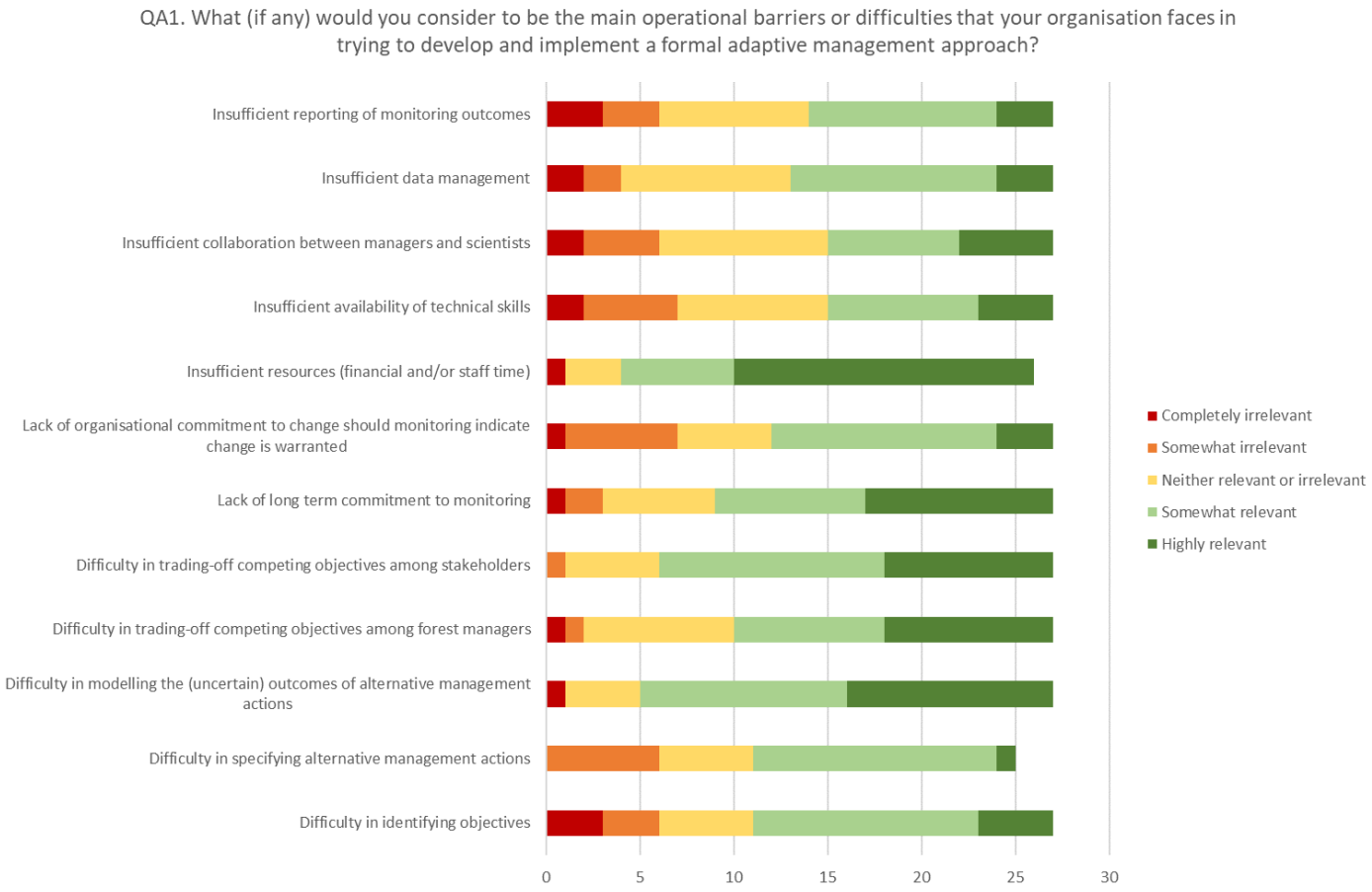

Figure 1. The perceived relevance of difficulties and barriers associated with **formal adaptive management,** rated by 27 survey participants**.**

Other barriers or difficulties of relevance to **formal adaptive management** identified by respondents:

- NSW does not have a formal or organised forest management or monitoring role
- challenges in comparison between different land types and tenures
- Engagement and confidence of private landholders with government programs
- Lack of a learning culture
- Lack of data collection to inform decision making
- Lack of government support for science based approaches to forest and park management affect all above.

- Lack of persistence and consistency and agreement on monitoring against forest management outcomes (e.g. varying focus and resourcing levels across agencies that have forest management as part of their remit)
- Long-term supply contracts

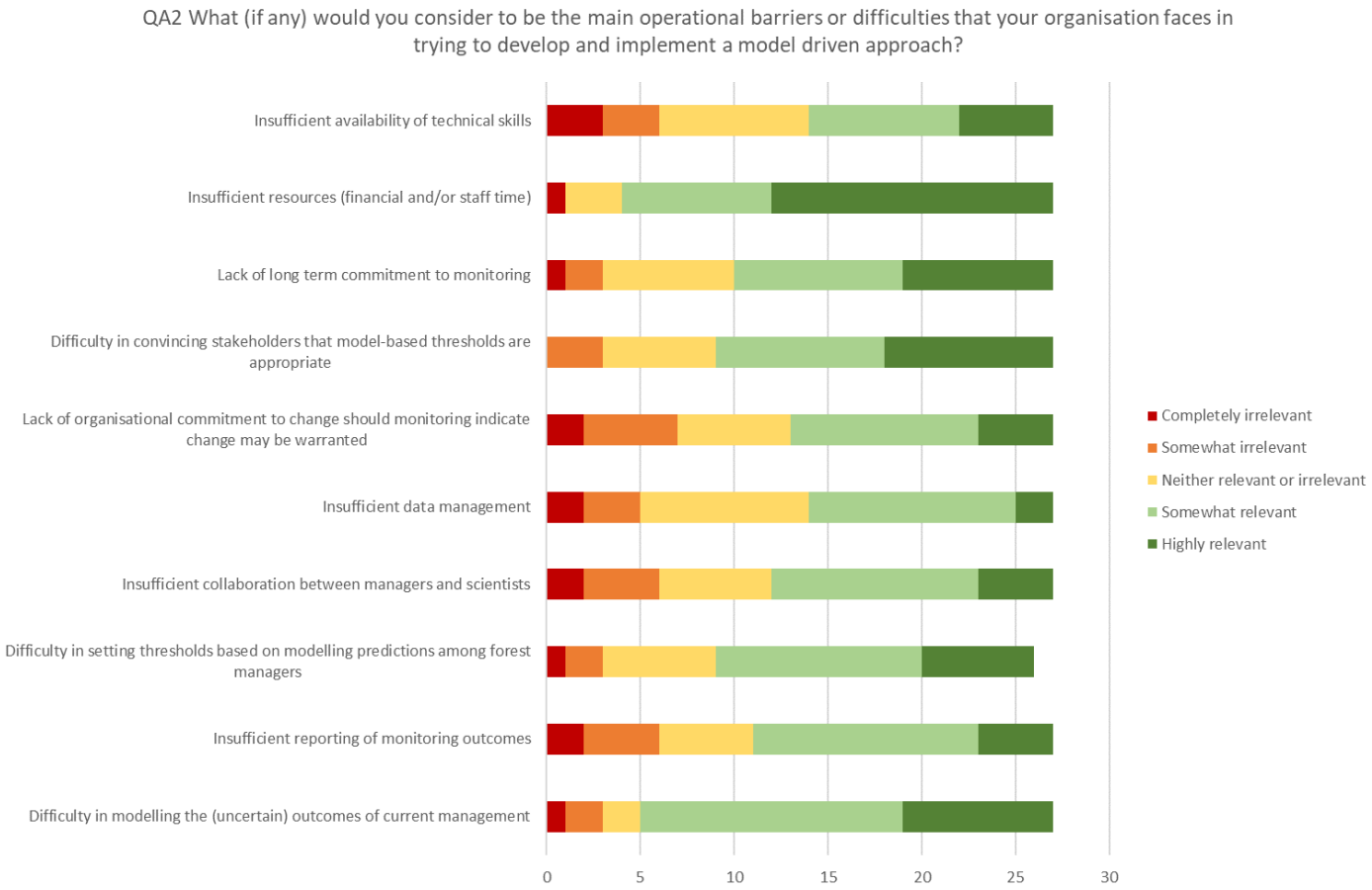

Figure 2. The perceived relevance of difficulties and barriers associated with **a model-driven approach,** rated by 27 survey participants**.**

Other barriers or difficulties of relevance to a **model-driven approach** identified by respondents:

- Engagement of private landholders with government monitoring programs
- Lack of government support for science based approaches to forest and park management affect all above.

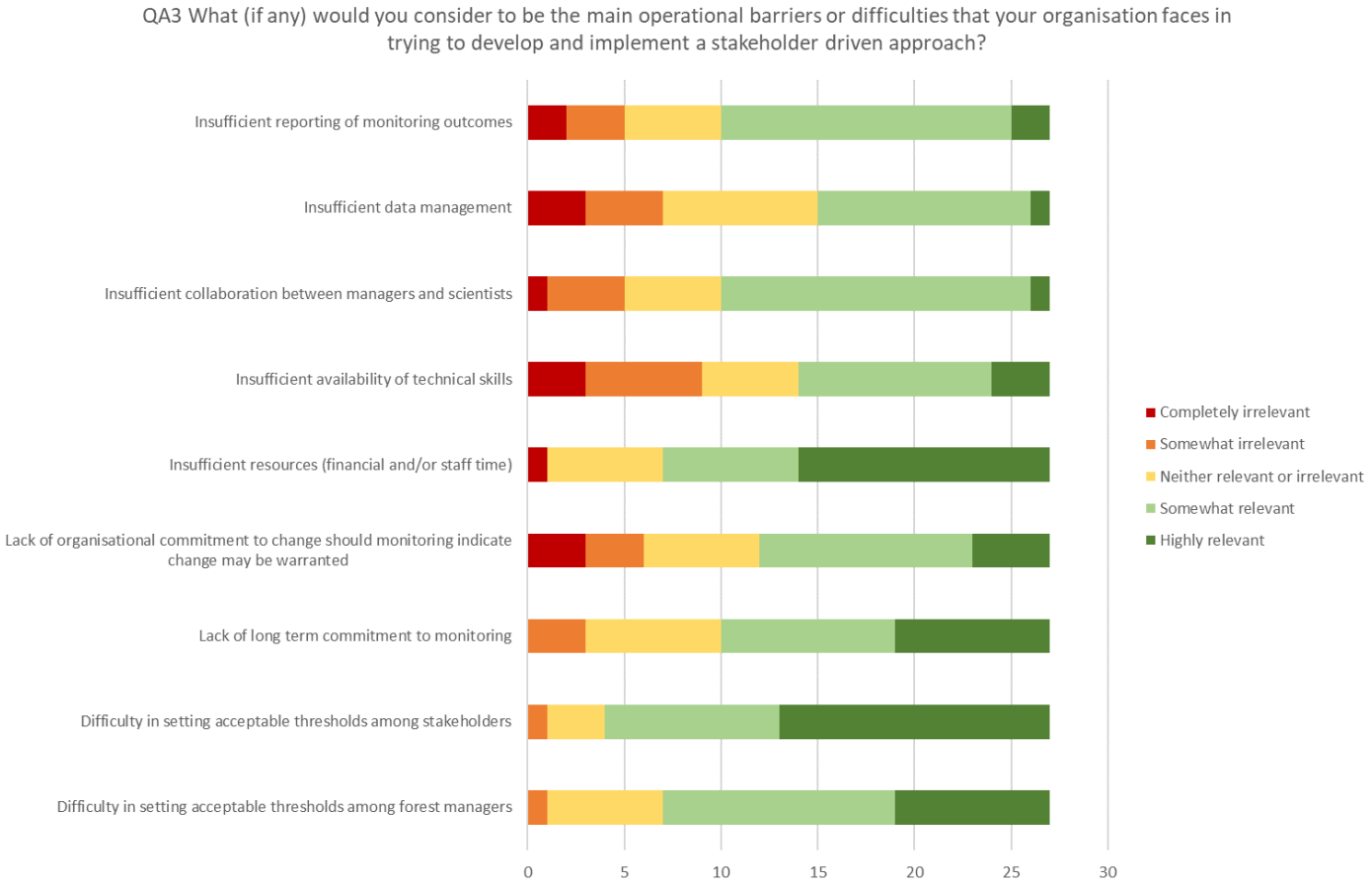

Figure 3. The perceived relevance of difficulties and barriers associated with **a stakeholder-driven approach,** rated by 27 survey participants**.**

Other barriers or difficulties of relevance to a **stakeholder-driven approach** identified by respondents:

- Engagement of private landholders with government monitoring programs
- Lack of government support for science based approaches to forest and park management affect all above.
- This stakeholder driven approach would be impossible

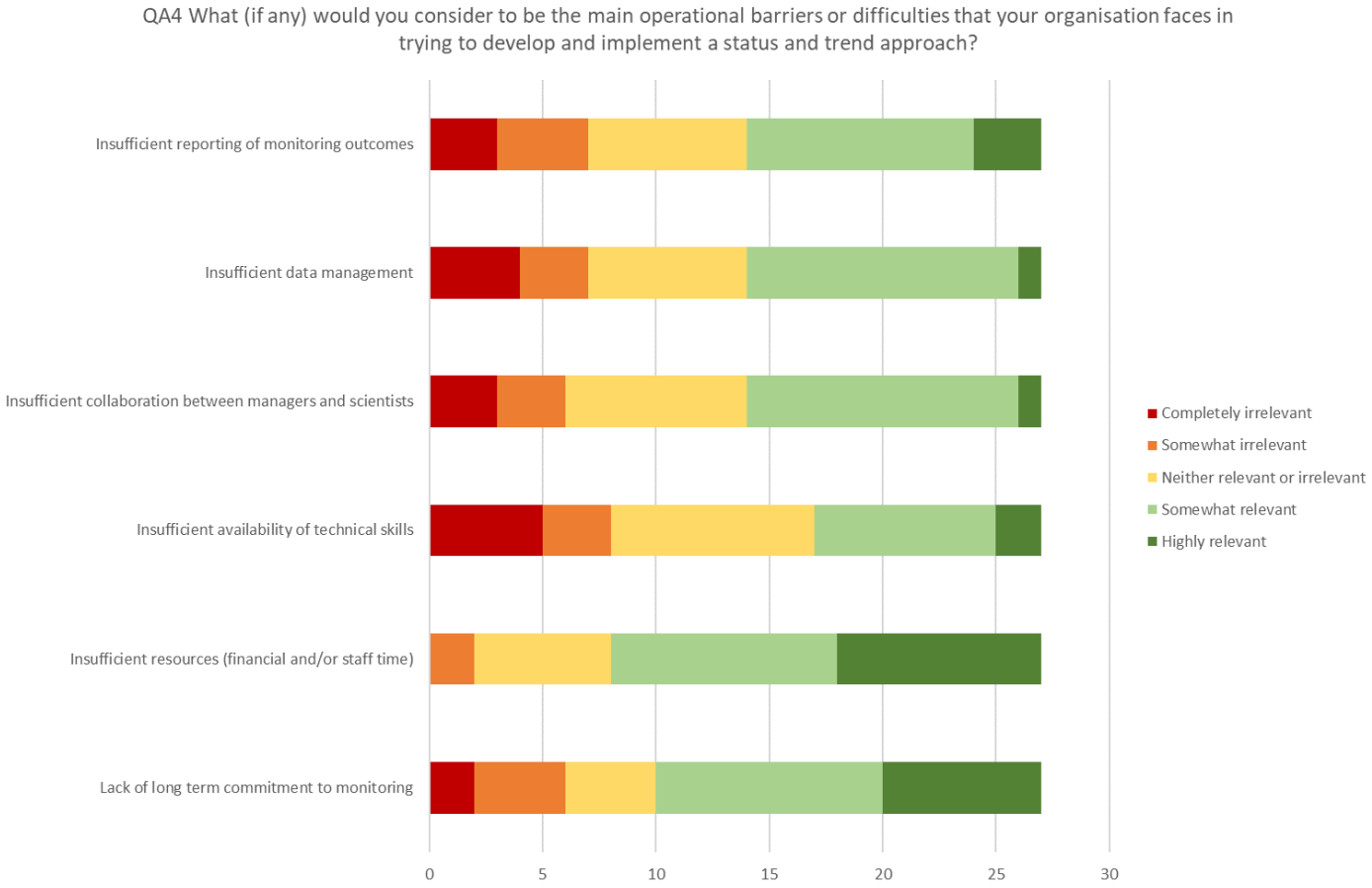

Figure 4. The perceived relevance of difficulties and barriers associated with **a status and trend approach,** rated by 27 survey participants**.**

Other barriers or difficulties of relevance to a **status and trend approach** identified by respondents:

- Engagement of private landholders with government monitoring programs
- Lack of government support for science based approaches to forest and park management affect all above.
- SOFR / MIG reporting

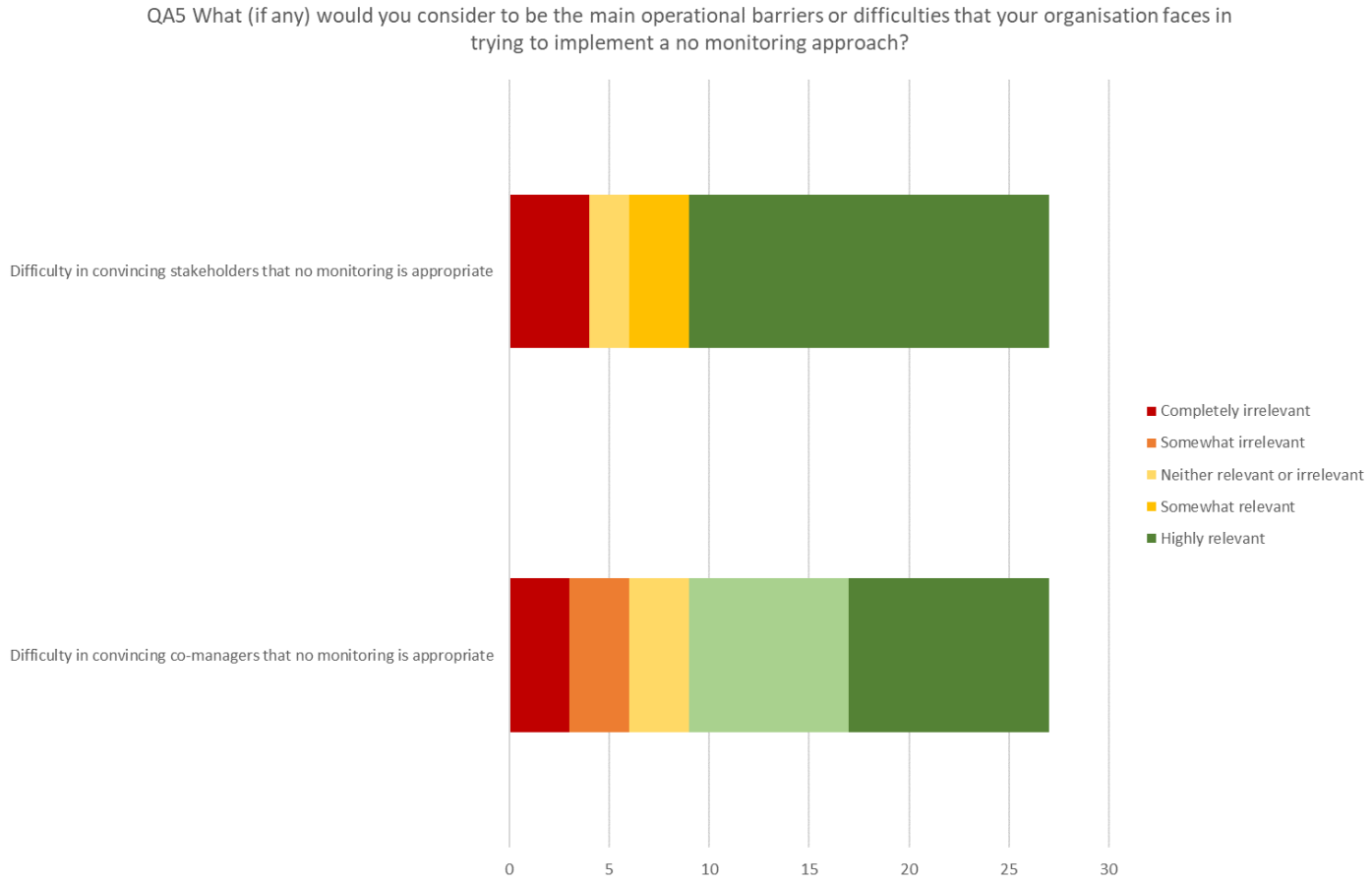

Figure 5. The perceived relevance of difficulties and barriers associated with **no monitoring,** rated by 27 survey participants**.**

Other barriers or difficulties of relevance to **no monitoring** identified by respondents:

- Agency reputational risk
- Current status - not many are worried
- Monitoring as a priority for government
- This is the default setting for most activities i.e. no on ground monitoring, although maybe just input /activity monitoring at best.

A summary of the outcomes of Part A of the online survey is tabulated below, showing the barriers or difficulties rated most relevant among respondents. All five approaches were viewed as having their challenges. Formal adaptive management had five difficulties or barriers considered especially relevant, including two involving trade-offs among managers and stakeholders. Similarly, the stakeholder driven-approach envisaged difficulties in setting thresholds among managers and stakeholders. Sourcing the expertise to conduct the modelling was seen to be a technical barrier to implementing a model-driven approach, along with the perceived difficulty of convincing stakeholders that model-based thresholds are appropriate. Beyond no monitoring, all approaches were challenged by a perception of insufficient resourcing.

Table 2. Barriers and difficulties rated most relevant across five alternative approaches to monitoring. The shortlist of relevant factors includes those that scored >12 points, where a single respondent contributed one point to scoring if they rated the factor *highly relevant* and half a point for *somewhat relevant*.

Technical barrier or difficulty	**Formal AM**	**Model driven**	**Stakeholder driven**	**Status and trend**	**No monitoring**
Difficulty in modelling the (uncertain) outcomes of alternative management actions	●				
Difficulty in modelling the (uncertain) outcomes of current management		●			

Social or institutional barrier or difficulty	**Formal AM**	**Model driven**	**Stakeholder driven**	**Status and trend**	**No monitoring**
Difficulty in trading-off competing objectives among forest managers	●				
Difficulty in trading-off competing objectives among stakeholders	●				
Difficulty in convincing stakeholders that model-based thresholds are appropriate		●			
Difficulty in setting acceptable thresholds among forest managers			●		
Difficulty in setting acceptable thresholds among stakeholders			●		
Difficulty in convincing co-managers that no monitoring is appropriate					●
Difficulty in convincing stakeholders that no monitoring is appropriate					●
Lack of long term commitment to monitoring	●	●	●		
Insufficient resources (financial and/or staff time)	●	●	●	●	

Factors *not* included in the Table 2 shortlist of high relevance can also be informative. In particular, we note the following that were viewed as being of lesser relevance:

- Insufficient reporting of monitoring outcomes
- Insufficient collaboration between managers and scientists
- Insufficient data management
- Lack of organisational commitment to change should monitoring indicate change may be warranted

PART B

Part B comprised a single question about the relevance of a set of pre-identified knowledge gaps. Again, additional self-identified factors are listed below Figure 6.

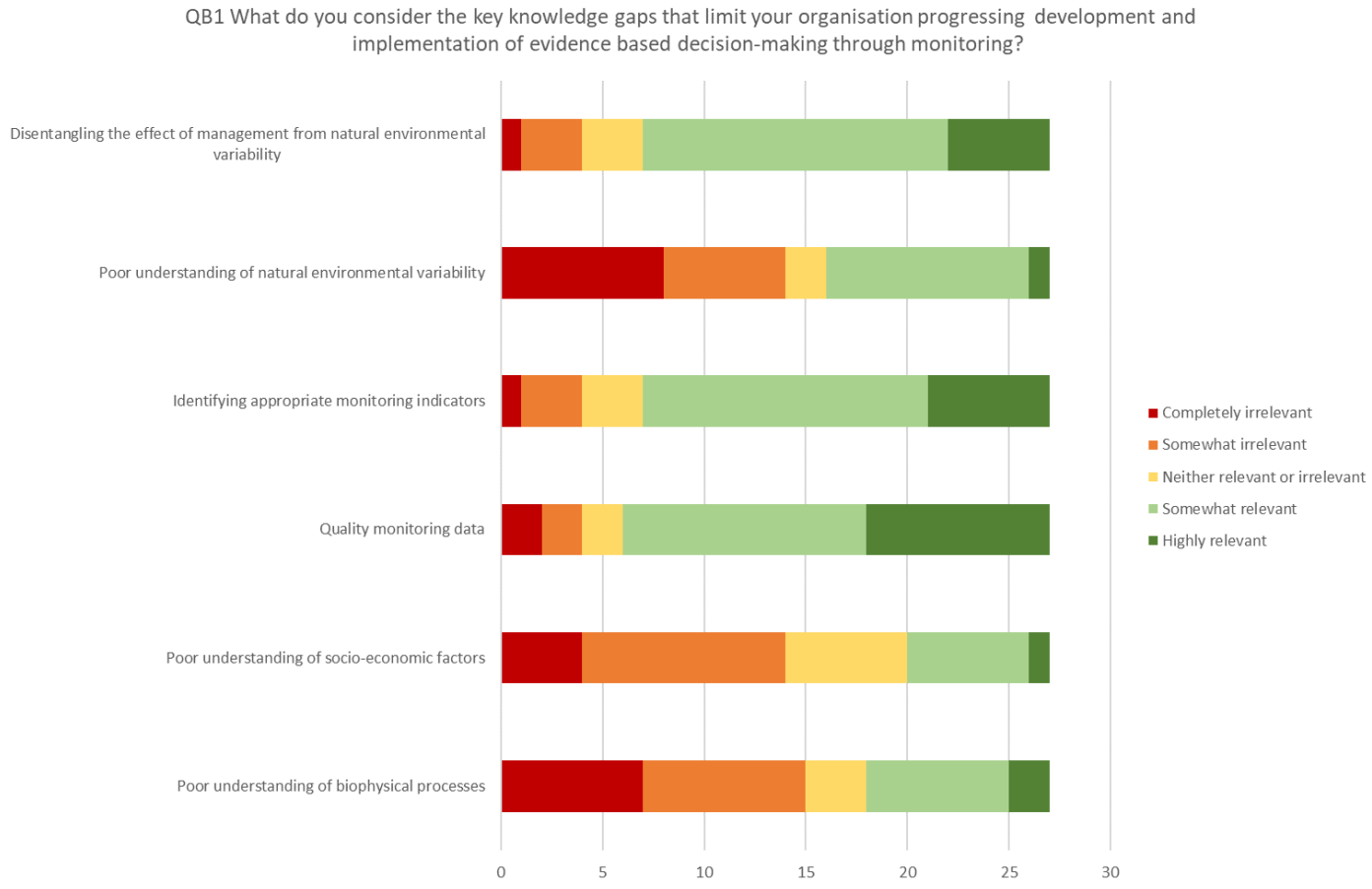

Figure 6. The perceived relevance of knowledge gaps (irrespective of monitoring approach)**,** rated by 27 survey participants**.**

Other factors of relevance to **knowledge gaps** identified by respondents:

- Lack of baseline and long-term (and comparable) monitoring data; lack of fundamental ecological and threat knowledge about a species (from no knowledge of population size, to basic ecological/biological

information); lack of understanding of future climatic impacts on species or what negative impacts may look like
- Lack of commitment to filling known knowledge gaps through long term monitoring and even recent on ground surveys.
- Management alternatives for climate refugia

Of the pre-identified potential knowledge gaps, the three rating highest for relevance were:

- Quality monitoring data,
- identifying appropriate monitoring indicators, and
- disentangling the effect of management from natural environmental variability.

PART C

We grouped responses received to the open-ended question at the end of the online survey into three groups – problems, needs and positives (Tables 3 – 5).

Table 3. Problems.

Theme	**Response**
Uncertainty and complexity	Ecosystems and threatened spp are complex with many uncertainties High-quality monitoring that informs adaptive management is hard Declines/changes in condition cannot always be influenced Targets are difficult to set, often arbitrary and changed when not met
Support	Lack of senior management and political support for evidence based decision making
Commitment	Planning and budget cycles don't allow for long term commitment to EBD
Time frames	Natural variability takes a long time to understand Long time frames problematic in government
Changing priorities	RFA C&I monitoring lost relevance and support as it didn't allow for changing priorities and emerging impacts
Culture	Lack of learning culture
Cost	Monitoring falls if too expensive or complicated
Mechanism	Lack of a feedback loop to evaluate the success or otherwise of management in achieving ecologically sustainable forest management BAU is unacceptable to stakeholders

Table 4. Needs.

Theme	Response
Funding and commitment	Long term commitment, resources and funding Needs to be cost effective
Mechanism	Supported by legislative and policy framework Independent scientific body to oversee monitoring and provide recommendations
Collaboration	Researchers and government collaborate
Monitoring approach	Fit for purpose tools that are useable and practical Compliment existing processes End users must be considered Cross tenure approach to developing baselines Credible and transparent monitoring Be relevant to changing management, environmental and socio-economic factors Robust evidence / data and analysis of survey design To be linked to clear objectives and associated management actions Trend monitoring, targeted monitoring and research On ground data and remote sensing Permanent multi tenure monitoring system Single process unlikely to be successful - need multiple approaches Need monitoring of management impacts

Table 5. Positives.

Comment
Good data base with CRA/RFAs as starting point including indicators
EBD is necessary to balance views of scientists, stakeholders, policy makers and land managers
Status and trend monitoring more likely to be appropriate for private land and encourage participation from private land holders

INTERVIEWS

One insight from the online survey was a perception among some respondents that a single 'best approach' to monitoring may be elusive, and that the approach adopted may be sensitive to context. Telephone interviews were conducted to develop a deeper understanding of:

- Motivations for monitoring.
- What approaches might best serve key motivations?
- How serious are perceived barriers and difficulties, and what are the prospects for overcoming them?
- The importance of public access and transparency.

See Appendix 3 for details.

Participation details for the interview phase are shown at Table 6. Note that the 41 invitees were the same individuals who were invited to participate in the online survey. Overall, the participation rate of 68% for the interview phase was very similar to that of the online survey (66%).

Table 6. Participation in the interview phase among eight organisations involved in the NSW Forest Monitoring and Improvement Program.

Organisation	**number of candidate participants invited**	**number of candidates that accepted**	**participation rate**
NSW Department of Primary Industries	4	3	75%
NSW Department of Planning, Industry and Environment	2	2	100%
NSW National Parks and Wildlife Service	11	7	64%
NSW Environment Protection Authority	3	2	67%
Forestry Corporation NSW	11	8	73%
NSW Crown Lands	7	4	57%
NSW Local Land Services	2	2	100%
Aboriginal Affairs NSW	1	0	0%
Total	41	28	68%

OUTCOMES

Question 1 of the interview asked respondents to rank their perceived emphasis of six different motivations for their organisation's current investment in monitoring, with a rank of 1 being the motivation with the greatest emphasis. Question 2 was similar, but asked respondents for where they believed the emphases *should* lie. Results are shown in Figure 7.

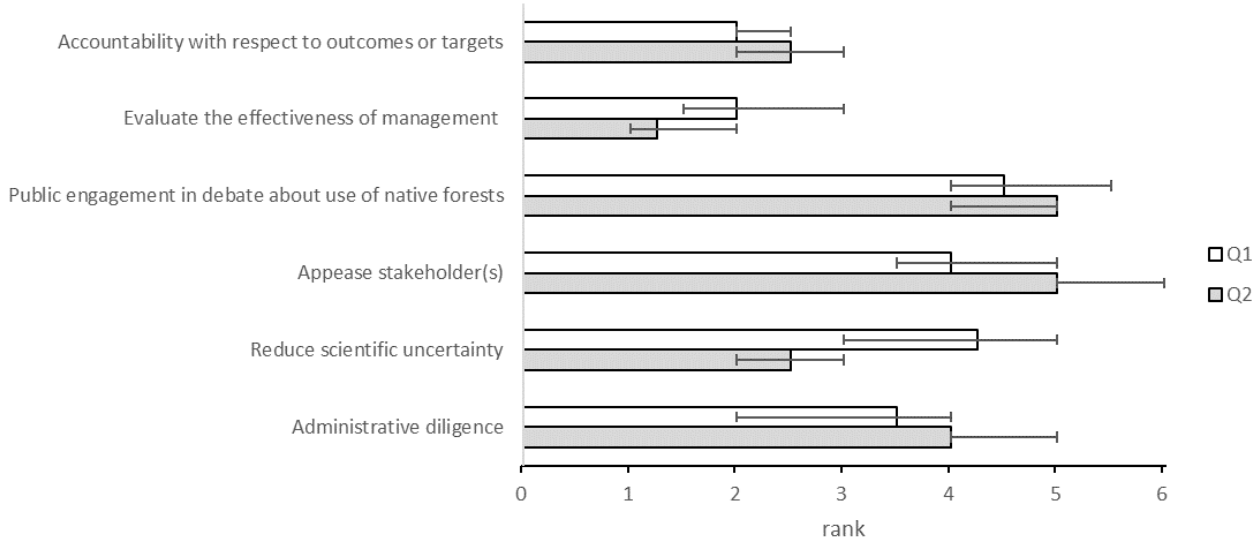

Figure 7. Median ranks assigned to perceptions of importance of six different motivations for monitoring according to where organisational emphases currently lie (Q1) and where they should lie (Q2), among *n* = 28 respondents. Error bars are 90% confidence intervals.

Accountability with respect to outcomes or targets and *evaluate the effectiveness of management* were highly ranked motivations, both for where organisations currently place their emphasis and where they *should* place their emphasis. In general respondents, believed greater emphasis *should* be placed on *evaluating the effectiveness of management* and *reducing scientific uncertainty*.

For each of their highest two ranking motivations in Question 2 (i.e. rank 1 and 2), Question 3 asked what monitoring approach each participant considered to be the most appropriate. Results are shown in Figure 8. There was a clear emphasis among respondents on the desirability of applying *formal adaptive management* to the *evaluation of management effectiveness*, with a lesser but substantial emphasis on *formal adaptive management* as the most appropriate approach for *reducing scientific uncertainty*. Where a primary motivation is *accountability with respect to outcomes or targets*, the approach to monitoring most frequently cited as most appropriate was *the model-driven approach*. There was intermediate support for status and trend monitoring spread across a suite of motivations, the most prominent being *evaluation of the effectiveness of management*.

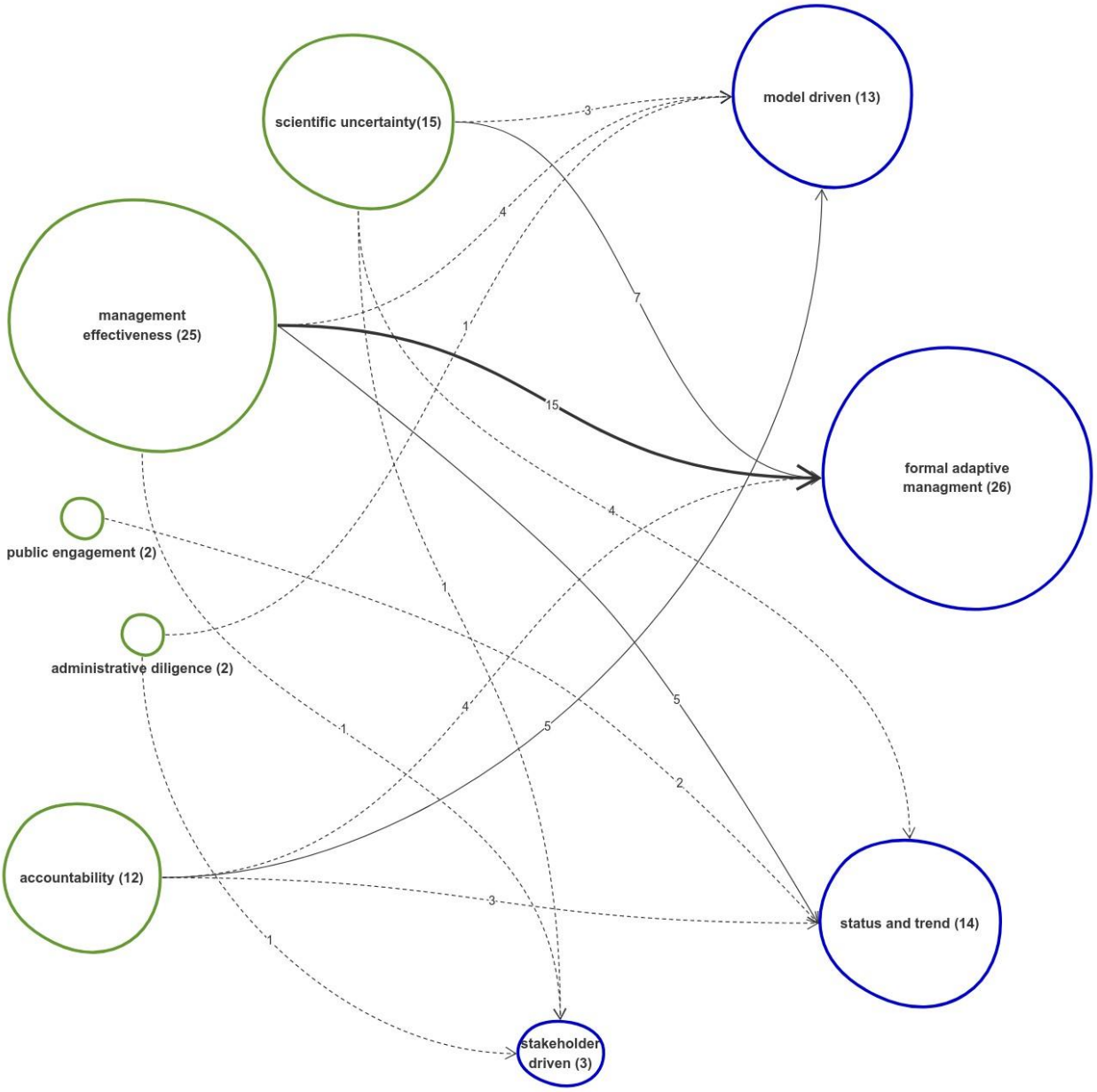

Figure 8. The number of times five different motivations (green circles) were paired with four different monitoring approaches (blue circles). The size of the green circles indicates the number of times motivations were cited in the top two (with numbers shown in brackets). Likewise, the number of times the different monitoring approaches were identified as the most appropriate is indicated by the size of the blue circles. The frequency of pairings is shown on the arrows linking motivations and approaches (bold arrow = high frequency, plain arrow = moderate, and dashed arrow – low frequency). Note that *appease stakeholders* was never cited as a high ranking motivation, and nor was *no monitoring* ever identified by participants as the most appropriate approach.

Interviewees were then asked to consider the shortlisted barriers and difficulties in Table 2 associated with the monitoring approach(es) they regarded as most appropriate for their top two ranking motivations. For each of top ranking motivation, participants were asked to rate how well their paired monitoring approach would serve the motivation *with* and *without* barriers and difficulties being meaningfully addressed in implementation. Responses were on a scale of 0 to 10, with 0 the worst and 10 the best. Results are shown in Figure 9.

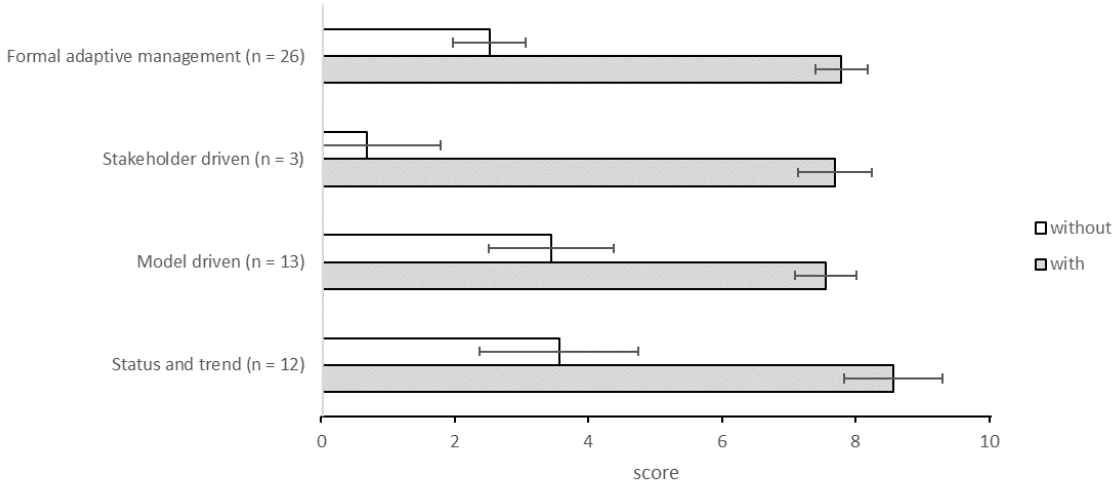

Figure 9. Mean prospects for successful implementation of different monitoring approaches with and without shortlisted difficulties and barriers being addressed. 0 = worst, and 10 = best. Error bars are 90% confidence intervals.

There are two striking observations to be made from Figure 9. First, participants considered shortlisted difficulties and barriers to be substantive issues with all four monitoring approaches (especially those pertaining to the stakeholder-driven approach), where mean scores *without* addressing these challenges ranged from 0.7 to 3.5. Second, was a distinct optimism across all four monitoring approaches that barriers and difficulties could largely be overcome, with mean scores *with* addressing challenges ranging from 7.5 to 8.5.

Note that judgments shown in Figure 9 considered barriers and difficulties associated with any single monitoring approach, *collectively*. In subsequent questions we asked about prospects for overcoming each of the shortlisted difficulties and barriers *individually*. Outcomes are shown in Figure 10.

The scores reported in Figure 10 are consistently lower than those shown in Figure 9 *with* shortlisted barriers and difficulties being addressed. Thinking about barriers and difficulties one at a time may make their challenges more apparent. We note that under *formal adaptive management*, participants viewed *difficulty in trading off competing objectives among stakeholders* as especially problematic (although it's worth noting the prospects for dealing with trade-offs among forest managers scored better).

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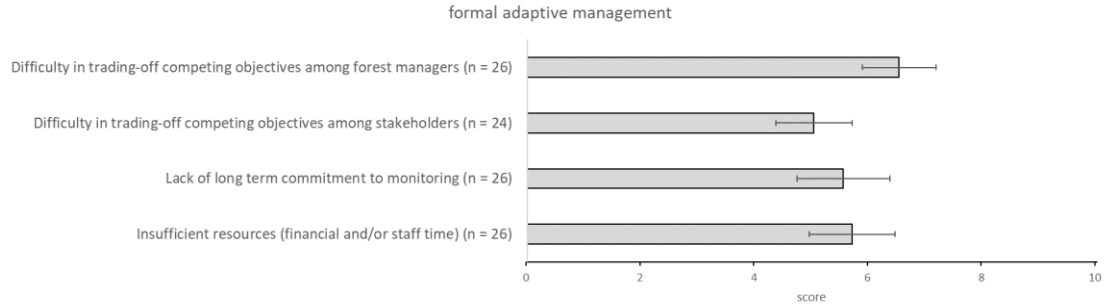

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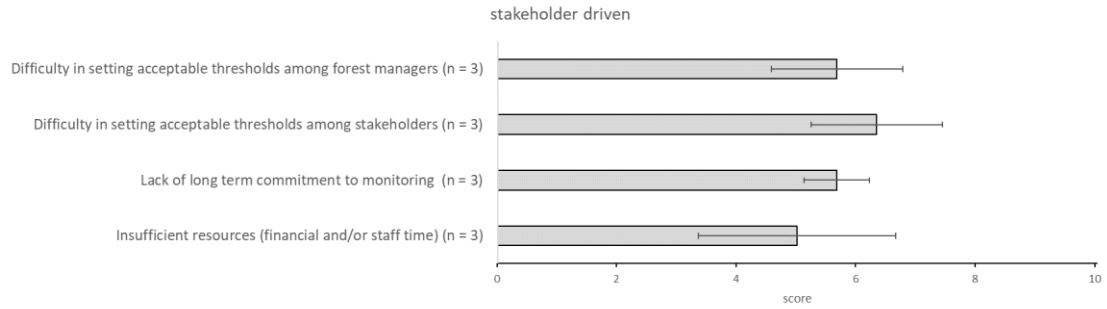

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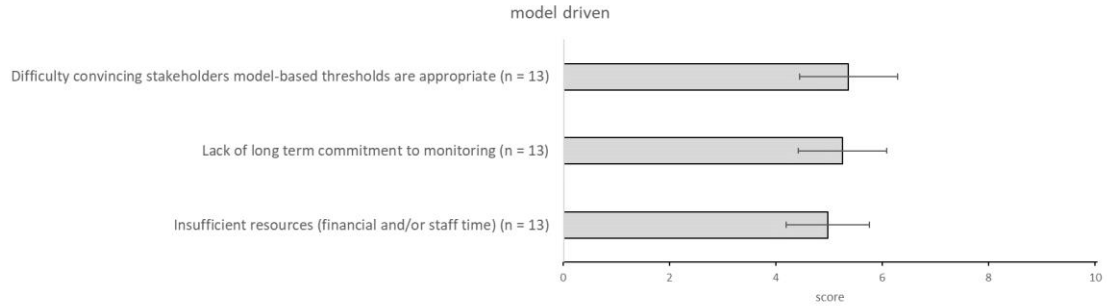

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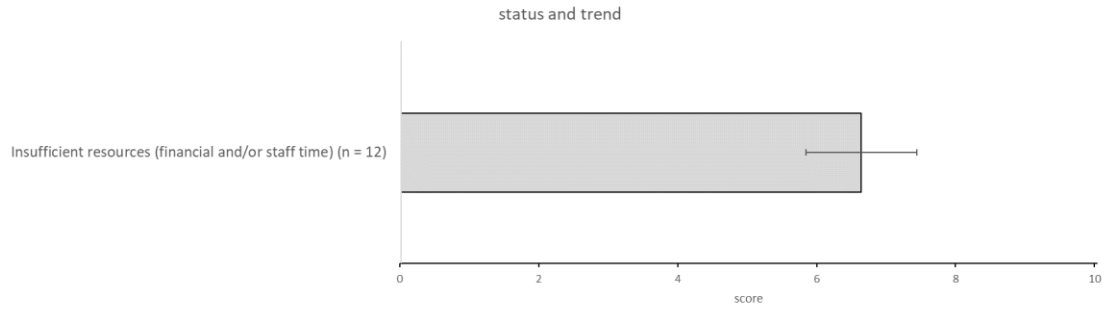


Figure 10. Mean prospects for overcoming individual social and institutional barriers and difficulties associated with (a) formal adaptive management, (b) a stakeholder driven approach, (c) a model-driven-approach, and (d) status and trend monitoring. 0 = worst, and 10 = best. Error bars are 90% confidence intervals. Note that the assessment of technical difficulties and barriers included in Table 2 were not assessed because we assume technical difficulties could be overcome with sufficient organisational commitment.

The interview then asked participants their views on public access to monitoring data and transparency. More specifically, for each of their top two motivation-monitoring approach pairings we asked, which of the following two options is more appropriate?

1. Ready public access to data and reports, and dedicated public engagement, or
2. limited public access, data and technical reports kept in-house; summary reports made available periodically.

The proportion of responses favouring option 1 is shown in Figure 11.

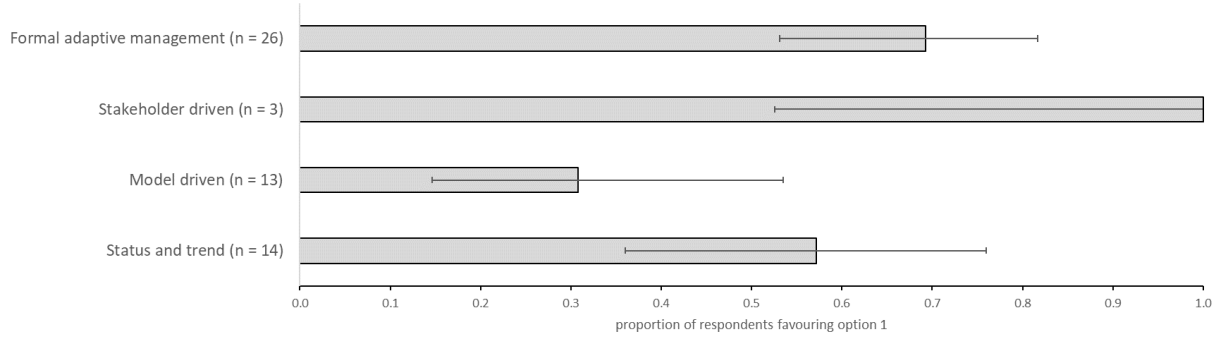


Figure 11. The proportion of responses favouring greater public access and transparency. Note that the sum of the sample sizes is 56, twice the number of participants (28), because we asked each participant to nominate their preference for each of their top two motivation-monitoring approach pairings.

There was a general tendency to support greater public access and transparency, but not overwhelmingly so. While greater transparency may be a pre-requisite of trust, there may be downside to ready public access to data, including the possibility of naïve analysis and interpretation. The potential for downside was seemingly most visible to those that viewed a model-driven approach as appropriate.

The last two questions in the interview were open-ended. We asked each participant:

- What improvements could be undertaken in the short term (next 12 months) to promote better use of monitoring data in decision-making within your organisation?
- What improvements will require a longer-term commitment?

Full responses are shown at Appendix 4. We collated and summarised responses according to emergent themes and sub-themes. Outcomes are presented in Tables 7 and 8.

Table 7. Summary of responses to the open-ended question, *what improvements could be undertaken in the short term (next 12 months) to promote better use of monitoring data in decision-making within your organisation?*

THEME	SUB-THEME	FREQUENCY	CONTENT
Resourcing	**Adequate Resourcing -** Sufficient funding to improve capacity, training and software.	6	• Hire staff that are really good at analysing data • Funding allocation for post fire monitoring • Address staff vacancies in monitoring and evaluation space • It's all to do with resourcing and making sure we've got the people on the ground who are capable of doing some form of monitoring, and the analysis and the interpretation of results to feed back into some form of management. Every step along the way needs dramatic improvement in resourcing. • Improving access and usability of the data through changes to data governance and investment in software. • Training for those that are doing the monitoring in monitoring design and data analysis to allow people to collect better data and understand what it says better
Monitoring and data	**Monitoring framework** - agreed metrics, targets, objectives, methods	6	• Accepted and agreed frameworks for measuring environmental condition and health that are both cost effective and reliable • Identify the metrics you want collected, identify targets in the org and regularly report on them and be clear about what decisions it will inform. • Simple deliverable monitoring framework • What monitoring is going to look like • ideas on what we're actually monitoring and what the objectives of any monitoring are • robust and tenure-neutral data capture methods
	Utilise existing data sets - can be used as proof of concept, answer questions now and identify gaps	5	• Use data we already have to answer simple management questions as a proof of concept • Some data sets are appropriate for some questions - such as bionet data - can be used to answer questions now. Use appropriate data sets for specific questions where it is statistically defendable. need to identify where the existing data sets can and can't be applied to short term decision making • Making visible and getting communication out there that the data is available to inform decisions • Demonstrate its (using monitoring data for decision making) benefits around social licence, • There is a lot of data being collected by a lot of different people that could be very useful

	Audit of current monitoring and data collation - to understand what is currently being measured and what needs to be continued. Develop a central data repository and coherent strategy.	4	• We don't understand what monitoring is being carried out across the agency and for what purpose. There is an enormous amount undertaken but there is no central repository for it no coherent strategy for it. • Document what monitoring is occurring at what sites across the reserve system and identify the gaps in those. Basic drawing together of existing information. • Collation of data from current programs. There is a lot of data being collected by a lot of different people that could be very useful but it is not held in a central repositories. • A better understanding of what is actually being monitored by public land managers
	Summary information and reporting - to improve understanding and traction of monitoring projects and access to data	6	• Needs clear, concise summary info of projects, plans and feedback all elements of the program to clearly articulate to senior managers where things are headed. • A series of snapshot reporting • Making visible and getting communication out there that the data is available to inform decisions, making information available in a way that can be used for decision making • Produce dashboards for managers to use • Promote more widely where the program is up to and what it's doing and what it's trying to achieve, demonstrate usefulness • Preparing and making available milestone reports from monitoring projects
Cultural change	**Collaboration between agencies** - sharing of data	3	• Transparency with the monitoring data among organisations. • No limitations on availability of data captured by organisations, in terms of forest management. Collaborating wherever possible, and providing that information so we're not duplicating and we're being more efficient with the information that's being gathered . You can share knowledge that the local managers have regarding those issues and maybe come up with better solutions. So it's more about sharing knowledge and information throughout regions and the state, rather than keeping it local. • Communities of practice are a useful process of sharing information and building trust among agencies and researchers and others. Trust built up that starts that information flow and makes it far easier to influence executives and others in their decisions.
	Commitment of senior management	2	• Need high level commitment and understanding • The organisation accepting the need or benefits of long term monitoring

Communication	**Demonstrate benefits of evidence based decision making**	5	• Show managers how monitoring data can be really useful for improving management and helping them make decisions • Promote the value to come out of the results. • People need to see the benefit in monitoring and data • We need to demonstrate things have been going on and that these things will be useful • Creating those forums to debate it, to look at it, to look at the implications of it, to understand what is required to undertake it - what resources will be required, what impacts it will have, what are the benefits, and making sure that that's clear so you can get that longer term commitment

Table 8. Summary of responses to the open-ended question, *what improvements will require a longer-term commitment?*

THEME	SUB-THEME	FREQUENCY	CONTENT
Resourcing	**Adequate Resourcing -** sufficient staff capacity (on ground, scientific and analysis) and finances to facilitate monitoring	7	• Data scientists, decision scientists are missing in the organisation • Proper investment in on ground staff to undertake monitoring with appropriately, scaled investment in systems and process • Funding and people. Because you need these things to get something worthwhile done rather than a piecemeal approach. • This needs a commitment to funding • We don't make a commitment in a budgetary sense • You have to see monitoring as a necessary tool for improvement that needs to be funded for the long term • Budget allocation so it can facilitate and improve monitoring

Cultural and structural changes	**Structural change** - Integrate monitoring, assessment and evaluation into strategic, business and operational planning cycles, program strategies and reserve plans. Build ability to have long term commitment.	5	• The structural stuff isn't there either so when we do our strategic and operational planning, monitoring and evaluation doesn't feature as a must do • It's integrating it into the systems and making it smooth sailing • Policy needs to filter down through that organisation - in terms of business plan requirements, KPIs, it needs to be embedded in position profiles as well • Make sure that is reflected in both the reserve planning documents and associated program strategies and making sure that it is integrated with business and operation planning for the organisation to complete the cycle of making the assessments, evaluation of assessment and then translating that into actions and activities that need to changes • Building in corporate structures that allow for longer term planning and commitments
	Culture change - all levels of staff, to understand and embrace evidence based decision making	4	• You have to see monitoring as a necessary tool for improvement that needs to be funded for the long term • Build culture of adaptive learning about the effectiveness of management, build on the small examples of where we have been able to use data to make better decisions to gradually get people thinking in that way. All staff from grassroots up to executive. • All layers of staff within land management agencies need to understand evidence based decision making and the benefits. • There is no culture of recognising the value and the pressures put on by senior management to deliver outputs tend to be higher than. The ability to plug that into improvement, how do we change what we are doing, is not there culturally as well. We are not a learning organisation we are a doing organisation
	Closing the loop - ensuring there is reporting, review and evaluation of data.	5	• A commitment to do the work, collate the data, and write it up - and writing it up is the important component of it. And then just feeding that back into your management decisions or your adaptive management stuff • Close the cycle on reporting and review. • A commitment to that adaptive management framework to ensure that there is this continuous reviewing and evaluating the management to then ensure that the goals of management are being met, and ensuring if they're not being met, then why.

	Collaboration - coordinated, cross agency approach and common vision	5	• Need common vision (across agencies) of what we need to do and clearly articulate, reiterate and instil that in the process • Acceptance of the validity of different objectives. We just waste time arguing over if we should be chopping down trees or conserving wildlife. The war is getting in the way of the outcomes. If we could just all agree that we have different legislative objectives and measure common things but accept that we will have different outcomes we can all get on with it. • Coordinated approach to across government, everyone on the same page about better forest management and its need to be coordinated. • Build a network of collaborators among organisations to bring in additional skills and viewpoints, because the principals don't know it all. • Partnering with other agencies is a useful thing. It's not something we're very good at! We need to be much better. There is too much jostling for position that's holding us back. The agencies' walls are so thick and this history and inability to work together for the greater good of the people of NSW. We need to collaborate better.
Long term monitoring	**Long term data collection**	4	• Getting the long term data is important to inform the public and the forest managers about what is happening and not happening. In longer term it allows for trends = so need to ensure there is repeat monitoring. • Will require a long-term commitment and this won't just be a 5 year program. We'll only be just scratching the surface on what the benchmarks mean by then. • Forest monitoring is a long term game so you must set up repeatable and robust forest monitoring that supports decision making - need long term commitment • Long term monitoring strategy. Things get more interesting, useful and valuable the longer they go.
	Legislated commitment to long term monitoring	3	• Monitoring fundamentally needs to have a basis in legislation to ensure that funding is long term otherwise you are at the whim of each political party as it comes through government. • Need legislated basis to oblige the state government to monitor. • If you want substantial improvements to be taken there needs to be a legislative or political need. That then needs to be embedded in legislation and policy and that policy needs to filter down through that organisation

	Appropriate monitoring approaches - develop cost effective, innovative, robust, best practice monitoring approaches	4	• On the data collection side of things, we need to get smarter. If it's not easy or the cheap way is not available and it's time consuming or expensive, governments don't commit to funding beyond three years if it's hard or expensive. • Low cost collection and analysis techniques. We need to move to remote sensing methods or we are all going to go broke. It can't be satellite imagery. Machine learning is going to be critical for us to analyse camera traps. • We need statistical rigour, sampling sites and methodology, so that we know that the data we're collecting is going to be useful in the long term. And I guess in terms of improvements my mind goes to what's the best technology we can leverage to get power into our data (e.g. song meters and remote cameras). • Commitment towards innovation to enable rapid, efficient and cost-effective monitoring
	Investment in data collection, storage and management	2	• Good data storage and management systems is a key one. So that data doesn't get lost and people are able to look back and see what people have done and if they have an opportunity they can continue it. • Set up data collection infrastructure - permanent plots, remote sensing data, data base
Communication	**Communicate and demonstrate benefits of evidence based decision making**	2	• I think we're an organisation that needs to see tangibles. If we can see that our investment and our spend is saving time and money and meeting our certification requirements and producing results ..... tangible outcomes then we can maintain and garner commitment. • Long term projects have budget implications those type of things need to be revisited and highlighted in front of managers and executive to update them about what has been happening, progress reports so that they understand the importance of the work and how it informs better regulation or better forest management in the end

DISCUSSION

Alongside a *no monitoring* option, the survey of forest managers reported here captured views on four alternative approaches to monitoring as a basis for evidence-based management.

- Formal adaptive management
- Stakeholder-driven
- Model-driven
- Status and trend

The review accompanying this report (Appendix 1) emphasises value judgments and cause-and-effect judgments as *necessary* elements of a decision. In this context, *formal adaptive management* and *status and trend* monitoring are 'bookend' alternatives. Formal adaptive management reconciles scientific uncertainty and the explicit articulation of trade-offs in delineating thresholds where a change in management is warranted. *Status and trend* monitoring offers no trigger for change in and of itself – value judgments are left to those that interpret and evaluate the data, typically via periodic reviews in committee settings. Difficulties in resolving or even addressing value-based positions in these settings make inaction a more likely outcome. The intermediate alternatives of *stakeholder-driven* and *model-driven* approaches seek to avoid a stalemate by assigning thresholds that are somewhat arbitrary, in that they don't coherently deal with value judgments and causal judgments. The *stakeholder-driven* approach emphasises value judgments, with little regard for cause-and-effect. The opposite is true of the *model-driven* approach.

In survey responses there was negligible support for *no monitoring*. But none of the approaches to monitoring were considered to be free of substantial challenges (Table 2)[3]. Of these, the least problematic was *status and trend* monitoring, where a single difficulty was identified – insufficient resourcing. The approach with the highest number of substantial difficulties or barriers was *formal adaptive management*, with five. We note that status and trend monitoring is the most common approach we've encountered in natural resource management, perhaps because its implementation poses relatively few challenges. But it's also the least likely to prompt a considered decision around change in management after review of the data.

Despite having the highest number of perceived difficulties, *formal adaptive management* was most commonly cited as the appropriate approach to monitoring (Figure 8). The *model-driven approach* and *status and trend* also received considerable support, but were each cited only about half as frequently as *formal adaptive management.* Technical challenges and barriers can be overcome. In the recommendations below, we make some tentative suggestions. But perhaps the more substantial challenge is addressing value judgments and trade-offs. Many of the social or institutional difficulties listed in Table 2 involve trade-offs, or the dubious basis of arbitrary thresholds. The entrenched positions of stakeholders, contrasts in emphases on different forest values among management organisations, and the history of diametrically opposed and sometimes spiteful debate suggests there's no short term remedy.

Figure 8 indicates considerable variability in what may be seen as the best approach under different circumstances or motivations. This variability stems, at least in part, from the differences in purpose and setting among the eight agencies involved. But it may also reflect a general lack of clarity around how monitoring is to be used in evidence-based forest management. Frustration stemming from ambiguity of purpose is evident in several comments in

[3] Many of the comments shown in Tables 7 and 8 offer further insight into the nature of these challenges and how they might be overcome.

Tables 7 and 8. Stronger themes in Tables 7 and 8 are the challenges of resourcing and long-term organisational commitment. Our view is that these issues are linked. That is, the provision of adequate resources over the long term rests on clarity of monitoring objectives and broad support for the legitimacy of those objectives among managers and stakeholders. In the interests of progressing clarity, we offer our view in Box 1.

BOX 1. ALIGNING DECISION SETTINGS AND DIFFERENT APPROACHES TO MONITORING.

Alternative monitoring approaches will vary in their merits according to the decision setting at hand. Let's say there are four settings:

1. Decisions involving (formal or informally described) standards, for which we have management options available (i.e. we can tighten or loosen standards as evidence from monitoring data unfolds) *and* there is a reasonable understanding of what is an acceptable and unacceptable impact. For example, hygiene practices aimed at managing the risk of introducing or spreading fungal pathogens may fit into this category. In this setting a monitoring approach based on **AGREED CRISP THRESHOLDS** will be appropriate. These thresholds may come from models, stakeholders, expert judgment or a combination thereof. Where thresholds are crossed a change in standards is clearly triggered (Figure 12).

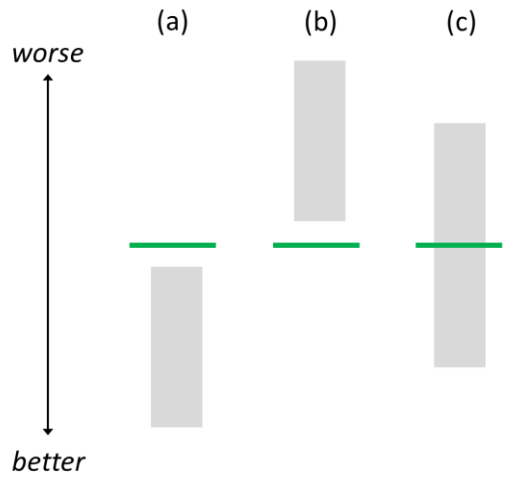


Figure 12. Possible configurations of scientific uncertainty and thresholds for social acceptability under *crisp thresholds*: (a) clearly acceptable, (b) clearly unacceptable , and (c) unclear. Uncertainty in the performance of status quo management is shown as a grey box. Social acceptability is indicated by the green line. Note that for illustrative purposes we show only the case where an increase in the indictor represents a worsening performance, and a decrease an improvement (e.g. incidence of disease). But the opposite will be true for many indicators.

2. Decisions involving (formal or informal) standards, for which we again have well described options but there is *not* a good understanding of thresholds delineating acceptable or unacceptable impact. For example, engineering standards applied to roading networks may fit here and the approach to monitoring may be **FUZZY THRESHOLDS**, where scientific uncertainty and/or contested views on what constitutes a tolerable impact imply an upper and lower bound on where change is triggered. Where bounds are crossed, a review may be prompted, the outcome of which may be retention of the status quo or a change in standards (Figure 13).

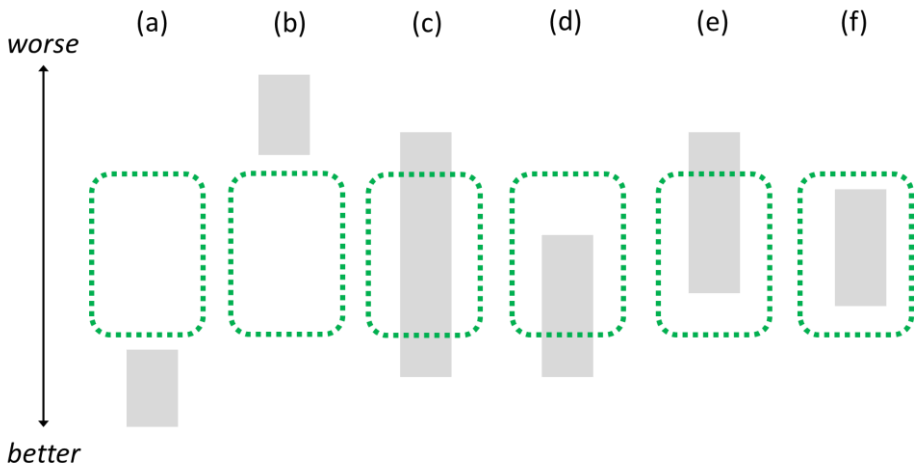


Figure 13. Possible configurations of scientific uncertainty and thresholds for social acceptability under fuzzy thresholds; (a) is clearly acceptable, (b) clearly unacceptable , and (c) and (d) are unclear. (e) and (f) are possibly unacceptable because the lower bound of uncertainty exceeds the lower bound of social acceptability.

3. Higher stakes decisions in forest management involve allocation of land to different uses and intensities of use. These decisions are typically revisited every 10 years in the updating of regional management plans. The decisions are complex, involving many sources of scientific uncertainty and strongly contested values. But if managers are able to circumscribe a finite set of possible management options for the future (comprising alternative spatial configurations of uses and use intensity) and a set of plausible future scenarios that may condition the merit or performance of those options, then there is scope to place monitoring effort in a formal decision analytic framework. In these settings, we suggest the framework of **FORMAL ADAPTIVE MANAGEMENT** be used to guide data acquisition, but *without* a requirement at the outset to specify thresholds delineating where one management option may be preferred over another. Thresholds rely on the ability of managers and/or stakeholders to make considered trade-offs among forest values (Appendix 1). Results of the survey presented here suggest this will be a significant stumbling block. In any case it may be folly to 'lock-in' value judgments for decisions that will be revisited 10 years hence. We suggest that trade-offs be explored iteratively over time, and that the data from monitoring be used to assist stakeholder and managers explore and resolve trade-offs incrementally. A parallel investment in monitoring societal values (see recommendation 2.2) will assist this process and encourage managers and stakeholders to look beyond the myopia of their immediate interests. We note that the FMIP is currently developing a set of scenarios and options which can directly provide the foundation for an adaptive management approach.

4. The three settings above all assume management options can be identified and broadly accepted as relevant by manager and stakeholders. That is, there is a decision or series of decisions to be made over time as monitoring data accumulates. But sometimes, institutional arrangements or an absence of policy make the specification of management options elusive. For example, the extent to which that portion of the forest estate zoned for timber production has a compensatory responsibility for loss of biota stemming from climate change (as opposed to losses attributable to harvesting) is an area of inexact policy. In these circumstances **STATUS and TREND** monitoring may be the most appropriate. Like the incremental approach to adaptive management outlined in (3) above, a position on acceptable impact and thresholds for management change should crystallise over time, and the consideration of stratus and trend monitoring data will form an important part of reaching a resolution. We suggest that public access, transparency, and structured forums for discussion and debate are especially important in these contexts. Without a commitment to discussion and debate, any investment in status and trend monitoring will be prone to decision paralysis.

RECOMMENDATIONS

The headline findings of the survey described in this report are:

- Formal adaptive management is broadly supported among NSW forest managers, but also poses the greatest number of challenges in its implementation.
- Status and trend monitoring poses relatively few problems in implementation, but provides a weak basis for bridging the gap between data capture and decision-making.
- Irrespective of what approach to monitoring and decision making is adopted, there is general concern that resourcing and organisational commitment to long term monitoring may be inadequate.

We make the following recommendations to better bridging the gap between data capture and decision-making:

1. Improvements that could be undertaken in the short term (next 12 months) to promote better use of data in decision-making:

    1.1. Align different monitoring approaches to different decision settings and embark on pilot applications of evidence-based decision support (see Box 1 for a suggested starting point).

    1.2. Co-invest in measures to overcome technical barriers and difficulties. Specifically, recruit competent quantitative modellers with a solid understanding of forest management and if possible, make their skills available across organisations.

    1.3 Establish administrative mechanisms to encourage long term resourcing of monitoring.

2. Improvements that will require a longer-term commitment:

    2.1. Introduce decision thresholds *into status and trend* and *adaptive management applications* incrementally, via co-ordinated and continuous review of monitoring data and structured debate and discussion of values and trade-offs.

2.2. Initiate long term monitoring of society's views of values and trade-offs as a basis for broadening and informing debate around trade-offs and their implications for evidence-based decision-making. The focus of this monitoring effort would be informed by the subset of applications identified in recommendation 2.1.

APPENDIX 1 - REVIEW

A1.INTRODUCTION

In the mid-1980s a Canadian biologist, Carl Walters, took a set of ideas about quality control in manufacturing and applied them to fisheries, coining the term 'adaptive management' (Walters 1986). The concept then and now enjoys great support, with natural resource planning documents littered with diagrams depicting cycles of continuous improvement[4] and earnest commitment to the principles of adaptive management.

Formal adaptive management as championed by Carl Walters is not easy. There are very few examples of successful implementation, much to the frustration of scientists (Lindenmayer et al. 2013, Williams and Brown 2014). Several reviews articulating shortcomings in current practice and associated recommendations for improvement are available (e.g. Lyons et al. 2008, Westgate et al. 2013, Dixon et al 2019), but uptake remains modest.

So, despite a lot of enthusiasm about the idea of adaptive management, by far the most common form of monitoring is status and trend or non-targeted monitoring, where the motivations for data acquisition are vague and any analysis or review of the data are not formally embedded in organisational decision-making. An unkind assessment of non-targeted monitoring is that it 'can be an inefficient use of scarce funding, it also can become a form of political and intellectual displacement behaviour or worse, a deliberate delaying tactic' (Nichols and Williams 2006).

The challenges of implementing formal adaptive management and the deficiencies of non-targeted monitoring can lead to a bleak assessment: the purported benefits of monitoring are wildly overstated. This assessment is not shared by the authors of this review. Nor do we believe that a blanket insistence on overcoming the difficulties of implementing adaptive management is the answer. Our guess is that organisations are best served by carefully assessing the merits of different approaches to evidence-based decision-making. There will be settings where formal adaptive management is worth the fuss. And there will be other circumstances where the rigour and formalism of adaptive management may be out of place, and other ways of bringing evidence to the decision-making table may be a better fit. This review seeks to inform those deliberations.

A1.1 CONTEXT OF THIS REVIEW

This review is part of a project exploring opportunities to improve how existing NSW agency monitoring, evaluation and research data programs can better inform adaptive forest management and decision making for ecologically sustainable forest management (ESFM). Its focus is determining what can be done to improve prospects for bridging the gap between data capture and adaptive decision-making.

The framework for the Forest Monitoring and Improvement Program sets out elements relevant to this work. For example:

- Use of existing monitoring data is maximized for evaluation and research into enhanced forest management.

[4] We couldn't resist a spot of littering ourselves. See Figure A1.

- Enhances synergies between NSW agencies, and enables cost sharing, improved consistency in data collection and duplication reduced.
- NSW agencies demonstrate how research informs their on-ground monitoring and evaluation of forest management practices.

Outcomes of the project will be a set of recommendations for consideration by the Program Steering Committee under three broad headings:

- Improvements that could be undertaken in the short term (next 12 months) to promote better use of data in decision-making, including relatively straightforward case study applications in adaptive management.
- Improvements that will require a longer-term commitment (because of the need for say cross-agency collaboration, the support of executive leadership, complex technical challenges).
- Settings where formal adaptive management may be too difficult or too costly to implement, but for which other approaches to evidence-based decision-making may be appropriate.

There is much potential for improvement, including those related to institutional arrangements, design and implementation, data management, and resourcing (Dixon et al. 2019; see section 3). We believe that with sufficient resourcing and organizational commitment, many of the technical challenges involved in design and implementation and data management can be overcome. A series of recent workshops held by the NRC demonstrated considerable technical capacity within and across stakeholder agencies and organizations (Anon 2019, Chapman 2020, Kavanagh 2020, Thackway 2020). While these workshops focused on design elements for status and trend monitoring, it was noted more than once that there was a 'tension' between status and trend monitoring and monitoring for adaptive management. This review explores this tension and provides a basis for thinking about where adaptive management might be appropriate and where alternative approaches might be a better fit. It may be that status and trend is enough in some circumstances. Perhaps there are settings where *any* monitoring effort is a waste of resources. And perhaps, there are instances where formal adaptive management is worth pursuing.

In the next phase of this project, we'll be interviewing forest managers to get their views on what approach(es) they consider appropriate. This review provides a basis for candid discussion in the interviews, and for broader debate within and across agencies.

A2.ADAPTIVE MANAGEMENT – EASY TO SAY, HARD TO DO

Adaptive management is motivated by the distinct possibility of regret in decision-making under uncertainty. The list of uncertainties is almost endless. We don't know the extent to which bushfires in the future will compromise forest values. We can't say with any precision what role recreation activities or timber harvesting have in the spread of fungal pathogens. The relationship between water yield and forest cover is broadly understood, but there is much variation from place to place. All these uncertainties and many others besides have implications for how we manage forests.

Adaptive management was invented by a scientist, and its most vigorous advocates are scientists. This is hardly surprising - uncertainty is the reason science and scientists exist. For these people, adaptive management is a clarion call that underlines their relevance and that of their work. But for many managers and organizations an explicit acknowledgement of uncertainty is a threat to carefully cultivated perceptions of sound management. The hand on the tiller knows exactly what it is doing. To admit otherwise is to invite criticism and instability. A guarded view of adaptive management among many managers is understandable.

A2.1 DECISION CONTEXT

The generic steps of decision-making and adaptive management are shown in Figure A1. The key feature of adaptive management that makes monitoring *targeted* is that data acquisition is embedded in an (uncertain) decision that typically has as its elements:

- two or more objectives,
- two or more candidate alternative management responses for how to best progress objectives,
- estimation of the uncertain consequences of each candidate alternative against each objective, and
- trade-offs among objectives.

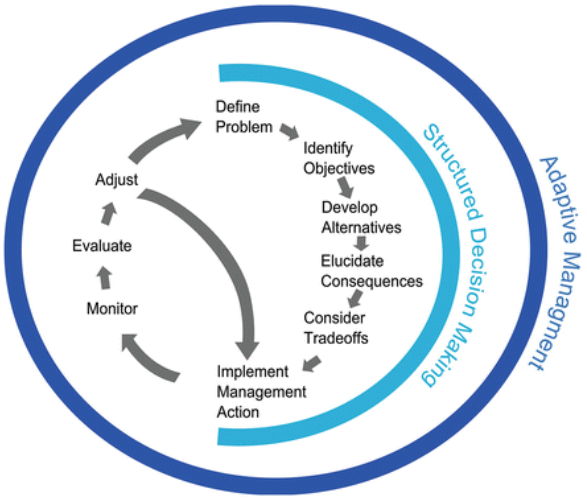


Figure A1. Steps in the adaptive management cycle (Source: Allen et al. 2017).

Learning via monitoring is the caboose on the decision-making train and only invoked where the gamble implicit in any uncertain decision makes managers uneasy about committing to a (tentatively) preferred alternative.

There is a yawning chasm between the ideal formalism of adaptive management and standard applications of status and trend monitoring, with the exception of the first step of identifying objectives. The long history of multiple use forest management has provided considerable clarity on objectives. The Montreal Criteria and Indicators (Montreal Process Working Group 2015) represent an international consensus on important values and objectives. But the Montreal Process does not in itself embed status and trend monitoring of indicators into any decision context. The decision context of non-targeted status and trend monitoring is usually vague and undescribed. It's rarely specified at what level or threshold an indicator would trigger a rethink of management, or what that change of management would look like. Where trends suggest that decline in one or more forest values is approaching some fuzzy precipice of unacceptability, managers may respond appropriately. But there are pitfalls. They may also:

- Lurch from one poorly conceived management response to another because the consequences of alternatives have not been elucidated, and trade-offs with other forest values likewise given sparse consideration.
- Ignore the decline(s), and just stick with the status quo.

Our guess is that sticking with the status quo is more common than the ill-conceived lurch because in many circumstances analysis and reporting is not undertaken routinely or is not made immediately visible to managers. But the broader argument is that if either of these pitfalls are common, the merit of untargeted monitoring is questionable. It's also worth noting that sometimes there simply are no alternatives available for implementation. If things go bad with the status quo, and there's not much that can be done about it, what's the use of monitoring?[5]

A2.2 A CARTOON ILLUSTRATION OF ADAPTIVE MANAGEMENT

The pitfalls of non-targeted monitoring can make the rigour and focus of adaptive management appealing. But there are considerable technical demands to implementing formal adaptive management. Here we sketch what's involved using a hypothetical example and highlight why it can be difficult to implement.

Imagine two branches of an organisation with responsibility for biodiversity conservation and timber production. As part of a periodic review of forest management, the organisation explores the merits of four broad alternative strategies, involving different proportions of the forest estate available for timber production, and two silvicultural techniques for timber production (Table A1). Managers of the two branches ask their scientists to estimate the consequences of each alternative against the two objectives - conservation and timber. The scientists account for uncertainty by providing estimates under best case (models A and D for biodiversity and timber, respectively) and worst case (models B and C).

Managers stare long and hard at Table A2. They argue over the likelihood of worst case consequences eventuating, and what it means for the organisation, for their branch, and for their careers. They argue over the relative importance of looking after our biological heritage and the provision of a renewable source of wood and fibre. After much animated discussion around what might be a reasonable trade-off that would be generally acceptable to most stakeholders, they (miraculously!) agree that a loss 7,000 m^3 of timber is a reasonable 'price' for avoiding decline (of some specified magnitude) in any one species, or scaling up, that a loss of 70,000 m^3 would be equally bad as a decline in 10 species.

Table A1. Alternative management regimes for the cartoon illustration.

management alternative	proportion of landscape available to timber harvesting	silvicultural system
I	60%	clear fell
II	60%	shelterwood
III	30%	clear fell
IV	30%	shelterwood

Branch managers have achieved a rare and commendable feat – they have explicitly articulated their position on the key trade-off between conservation and timber production. But they remain a rabble when it comes to assigning beliefs in the likelihood of worst case and best case scenarios unfolding. An analyst steps in and identifies the best option under the full set of possible probabilistic beliefs in competing models (Table A3)[6]. If managers are inclined to place high credence on the best case model D for timber production, and high belief in

[5] Under formal adaptive management, the answer is naught! But there may be other motivations for monitoring beyond resolving uncertainty associated with two or more alternatives. We revisit this theme in section 3.1.

[6] Note that in this simple example where there are only two competing models for each objective, Pr{model B} = 1- Pr{model A} for biodiversity, and Pr{model C} = 1- Pr{model D} for timber.

the relatively benign best case model A for biodiversity, then alternative I involving intensive silviculture over a large portion of the estate is the best choice (the bottom right corner of Table A3). But if the belief in model A falls below 0.7 (i.e. there is substantial support for the relatively grim model B) then the best option is low intensity silviculture over a reduced area of the forest estate (alternative IV). Alternatives II and III are also in the mix, depending on probabilities assigned. Table A3 delineates probabilistic zones in which each alternative is preferred. These delineations can be thought of as *thresholds* for triggering a change in management strategy. If our beliefs change such that a threshold is crossed, then a change in management may be warranted (Martin et al. 2009).

Table A2. Consequences for biodiversity and timber yields under each alternative management regime. Models A and D represent best-case scenarios for biodiversity and timber yield, respectively, and models B and C worst-case.

management alternative	biodiversity - number of species in decline		timber yield ('000m^3)	
	model A	model B	model C	model D
I	8	20	130	200
II	3	10	65	100
III	2	6	40	70
IV	0	4	0	45

Let's say the wrangling over beliefs in competing models bubbles along until an agreement is begrudgingly reached among managers of the two branches that the best case model for biodiversity conservation seems less likely than the worst case, but that the best case for timber production is more plausible than the worst case. Accordingly, Model A is assigned a probability of 0.3 and Model D a probability of 0.8. Consulting Table A3, the preferred alternative is IV, with a reduced area available to timber production and a silvicultural system of lesser intensity.

Some in the timber management branch feel aggrieved. They suspect the emphasis on worst case for biodiversity consequences is misplaced. They vigorously support an adaptive management monitoring program, with a quiet conviction that over time results will indicate harm to biodiversity is limited and Alternative I a better alternative. Should the organisation proceed with adaptive management in this circumstance?

Before we get into the nitty gritty of answering that question, we note that the outcomes in Table A3 are specific to the value-based judgment underpinning the organisation's trade-off position, *avoiding decline in a single species is equally important as avoiding a loss of 7,000m^3 of timber.* Different emphases on biodiversity and timber will lead to different thresholds. Some value-based positions make our beliefs in competing models redundant. If there is a strong emphasis on timber production in the values of the organisation, Option I might always be the preferred alternative (within the context of plausible bounds described by best and worst case models). Likewise, beliefs in competing models can be immaterial if there is a strong emphasis on biodiversity – Alternative IV will be the best (at least within the set of alternatives under consideration here). We emphasise the place of value judgments and trade-offs because they have a key role in shaping the merit, or otherwise, of implementing adaptive management. If trade-off judgments are such that our beliefs in competing models won't lead to a change in management, what's the use of learning whether model A or model B (for biodiversity), or model C or model D (for timber production), is closer to the truth?

Table A3. The best management alternative under a set of probabilistic beliefs for competing models about the consequences for conservation and timber production, where the trade-off position is that avoiding decline in a single species is equally as important as avoiding a loss of 7,000m^3 of timber. The bold entry at Pr{A} = 0.3 and Pr{D} = 0.8 is the outcome relevant to our hypothetical cartoon. See text for details.

Pr{A} \ Pr{D}	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.00	III	III	III	III	III	III	III	IV	IV	IV	IV
0.10	III	III	III	III	III	III	III	IV	IV	IV	IV
0.20	III	III	III	III	III	III	III	IV	IV	IV	IV
0.30	III	III	III	III	III	III	III	IV	**IV**	IV	IV
0.40	III	III	III	III	III	III	III	IV	IV	IV	IV
0.50	III	III	III	III	III	III	III	IV	IV	IV	IV
0.60	III	III	III	III	III	III	III	IV	IV	IV	IV
0.70	III	III	III	III	III	III	III	IV	IV	IV	IV
0.80	II	II	II	II	II	II	II	II	I	I	I
0.90	II	II	II	II	II	I	I	I	I	I	I
1.00	II	II	II	I	I	I	I	I	I	I	I

Table A4. The expected value of perfect information under a set of probabilistic beliefs for competing models about the consequences for conservation and timber production, where the trade-off position is that avoiding decline in a single species is equally as important as avoiding a loss of 7,000m^3 of timber. The bold entry at Pr{A} = 0.3 and Pr{D} = 0.8 is the outcome relevant to our hypothetical cartoon. See text for details.

Pr{A} \ Pr{D}	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
0.10	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.20	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01
0.30	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	**0.02**	0.02	0.02
0.40	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
0.50	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04
0.60	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.04
0.70	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05
0.80	0.01	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.03
0.90	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02
1.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00

Now, returning to the question of whether or not to proceed with adaptive management. Here's something that is spectacularly under-appreciated by those spruiking the virtues of adaptive management: it's not always worth the effort. In his pioneering work, Carl Walters recognized that the costs of monitoring can be substantial, and that resolving or reducing uncertainty through monitoring may come at too high a price. In short, managers may be better off to set and forget. Before implementing adaptive management, managers should question the value of information to be obtained from learning via monitoring and research (Williams et al. 2012).

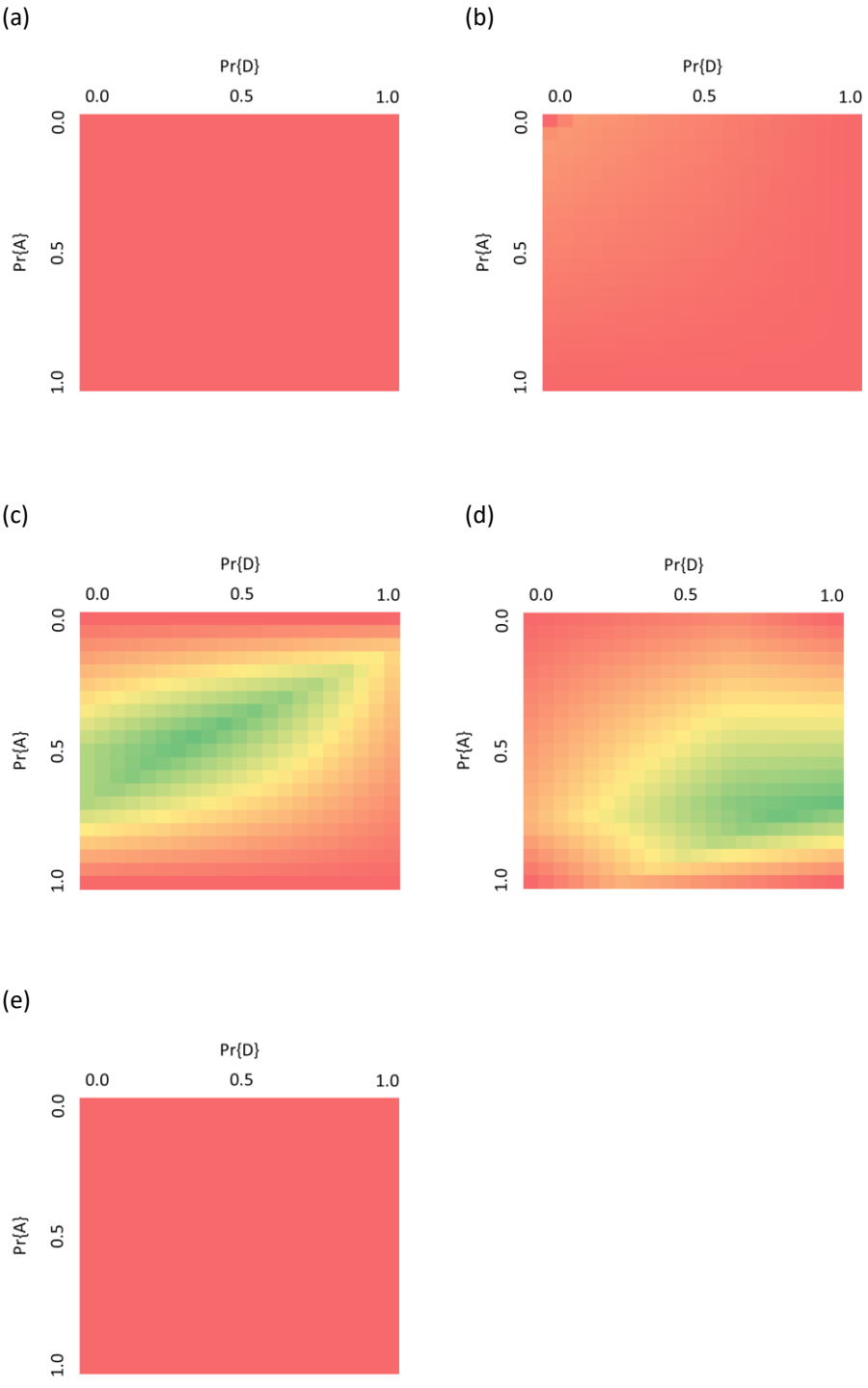
There are several variants on the formula for calculating value of information, the simplest of which is the expected value of *perfect* information (i.e. no possibility of error in interpretation of the signal in noisy data). Outcomes of the calculation for our cartoon example are shown in Table A4. Intuitively, there is no value to learning if our beliefs are absolute (the four corners of the body of Table A4) – there is no uncertainty to resolve! The green zone represents the area of highest information value, corresponding to the thresholds where all four alternatives are in play (see Table A3). The highest value reported in Table A4 is 0.05, where Pr{A} = 0.70 and Pr{D} = 0.90. What does this mean? It means that if you're starting with a 0.70 belief in the best case model for biodiversity and a 0.90 belief in the best case for timber production, then *at most*, you should be willing to pay up to 5% of the total stakes involved in the decision to meet the costs of monitoring under adaptive management. The total stakes in the decision is 20 threatened species and 200,000 m^3 of timber. If, after anguishing over the monetary equivalent of this proposition, managers estimate that the costs incurred in monitoring will be greater than 5%, then adaptive management is not worth the fuss. For our cartoon, the critical value at Pr{A} = 0.3 and Pr{D} = 0.8 is 2%. At this level, the modest value of information may make adaptive management a poor spend for the organisation, at least in this instance.

Recall that Table A4 is the value of information for the trade-off position, *avoiding decline in a single species is equally important as avoiding a loss of 7,000m^3 of timber.* Relative outcomes are shown for a set of trade-off positions in Figure A2. Where the importance of timber production values is heavily emphasised (Figure A2a), the value of information is always zero because we will always prefer Alternative I, no matter what we learn from monitoring about the credibility of competing models from monitoring. Similarly, heavy emphasis on biodiversity conservation (Figure A2e) can lead to no use for learning because we will always prefer Alternative IV. At intermediate trade-offs, the value of information can be substantial, but it depends on where you start with your probabilistic beliefs and on your trade-off position (see the qualitative contrast in the zones of highest value in Figures A2c and A2d).

The cartoon explored here is a gross simplification of most strategic decisions forest managers make. But it demonstrates the key steps that are needed if an organisation wants to formally and judiciously implement adaptive management. Specifically:

i. Managers articulate objectives of relevance.
ii. Mangers and stakeholders identify a set of candidate alternative management actions or strategies.
iii. Scientists need to estimate the consequences of each candidate alternative against each objective, and describe the uncertainty in those estimates.
iv. Managers (usually in consultation with stakeholders) state their trade-off position(s).
v. Mangers and/or scientists assign beliefs to uncertain outcomes and identify the preferred alternative under uncertainty.
vi. Managers and/or scientists estimate the value of information and decide whether to (a) implement the preferred alternative provisionally together with a monitoring program under an adaptive management framework, or (b) set and forget, where the preferred alternative is implemented for the foreseeable future and any potential insights from monitoring are foregone.

Figure A2. Expected value of perfect information (EVPI) for a set of five different trade-off positions, where the value judgment is that avoiding decline in a single species is equally important as avoiding a loss of (a) 23,000m^3 (b) 15,000m^3 (c) 10,000m^3 (d) 7,000m^3 (e) 4,000m^3 of timber. Red, EVPI ≈ 0, yellow ≈ 0.02, green ≈ 0.05.



Many organisations have the capacity to work through most of these steps. The stumbling blocks will often be step iv (trade-offs) and step v (assigning beliefs to uncertain future consequences). Making value judgments and stating trade-offs explicitly is a non-trivial technical task, but even where these difficulties can be overcome, the

appeal to evidence-based decision-making can sit uneasily with what is plainly a subjective judgment. Yet these judgments are an unavoidable element of decision-making where two or more objectives are involved. Assigning beliefs can also be a substantial technical task in interrogating data or eliciting expert judgment. Many scientists are capable of deploying these methods, but the more salient issue is often one of trust. If stakeholders do not grant the organisation authority to make these assessments and judgments then muddling through can seem the only path forward.

The diverse and sometimes diametrically opposed views of stakeholders might be the most powerful argument for persisting with adaptive management, even in circumstances where the organisation itself may see little value to learning through monitoring. Our carton caricature included hints of terse exchange between different branch managers. These dynamics are commonplace in large organisations. It's possible, as in our little cartoon, that key individuals within organisations can overcome their differences to the point where they are able to make sensible decisions about management directions under uncertainty, and indeed, whether or not it's worth implementing adaptive management. The same can't always be said about stakeholders and the positions they adopt at critical junctures in the planning cycle of forest management. For those reliant on the timber resource for a livelihood, motivated reasoning can lead to strong beliefs that consequences for non-timber values are benign, and a value-based conviction that access to timber is more important than conservation. If we were to go through the sort of analysis described above with these stakeholders, we may arrive at the outcome shown in Figure A2a: monitoring isn't needed because Alternative I (with large tracts of intensively managed forest available to timber production) is always the answer. Of course, the exact opposite may be the case if we were to indulge the exercise with conservationists. Again, we don't need to learn anything because the answer is always Option IV (Figure A2e). But for the agency or organisation(s) responsible for forest management, these polarised outcomes represent the very settings where an improved evidence base via appeal to adaptive management may look to be the *only* way to obtain a social license to operate in the short term and to progress a rough consensus over the longer term.

A3. OTHER APPROACHES TO EVIDENCE-BASED DECISION-MAKING

How can we bridge the gap between data capture and decision-making? Adaptive management is the bog standard response from the scientific community. But under formal adaptive management, monitoring and data capture are preceded by a grinding exercise in structured decision-making involving objectives, alternatives, consequences and trade-offs (Figure A1). These preceding steps are major structural elements of the bridge, but few managers or organisations seemingly have the stomach to take them on.

Westgate et al. (2013) reviewed evidence for uptake of adaptive management in the published literature dealing with biological systems. 'Uptake' included the following six elements:

- Identification of management objectives
- Specification of two or more alternatives
- Implementation of two or more management alternatives
- A rigorous process for interpreting how the system responds to management interventions via models or experimental design
- Regular monitoring of system response to management interventions.
- Adjust management practice in response to results from monitoring.

Of 61 articles claiming to describe adaptive management applications, only four included all six elements.

The challenges of implementing adaptive management are not restricted to those associated with formally embedding monitoring in a structured decision-making process. In a survey of 243 conservation managers in Australia and overseas, Dixon et al. (2019) asked respondents to self-rate the extent to which a suite of factors explained the success or otherwise of monitoring and evaluation programs within their organisations (Table A5). Results suggest that prospects for success are better where:

- managers and scientists work closely together,
- objectives are documented,
- monitoring of the performance of actions has been long term, and
- systems are in place to store, analyse and report on monitoring data.

When asked what could be done to improve monitoring in their organisation the most common response among respondents was an increase in funding.

A3.1 MOTIVATIONS FOR MONITORING BEYOND SCIENTIFIC UNCERTAINTY

This review has emphasised scientific uncertainty as the motivation underpinning adaptive management. But much monitoring effort might be less about resolving uncertainty and more about the managerial need for accountability and diligence in the expenditure of organisational funds. These settings rarely include explicit consideration of uncertainty or alternative courses of action. But they can be roughly regarded as adaptive through provision of an evidence base for policy and decision review. In concept, monitoring motivated principally by public accountability (e.g. reporting on Montreal Process criteria and indicators) relies on socio-political processes to prompt policy change, whereby stakeholders express dissatisfaction with status and trend and institutions adjust accordingly (albeit slowly). Monitoring motivated by diligence that reveals poor outcomes from any management action should prompt a rethink of what course of action might be more appropriate but is no guarantee to do so (Martin et al. 2012). Formal use of adaptive management anticipates the possibility of non-desirable outcomes and defines effect sizes or thresholds that trigger a change in management and what that change involves (as illustrated in Table A3). In short, public accountability and diligence monitoring relies on stakeholders or managers being alert to trends of concern and institutions responding nimbly to those concerns. Adaptive management, at least in concept, avoids these pitfalls but requires stakeholders and managers to work through a raft of biophysical and value-based considerations to arrive at a reasonable consensus on critical effect sizes and thresholds, and alternative management arrangements when those triggers or thresholds are breached.

A related perspective on motivations for monitoring is that it can help inform considered debate among stakeholders about policy directions. An important finding in the psychology of decision-making is that people rarely have static views on the importance of different values. Rather, their position on different objectives and trade-offs evolves dynamically and according to the context at hand (Gregory et al 2012). A shift in the weight of public opinion is clearly evident in the broad sweep of change in native forest management in Australia since the 1960s. Access to analyses and data describing long term status and trend in key values can be an important part of informing social and organisational positions in contested policy settings and catalysing change. Untargeted monitoring has on occasion been highly influential in triggering and informing urgent action (Wintle 2018).

Table A5. Questions included in the survey conducted by Dixon et al. (2019). Highlighted questions indicate the top seven aspects that were found to be correlated with perceptions that monitoring and evaluation were 'working very well' or 'somewhat well.'

Theme	Potential explanatory variable
Institutional arrangements	***Organisation type***
	Is it mandated (by policy or by legislation) to report on the impact to biodiversity?
	How many of the people responsible for carrying out the management action also carry out biodiversity monitoring?
	Is there a dedicated research section in your organisation?
	How closely and cooperatively do research and management staff work together?
	Have data been used to inform management?
Design and implementation	***Are there documented management objectives?***
	Are objectives specific, measurable, achievable, relevant and time-bound (SMART)?
	Are there documented biodiversity thresholds in place that will trigger management intervention?
	Are there documented management intervention options?
	How frequently is biodiversity monitoring undertaken?
	How long has monitoring been conducted in relation to the management action?
	Is monitoring for the management action part of larger biodiversity monitoring program?
	Is the management action implemented in different ways to facilitate learning?
Data management	What type of monitoring data are collected?
	Is there a written monitoring data collection protocol?
	What happens to the monitoring data when they are collected?
	Where are the monitoring data stored?
	How frequently are monitoring data reported?
Resourcing	Is the budget for monitoring separate to the management budget?
	Has the monitoring budget increased, decreased or remained stable over the last 10 years?
	What is the primary source of funding for biodiversity monitoring?

A3.2 EXAMPLES OF EVIDENCE-BASED MANAGEMENT, OR ATTEMPTS THEREOF

In this section we summarise examples of monitoring applications in natural resource management that seek to inform evidence-based management, not all of which make an explicit claim to be implementing adaptive management.

LONG TERM MONITORING OF THE GREAT BARRIER REEF

The Australian Institute of Marine Science has been monitoring status and trend of coral cover and various threats to the Great Barrier Reef for over 30 years (AIMS 2020). While most of the funding for the monitoring program is publicly sourced, there is no formal link between monitoring outcomes and decision making by public agencies charged with the responsibility of managing the reef. Despite the absence of a direct bridge spanning data capture and decision-making, it can be argued that the monitoring effort has made a very substantial contribution to public debate about use of the reef and adjacent catchments. Outcomes are regularly reported, and the data are publicly available and readily accessible on the internet (see https://eatlas.org.au/home).

THE MONTRÉAL PROCESS

The primary contribution of the international Montréal Process has been a set of criteria and indicators of 'sustainable forest management' (Montréal Process Working Group 2015). Participating countries and jurisdictions report status and trend for a suite of forest values, including biodiversity, productive capacity, ecosystem health, soil and water, and carbon. Although there are clearly trade-offs among these values, the Montréal Process does not prescribe how decisions in the interests of sustainability should be made on the basis of indicator status and trend. The process is essentially one of public accountability, including accountability to the community of interested international stakeholders. Like the Great Barrier Reef long term monitoring program, it can be argued that expenditure on data capture, analysis and reporting under the Montréal process is a worthwhile contribution to debate on sustainable forest management. Of course, there is considerable scope for counter-argument, especially if specific decision contexts are not developed.

CHESAPEAKE BAY RESTORATION

The Chesapeake Bay Program (see https://www.chesapeakebay.net/) is a large scale and longstanding restoration effort in the northeast United States. Formed in 1983, the program involves partnerships among 20 or so federal and state agencies, plus many research institutions and non-government organisations. Monitoring is focussed on tracking progress towards aspirational goals that include 40% reduction in nutrient inputs, protection of 460 km^2 of seagrass habitat, and 20% of catchments preserved from development. Alternative management actions or strategies for achieving these goals are not expressly articulated, nor their feasibility formally assessed. Data from monitoring are rarely used to test and update the credibility of competing models. Trade-offs with other values that may be compromised in the advancement of notional goals is explored on the fly in committee settings. Although not couched in a formal adaptive management framework, the program has made considerable progress in improving the health of Chesapeake Bay. Some in the science community advocate for a more rigorous adaptive management approach (Boesch 2006), but the focus of the program in its use of monitoring data remains tracking progress against agreed goals and compelling further commitment and action from member organisations where trends disappoint.

MOLONGLO URBAN DEVELOPMENT

The Australian Capital Territory's Molonglo Adaptive Management Strategy (ACT Government 2013) was developed as part of a strategic assessment under the Commonwealth's *Environment Protection and Biodiversity*

Conservation Act 1999. The strategy includes goals for the protection of listed communities and species. For example, maintaining and enhancing the ecological condition of designated box-gum woodlands, temperate grasslands and habitat for the pink-tailed worm-lizard. Monitoring in this regulatory setting is essentially an exercise in demonstrating compliance. Where trends suggest goal failure, the strategy implies a requirement for additional investment in a raft of management actions dealing with weeds, pests, fire and recreation. That is, the strategy provides a mechanism for regulators to call for further action, without identifying what actions are most appropriate or most effective. Although the strategy claims to be underpinned by the principles of adaptive management, there is no visible attempt to assess the (uncertain) payoff of alternative actions against specified goals, or to update beliefs about the effectiveness of different actions in the light of monitoring insights.

NSW LOBSTER FISHERY

The overarching goals of the NSW Lobster fishery management strategy (NSW DPI 2007) extend beyond the traditional target species focus to include mitigation of harvesting impacts on marine biodiversity and social equity. The strategy details a hierarchy of objectives and management actions. Model development is encouraged as part of the set of actions for uncertain aspects, with subsequent collection of data and model updating. The strategy includes a suite of performance indicators to be monitored and a set of thresholds, which when exceeded, trigger a review of management. Reviews 'will determine the suspected reasons for the breach of the trigger point and whether any action is required'. We term this approach adaptive management 'lite'. It includes many elements of formal adaptive management, but in contrast to the analyses underpinning Table A3, thresholds are not derived from a structured decision analysis, nor is the nature of the management response prescribed when thresholds are exceeded. Instead, they are approximate judgments of when outcomes may be considered undesirable or unacceptable, and a committee is typically charged with the responsibility of identifying appropriate remedial action(s).

NSW THREATENED SPECIES MANAGEMENT

Monitoring, evaluation and reporting under the NSW Saving Our Species program (NSW OEH 2018) is similar to the approach adopted by the NSW lobster fishery. Simple models predict the response of threatened species to management intervention over time, including a range of uncertainty, the lower bound of which effectively acts as a threshold for review. Monitoring of species status and trend tracks the extent which actual responses are consistent with model predictions. Monitoring effort is also devoted to status and trend of threats. Where the response of species falls short of the range of predicted outcomes a review is triggered. Again, the thresholds for review are not formally embedded in a structured decision-making process where the consequences of alternative candidate actions are assessed. It is left to a committee to devise an appropriate response where outcomes disappoint.

DUCK HUNTING ON THE PRAIRIES OF NORTH AMERICA

The US Fish & Wildlife Service instigated one of the few practical examples of formal adaptive management in the mid-1990s . The program continues to this day, although monitoring has substantially reduced the uncertainties encountered 25 years ago (Johnson et al. 2015). At that time, the agency was mired in claims and counter claims of hunters and conservationists over the merits of liberal and conservative bag limits. After a long and difficult (but ultimately worthwhile) stakeholder engagement process, scientists were able to develop a set of competing models that captured the range of views about population response to reduced densities associated with harvesting. Different swathes of the prairies were managed under different models, outcomes monitored, and model beliefs updated. The area managed under each model is adjusted over time, proportional to belief in credibility. Technical rigour has underpinned much of the program's success. But the capacity of adaptive

management to capture and reconcile the strongly divergent views of entrenched stakeholders has also highlighted the story's social success.

AUSTRALIAN COMMONWEALTH FISHERIES

Since 2007, catch limits for most commercial fisheries in Commonwealth waters have been set using a formal harvest strategy policy, a variant of adaptive management (Smith et al. 2014). The overarching objective is to maximise economic yield within a constraint of maintaining biomass above specified threshold levels. The system also accounts for uncertain environmental perturbations through specification of an acceptable level of risk for falling below threshold biomass. There is scope for learning about risk exposure and tolerable risk. Monitoring focuses on biomass estimates (via catch per unit effort), and quotas are frequently adjusted according to the confidence with which thresholds can be maintained. Again, the system represents a very substantial technical achievement, and is broadly accepted by key stakeholders.

In Table A6, we summarise how each of these examples stack up against key elements of formal adaptive management. Only two of the eight examples could be considered the real deal. But departures from strict formalism need not imply ineffective use of monitoring data in decision-making

Table A6. Eight natural resource management applications of monitoring programs aimed at informing decision-making, and the extent to which they fulfil the criteria of Westgate et al's (2013) interpretation of adaptive management. 1 = identification of management goals, 2 = specification of two or more management options, 3 = inclusion of a rigorous statistical process for interpreting how the system responds to management interventions (quantitative conceptual models and/or a rigorous experimental design), 4 = number of management actions implemented (ideally two or more), 5 = regular monitoring of system response to management interventions 6 = adjust management practice in response to results from monitoring.

Application	**1**	**2**	**3**	**4**	**5**	**6**
Great Barrier Reef long term monitoring	no	no	yes	no	yes	no
Montréal Process	yes	no	yes*	no	yes	no
Chesapeake Bay restoration	yes	no	yes	no	yes	yes
Molonglo urban development	yes	yes	no	no	yes	yes
NSW lobster fishery	yes	yes	yes	no	yes	yes
NSW threatened species management	yes	yes	yes	no	yes	yes
Duck hunting on the prairies of North America	yes	yes	yes	yes	yes	yes
Australian Commonwealth fisheries	yes	yes	yes	yes	yes	yes

**statistical rigour varies across participating jurisdictions*

A4. OPTIONS FOR EVIDENCE BASED MANAGEMENT OF NSW FORESTS

This review has canvassed a number of different approaches to evidence-based continuous improvement. The right approach probably depends on the setting of specific decisions, as well as the resources made available to agencies, and their technical capacities. Here's a list of candidates for bridging the gap between data capture and decision-making:

- Status and trend monitoring
- Goal setting
- Notional thresholds (adaptive management lite)
- Formal adaptive management

Within each approach, we may consider two options for transparency:

- ready public access to data and reports, and dedicated public engagement;
- limited public access (data and reports are kept in-house).

And of course, we may also encounter circumstances where monitoring appears to be of no use, in which case we may opt for,

- set and forget.

In Table A7, we classify the eight examples according to the approach used to promote evidence-based decision-making.

Table A7. Coarse classification of eight natural resource management applications of monitoring, according to their approach to promoting evidence-based decision-making.

Approach	Description	Examples
Status and trend	A set of indicators representing important values are monitored over time. The decision context is vague or unspecified.	Great Barrier Reef long term monitoring Montréal Process
Goal setting	Aspirational goals are set for key objectives in the absence of formal models linking management actions to outcomes. Further investment is urged where monitoring suggests goal failure.	Chesapeake Bay restoration Molonglo urban development
Notional threshold (Adaptive management lite)	Changes to management are considered where monitoring indicates thresholds have or will be breeched, typically in a committee setting. Thresholds are based on intuitive notions of unacceptability rather than a formal structured decision analysis.	NSW lobster fishery NSW threatened species management
Formal adaptive management	Changes in management as evidence form monitoring accumulates have been pre-determined through a formal structured decision-making exercise. Thresholds for change are switch points in the merit of alternative actions or strategies based on probability weighted consequences and value-based positions on trade-offs.	Duck hunting on the prairies of North America Australian Commonwealth fisheries

Which approach is best? Our opinions don't really matter. In truth, we're poorly placed to judge what's needed by NSW agencies involved in forest management. In the next stage of this project, we'll be interviewing NSW agency staff to gather their perspectives. But we're brazen enough to offer, by way of concluding remarks, the dot points below as tentative thoughts on each of the approaches listed in Table A7.

- 'Status and trend' may be a reasonable approach if the motivation for monitoring is to engage public debate. In this setting, it seems self-evident that public access to data and reports is made readily available. Its main drawback is that despite clear evidence of decline in important values, governance failures can lead to inaction (Martin et al. 2012).
- 'Goal setting' can be foolhardy. Setting aspirational goals without thinking through their feasibility, implicit trade-offs, and their exposure to uncertainty can lead to frustrated managers, disenchanted stakeholders, and policy paralysis. It may be appropriate in regulatory settings (e.g. the Molonglo strategic assessment) where statutory requirements provide reasonable clarity on what goals are appropriate (e.g. no net loss) and regulators and proponents require a clear basis for demonstrating compliance.
- The 'notional threshold' approach (adaptive management lite) comes without the burden of a formal structured decision-making exercise preceding a commitment to learning via monitoring, which can be seen as both a strength and a weakness. Unlike 'status and trend' monitoring, thresholds provide a trigger for review and possible change in management. There is a growing literature on how to implement the approach (Addison et al. 2016, Cook et al. 2016, de Bie et al. 2017), including application to forest management (Wintle and Lindenmayer 2017).
- 'Formal adaptive management' is the most rigorous approach, and the most appropriate *if*, (a) scientific uncertainty is the motivation for monitoring, and (b) the preceding structured decision making exercise indicates substantial value to the information to be acquired through monitoring.
- 'Formal adaptive management ' is the only approach that clearly offers a defensible basis for 'set and forget'. One of the core emphases of the Program Framework (NSW Natural Resources Commission 2019) is cost-effectiveness. Although adaptive management has been widely touted as a key underpinning of modern natural resource management its implementation can involve high costs. Often substantial transaction costs are involved in agencies formulating coherent and effective adaptive mechanisms. Sometimes the costs of acquiring data aimed at resolving uncertainties that motivate the use of adaptive management may be greater than the anticipated costs of sub-optimal management. Where the value of information is modest, 'set and forget' can be justified.

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APPENDIX 2 – ONLINE SURVEY

WELCOME!

This project is exploring opportunities to improve how existing NSW agency monitoring, evaluation and research data programs can better inform adaptive forest management and decision making. The focus is determining what can be done to bridge the gap between data capture and adaptive decision making. Outcomes will be identification of areas for potential improvement, for consideration by the NSW Forest Monitoring Steering Committee.

Thank you for your participation in this survey. This research is being conducted by the School of BioSciences, University of Melbourne, on behalf of the NSW Natural Resource Commission. All responses to this survey will be anonymous.

We anticipate the survey will take approximately 20 minutes. If you have any questions regarding the survey or the project, please contact Kelly de Bie (kelly.debie@unimelb.edu.au).

PLEASE READ THIS CAREFULLY. THE SURVEY MAKES LITTLE SENSE IF YOU DON'T!

One common sense way of linking monitoring and organisational decision-making is to identify targets or thresholds which managers would use as triggers to revisit management arrangements when data indicates significant changes and unsatisfactory outcomes.

Let's say there are three approaches to monitoring against targets or thresholds:

- formal adaptive management,
- stakeholder driven, and
- model driven.

And two other options that may be worth considering:

- status and trend monitoring, and
- no monitoring.

Here in this survey we're interested in your views of each approach on the assumption that your organisation may have some interest in using them. The main elements of each approach are shown in the table below. Please take a moment to think about each of the five approaches, their strengths, and their weaknesses.

Approach	Description
Formal adaptive management	Changes to management are made as evidence from monitoring accumulates. These changes have been pre-determined through a formal structured decision-making exercise. Thresholds for change are switch points in the merit of alternative actions or strategies based on probability weighted consequences and value-based positions on trade-offs.

Stakeholder driven	Targets or thresholds are set for key values and indicators based on some sense of what would be considered acceptable performance among stakeholders. It is unclear whether or not targets are feasible. Remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Model driven	Targets or thresholds are set for key values and indicators based on predictive modelling linking management and outcomes. Although success is not guaranteed, targets are considered feasible because they are set within the bounds of model uncertainty. Again, remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Status and trend	A set of indicators representing important values are monitored over time. No thresholds or targets are specified. Periodic reporting of monitoring results may or may not lead to changes in management.
No monitoring	No explicit attempt to learn about the performance of management through monitoring. Any change in management is based on piecemeal or anecdotal evidence.

In Part A of this survey we ask you about potential operational barriers to adopting each of the five approaches, one at a time. It will take about 10 minutes.

In Part B we ask you about knowledge gaps that might limit application of evidence-based decision making, irrespective of what approach is taken. Part B will take only a few minutes.

Part C is an open-ended question, simply asking if there is anything at all you would like to add.

In follow-up interviews, we'll be seeking some detail on your views on which approach (or approaches) you think are more appropriate in different circumstances.

PART A (Q1 of 5)

Recall our description of **formal adaptive management…**

Changes to management are made as evidence from monitoring accumulates. These changes have been pre-determined through a formal structured decision-making exercise. Thresholds for change are switch points in the merit of alternative actions or strategies based on probability weighted consequences and value-based positions on trade-offs.

What (if any) would you consider to be the main **operational barriers** or difficulties that your organisation faces in trying to develop and implement a **formal adaptive** management approach? Rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant or irrelevant	Somewhat relevant	Highly relevant
Difficulty in identifying objectives	o	o	o	o	o
Difficulty in specifying alternative management actions	o	o	o	o	o
Difficulty in modelling the (uncertain) outcomes of alternative management actions	o	o	o	o	o
Difficulty in trading-off competing objectives among forest managers	o	o	o	o	o
Difficulty in trading-off competing objectives among stakeholders	o	o	o	o	o
Lack of long term commitment to monitoring	o	o	o	o	o
Lack of organisational commitment to change should monitoring indicate change is warranted	o	o	o	o	o
Insufficient resources (financial and/or staff time)	o	o	o	o	o
Insufficient availability of technical skills	o	o	o	o	o
Insufficient collaboration between managers and scientists	o	o	o	o	o
Insufficient data management	o	o	o	o	o
Insufficient reporting of monitoring outcomes	o	o	o	o	o
Other (please specify)	o	o	o	o	o

PART A (Q2 of 5)

Recall our description of the **model driven** approach…

Targets or thresholds are set for key values and indicators based on predictive modelling linking management and outcomes. Although success is not guaranteed, targets are considered feasible because they are set within the bounds of model uncertainty. Again, remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.

What (if any) would you consider to be the main **operational barriers** or difficulties that your organisation faces in trying to develop and implement a **model driven** approach? Rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant or irrelevant	Somewhat relevant	Highly relevant
Difficulty in modelling the (uncertain) outcomes of current management	○	○	○	○	○
Difficulty in setting thresholds based on modelling predictions among forest managers	○	○	○	○	○
Difficulty in convincing stakeholders that model-based thresholds are appropriate	○	○	○	○	○
Lack of long term commitment to monitoring	○	○	○	○	○
Lack of organisational commitment to change should monitoring indicate change is warranted	○	○	○	○	○
Insufficient resources (financial and/or staff time)	○	○	○	○	○
Insufficient availability of technical skills	○	○	○	○	○
Insufficient collaboration between managers and scientists	○	○	○	○	○
Insufficient data management	○	○	○	○	○
Insufficient reporting of monitoring outcomes	○	○	○	○	○
Other (please specify)	○	○	○	○	○

PART A (Q3 of 5)

Recall our description of the **stakeholder driven** approach…

Targets or thresholds are set for key values and indicators based on some sense of what would be considered acceptable performance among stakeholders. It is unclear whether or not targets are feasible. Remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.

What (if any) would you consider to be the main **operational barriers** or difficulties that your organisation faces in trying to develop and implement a **stakeholder driven** approach? Rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant or irrelevant	Somewhat relevant	Highly relevant
Difficulty in setting acceptable thresholds among forest managers	o	o	o	o	o
Difficulty in setting acceptable thresholds among stakeholders	o	o	o	o	o
Lack of long term commitment to monitoring	o	o	o	o	o
Lack of organisational commitment to change should monitoring indicate change is warranted	o	o	o	o	o
Insufficient resources (financial and/or staff time)	o	o	o	o	o
Insufficient availability of technical skills	o	o	o	o	o
Insufficient collaboration between managers and scientists	o	o	o	o	o
Insufficient data management	o	o	o	o	o
Insufficient reporting of monitoring outcomes	o	o	o	o	o
Other (please specify)	o	o	o	o	o

PART A (Q4 of 5)

Recall our description of the **status and trend** approach…

A set of indicators representing important values are monitored over time. No thresholds or targets are specified. Periodic reporting of monitoring results may or may not lead to changes in management.

What (if any) would you consider to be the main **operational barriers** or difficulties that your organisation faces in trying to develop and implement a **status and trend** approach? Rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant or irrelevant	Somewhat relevant	Highly relevant
Lack of long term commitment to monitoring	o	o	o	o	o
Insufficient resources (financial and/or staff time)	o	o	o	o	o
Insufficient availability of technical skills	o	o	o	o	o
Insufficient collaboration between managers and scientists	o	o	o	o	o
Insufficient data management	o	o	o	o	o
Insufficient reporting of monitoring outcomes	o	o	o	o	o
Other (please specify)	o	o	o	o	o

PART A (Q5 of 5)

Recall our description of the **no monitoring** approach…

No explicit attempt to learn about the performance of management through monitoring. Any change in management is based on piecemeal or anecdotal evidence.

What (if any) would you consider to be the main **operational barriers** or difficulties that your organisation faces in trying to develop and implement a **no monitoring** approach? Rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant or irrelevant	Somewhat relevant	Highly relevant
Difficulty in convincing co-managers that no monitoring is appropriate	o	o	o	o	o
Difficulty in convincing stakeholders that no monitoring is appropriate	o	o	o	o	o
Other (please specify)	o	o	o	o	o

PART B (Q1 of 1)

What do you consider the key **knowledge gaps** that limit your organisation progressing the development and implementation of any approach to **evidence based decision-making through monitoring**? Please rate the following on a 5 point scale describing relevance, where 1 = completely irrelevant, and 5 = highly relevant.

	Completely irrelevant	Somewhat irrelevant	Neither relevant nor irrelevant	Somewhat relevant	Highly relevant
Poor understanding of biophysical processes	o	o	o	o	o
Poor understanding of socio-economic factors	o	o	o	o	o
Quality monitoring data	o	o	o	o	o
Identifying appropriate monitoring indicators	o	o	o	o	o
Poor understanding of natural environmental variability	o	o	o	o	o
Disentangling the effect of management from natural environmental variability	o	o	o	o	o
Other (please specify)	o	o	o	o	o

PART C (Q1 of 1)

Would you like to make any further comments regarding evidence based decision-making through monitoring?

Thank you for your time. Please click below to submit your responses.

APPENDIX 3 - INTERVIEW

ABOUT THIS INTERVIEW

This interview is part of a project exploring opportunities to improve how existing NSW agency monitoring, evaluation and research data programs can better inform adaptive forest management and decision making. The focus is determining what can be done to bridge the gap between data capture and adaptive decision making . Outcomes will be identification of areas for potential improvement, for consideration by the NSW Forest Monitoring Steering Committee.

Thank you for your participation. This research is being conducted by the School of BioSciences, University of Melbourne, on behalf of the NSW Natural Resource Commission.

All responses to this interview will be anonymous. We anticipate the interview will take approximately 20 minutes.

BACKGROUND TO THE INTERVIEW

In August of this year you were invited to participants in an online survey. The focus of the survey was barriers and difficulties encountered in different approaches to use of monitoring data to inform organisational decision-making.

Recall the different approaches to monitoring sketched in the online survey…

Approach	Description
Formal adaptive management	Changes to management are made as evidence from monitoring accumulates. These changes have been pre-determined through a formal structured decision-making exercise. Thresholds for change are switch points in the merit of alternative actions or strategies based on probability weighted consequences and value-based positions on trade-offs.
Stakeholder driven	Targets or thresholds are set for key values and indicators based on some sense of what would be considered acceptable performance among stakeholders. It is unclear whether or not targets are feasible. Remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Model driven	Targets or thresholds are set for key values and indicators based on predictive modelling linking management and outcomes. Although success is not guaranteed, targets are considered feasible because they are set within the bounds of model uncertainty. Again, remedial action is urged where monitoring suggests target failure, with the nature of that action decided 'on the fly'.
Status and trend	A set of indicators representing important values are monitored over time. No thresholds or targets are specified. Periodic reporting of monitoring results may or may not lead to changes in management.
No monitoring	No explicit attempt to learn about the performance of management through monitoring. Any change in management is based on piecemeal or anecdotal evidence.

A summary of the outcomes of the online survey is tabulated below.

Technical barrier or difficulty	Formal AM	Model driven	Stakeholder driven	Status and trend	No monitoring
Difficulty in modelling the (uncertain) outcomes of alternative management actions	•				
Difficulty in modelling the (uncertain) outcomes of current management		•			

Social or institutional barrier or difficulty	Formal AM	Model driven	Stakeholder driven	Status and trend	No monitoring
Difficulty in trading-off competing objectives among forest managers	•				
Difficulty in trading-off competing objectives among stakeholders	•				
Difficulty in convincing stakeholders that model-based thresholds are appropriate		•			
Difficulty in setting acceptable thresholds among forest managers			•		
Difficulty in setting acceptable thresholds among stakeholders			•		
Difficulty in convincing co-managers that no monitoring is appropriate					•
Difficulty in convincing stakeholders that no monitoring is appropriate					•
Lack of long term commitment to monitoring	•	•	•		
Insufficient resources (financial and/or staff time)	•	•	•	•	

This interview is about how we can improve things for considered use of monitoring into the future. It asks for your views on:

- Your organisation's motivations for monitoring.
- What approaches might best serve key motivations?
- How serious are perceived barriers and difficulties, and what are the prospects for overcoming them?
- The importance of public access and transparency.
- Short-term and longer-term improvements.

THE INTERVIEW

Q1. Organisations have different motivations for monitoring. Rate your perception of the relative emphasis of the following factors as motivations for *your* organisation's current investment in monitoring, in general.

Rank the following, with 1 being the motivation with the greatest emphasis (tied ranks are allowed).

- Accountability with respect to outcomes or targets
- Evaluate the effectiveness of management
- Public engagement in debate about use of native forests
- Appease stakeholder(s)
- Reduce scientific uncertainty
- Administrative diligence
- Other (please specify)…

Q2. In general, where do you think emphases *should* lie?

Rank the following, with 1 being the motivation with the greatest emphasis (tied ranks are allowed).

- Accountability with respect to outcomes or targets
- Evaluate the effectiveness of management
- Public engagement in debate about use of native forests
- Appease stakeholder(s)
- Reduce scientific uncertainty
- Administrative diligence
- Other (please specify)…

Q3. Question 2 asked you where you think emphases *should* lie. You identified ***X*** and ***Y*** as the highest ranking motivations.

Putting aside difficulties and barriers, which of the five approaches outlined in the Table on page 1 do you consider most appropriate for

X**?**

Y**?**

You selected ***x*** as the most appropriate approach for ***X***. Noting the barriers and difficulties identified in the Table on page 2 for ***x***…

Q4. On a scale of 0 to 10 (with 0 the worst and 10 the best) , how well do you think ***X*** will be served by ***x***

a. with neither *technical* nor *social/institutional* barriers and difficulties addressed

b. with both *technical* and *social/institutional* barriers addressed.

You selected ***y*** as the most appropriate approach for ***Y***. Noting the barriers and difficulties identified in the Table on page 2 for ***y***…

Q5. On a scale of 0 to 10 (with 0 the worst and 10 the best) , how well do you think ***Y*** will be served by ***y***

a. with neither *technical* nor *social/institutional* barriers and difficulties addressed

b. with both *technical* and *social/institutional* barriers addressed.

We assume that *technical* barriers and difficulties can be overcome with enough resources and organizational commitment.

Q6. Let's say that next year senior managers in your organisation commit to ***x*** (or ***y***) as the way forward for ***X*** (or ***Y***). What do you think are the prospects for successfully addressing each of the identified social/institutional barriers or difficulties associated with

x?

y?

Rate each from 0 to 10, with 0 being zero prospect of success and 10 being certain success.

Q7. Thinking now about public access and transparency. Which of the following options do you consider appropriate for ***X*** and ***x***?

☐ ready public access to data and reports, and dedicated public engagement;

☐ limited public access, data and technical reports kept in-house; summary reports made available periodically;

☐ not applicable (*no monitoring* selected)

Q8. Which of the following options do you consider appropriate for ***Y*** and ***y***?

☐ ready public access to data and reports, and dedicated public engagement;

☐ limited public access, data and technical reports kept in-house; summary reports made available periodically;

☐ not applicable (*no monitoring* selected)

Q9. In your view, what improvements could be undertaken in the short term (next 12 months) to promote better use of monitoring data in decision-making within your organisation?

Q10. What improvements will require a longer-term commitment? Why?