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Adaptive management for water quality planning – from theory to practice

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Abstract. Adaptive management has been promoted as a structured approach to learning in response to the uncertainty associated with managing complex systems. We developed and tested a protocol to guide an adaptive approach to water quality management in north-eastern Australia. The protocol articulates a framework for documenting uncertainties and performance expectations, negotiating feedback and anticipating iterative and transformative responses to future scenarios. A Water Quality Improvement Plan developed for the Tully–Murray catchment in the Great Barrier Reef region was used to test the protocol and three benefits of its use were identified. First, developing rigorous and timely monitoring and evaluation ensures that opportunities for iterative planning are realised. Second, anticipating future endogenous or exogenous changes to the plan enables the early initiation of actions to inform transformative planning responses. Finally, the protocol exposed the need to coordinate multi-scalar responses to tackle environmental knowledge and management uncertainties and assumptions. The protocol seeks to provide a practical translation of adaptive planning theory that will enable the benefits of adaptive management to be realised on the ground.

Additional keywords: collaboration, Great Barrier Reef, integrated, iterative, natural resource management, partnerships, risk, transformative, uncertainty, watershed planning.

Introduction

Adaptive management emerged as a scientific response to the management of complex systems in the 1970s (Holling 1978; Lee 1993). An adaptive approach involves adjusting actions in response to feedback on progress towards management objectives, as well as responding to contextual changes (anticipated or not) that may arise. Implementation of adaptive management approaches has occurred across a spectrum of styles (Broderick 2008), from formal experimental approaches (Walters 1986; Gunderson 1999) to recent work that focuses on the role of participation and social learning processes (Berkes and Folke 1998; Pahl-Wostl 2006). Although adaptive management is a well established concept that has received significant theoretical attention, there is limited evidence of its practical effectiveness (see Walters and Holling 1990; Lee 1999; Rogers *et al*. 2000). Schreiber *et al*. (2004) listed the vulnerabilities of adaptive management to both scientific limitations and social and institutional constraints. Little information is available to managers on how to undertake adaptive management (Allan and Curtis 2003). In the present paper, our focus is on a practical approach to guide structured learning in response to uncertainty in knowledge at the catchment scale.

It is useful to consider the distinction between adaptive responses through planning and implementation cycles separately. The planning cycle refers to the process that typically involves significant institutional review (i.e. a new plan) and operates over a longer time cycle (typically 5–10 years). During plan review, goals, objectives and strategies are changed in response to changing circumstances and change in knowledge. During the life of the plan, there is a series of relatively rapid implementation cycles during which management responds to feedback on progress towards objectives. This results in two distinct cycles of feedback and learning, with the implementation feedback cycle nested within the larger planning cycle (Fig. 1). The implementation cycle can be related to 'single-loop learning' that describes an iterative process that results in incremental policy change. Alternatively, a process of 'double-loop learning' (Argyris and Schön 1978) describes transformative

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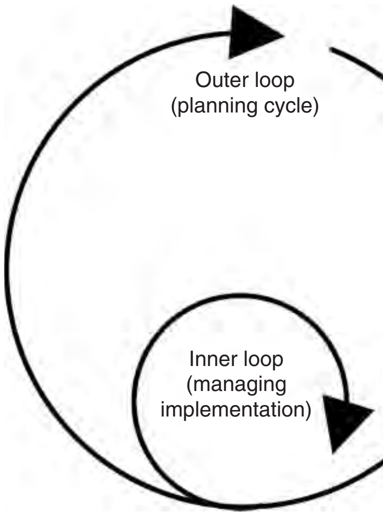


Fig. 1. Planning and implementation cycles of feedback (adapted from Jones 2005).

planning-cycle changes where the problem is reframed as a result of critical assumptions being revealed and tested. In this sense, transformative planning is a response to fundamental changes in the underlying knowledge of system behaviour and response. Throughout this paper, we relate adaptation through the implementation cycle to iterative planning, and adaptation through the planning cycle as potentially transformative planning.

The protocol was applied to catchments in north-eastern Australia (fig. 1 in Kroon 2009), where the Great Barrier Reef (GBR) is threatened by the water quality impacts of land-based pollution (Hughes 2008). The Australian and Queensland Governments developed the Reef Water Quality Protection Plan (Anonymous 2003*a*) that contains actions to manage these threats. The Reef Water Quality Protection Plan is supported by catchment-based Water Quality Improvement Plans (WQIPs). WQIPs are developed and implemented by non-government organisations (regional natural resource management bodies) and rely heavily on collaborative partnerships to support voluntary practice change through a variety of incentive mechanisms (Kroon 2009). This context has two critical implications for plan development and implementation: knowledge uncertainty and collaboration.

Uncertainty in complex systems arises from both irreducible uncertainty inherent in the issue and the presence of multiple perspectives (Funtowicz and Ravetz 1994). Knowledge integration describes the challenge of developing a holistic 'systems' understanding from diverse and often incomplete or inadequate data and information sources. Kroon *et al.* (2009) identified knowledge integration challenges in resolving tensions between the uncertainty and bias in different types of knowledge brought to the planning process. Negotiating solutions within this 'swamp of real life' (Schön 1995) highlights the importance of collaborative planning, action and learning processes. The use of deliberative processes to facilitate this negotiation across multiple institutions (social learning) is promoted as a mechanism to support transformative planning and action (Steyaert and Jiggins 2007).

Methods

The analysis presented here is the result of an iterative process of reflection and discourse within a multi-disciplinary project team. The project team comprised biophysical scientists (authors B.H., J.P. and R.G.), social scientists (C.R. and B.T.) and practitioners (R.E. and J.W.). All members of the team were concurrently engaged in catchment-level planning activities across the GBR and elsewhere in Australia, through scientific advice, science coordination, strategic planning and research roles. The project team was thus a Community of Practice (Wenger 1998) that built upon a shared history of experiential learning and reflection through open discussion around the business of water quality planning. The deliberations of the project team were strongly influenced by the practical challenges faced by water quality planners in the GBR. The project team considered the technical challenges of knowledge integration and synthesis, and the social dimensions of collaborative partnerships to be strong determinants of the capacity and nature of planning adaptation.

Protocol design and description of elements

The purpose of the adaptive management protocol is to establish a 'best practice standard' to guide catchment planners in developing and articulating adaptive approaches to water quality plans. The project team identified three categories of knowledge uncertainty that may trigger iterative or transformative changes to the plan: system understanding, measuring progress and anticipating changes. Each category contains two elements that describe the current knowledge and actions proposed. Negotiating, documenting and communicating the uncertainty and responses were considered to contribute to both the deliberative processes that support social learning as well as a structured approach to managing uncertainty.

The first category in the protocol relates to system understanding, and includes a conceptual model and learning objectives. The purpose of the conceptual model is to describe (in simple terms) the plan's logic of actions to outcomes through a series of cause–effect linkages. This element effectively describes the *hypothesis* of the plan, based upon the integration of current knowledge, and provides the baseline knowledge synthesis for iterative and transformative planning. Actions identified to address critical uncertainties within the conceptual model are described as learning objectives. By articulating the learning objectives, this element of the protocol seeks to provide direction for priority investigation, assessment or research activities to reduce uncertainty or test and resolve critical assumptions in the model. If achieved, the learning objectives could confirm or challenge the theory of action to outcomes articulated, and thus support iterative or transformative planning responses, depending on the timing and nature of the response triggered.

The next category of the protocol addresses uncertainty in measuring performance over time. Performance trajectories articulate the theory of change in elements of the conceptual model over time. While mapping performance trajectories is likely to prove technically challenging (and draw upon research findings and expert judgement), the trajectories communicate more information than targets set for some time in the future. Performance trajectories allow the consideration of expected lags in response times, an important issue when planning key milestones or triggers for review, and performance evaluation. Feedback loops describe the monitoring, assessment and reporting actions that will provide feedback on progress over time. By articulating what, when, how and by whom feedback will occur, this element of the protocol is designed to ensure monitoring and modelling activities will support iterative planning responses.

The last category of the protocol encompasses the anticipation of future scenarios that would require changes to the plan, and plan responses to those scenarios. This category is designed to open up the deliberative process to draw upon a wide knowledge base, including bureaucratic, technical and practical experiential knowledge, to consider what internal or external events are likely to have an impact on the implementation of the plan. Explicitly considering these scenarios enables the early preparation of additional or alternative strategies and guides supporting research and development priorities for transformative planning.

Protocol testing

The project team reviewed the draft Tully WQIP (Kroon 2008) as a case study to inform the application of the draft protocol. The Tully WQIP was chosen as a WQIP nearing completion that had a strong scientific foundation. The purpose of the review was to provide concrete examples to inform and test the development of the protocol. The author of the Tully WQIP was also interviewed to provide further information and clarification of uncertainty and risks that may not have been evident in the then-draft WQIP document.

The draft protocol was then iteratively tested and refined through scientific and practitioner review. The former was undertaken by a scientific advisory panel and the latter by a panel of regional and catchment planners. Both of these groups had been formally established as part of the governance arrangements of the Reef Water Quality Protection Plan. First, the two groups undertook a practical exercise using the protocol to work through a hypothetical scenario, and then discussed the results. Second, the revised protocol and a worked example of its application (developed by the project team from the Tully case study) were presented to the two groups for their consideration and feedback. In this way, the practitioner planners were actively involved as co-researchers, contributing to the co-construction of the protocol in a joint process with the formal research team.

Results

System understanding

In the Tully WQIP, the system understanding is expressed as a conceptual model based on a hierarchy of targets as per the National Framework for Natural Resource Management Standards and Targets (Anonymous 2003*b*). An aspirational target of at least an 80% reduction in nitrate load leaving rivers is set to meet draft marine water quality guidelines (GBRMPA 2007) to protect the health and resilience of inshore coral reefs. Modelling, however, suggests that this is not attainable from the adoption of the current suite of agricultural 'best' management practices, and instead an interim target of a 25% reduction in nitrate load is adopted, based upon modelling of 100% adoption of current best management practices (Armour *et al*. 2009). Although the level of uncertainty associated with these modelled estimates can be high (Hateley *et al*. 2006; Wooldridge *et al*. 2006), the Tully load estimates were assessed as only moderately uncertain because of general agreement between the modelled estimates and monitoring data (Brodie *et al.* 2009).

The key uncertainties identified by the catchment planner included the effectiveness of incentives in accelerating the adoption of best management practices, and the effectiveness of best management practices in achieving water quality benefits. The interim target adopted by the WQIP is still an ambitious one. Some doubt exists as to the likelihood of achieving 100% adoption of any practice, and particularly in achieving this within 5 years in sugarcane (the main crop grown), which has a cropping cycle of 4–5 years.

Performance measurement

The performance trajectories presented in the worked example (Fig. 2) were prepared by the project team using their expert knowledge. Different response characteristics are anticipated across elements and scales. For example, the delivery of incentives is assumed to be steady over time, while adoption rates are expected to accelerate initially as acceptance of new practices is built, then tail off as additional interest with the remaining 'non-adopters' wanes. Water quality benefits are expected to be slowly realised. There was scant information available to inform the drafting of these trajectories, and the project team considered the current knowledge base insufficient to attempt to generate a performance curve for the ecological response of coral reefs to water quality improvements.

Similarly, the feedback loops described in the worked example are based on generic roles and responsibilities for monitoring and evaluation in the GBR region that are not necessarily endorsed by all the organisations in question. For example, the regional NRM body reports actions and outputs each year, whereas industry partners could report adoption rates of key practices, and the state government has nominal responsibility for monitoring and modelling the impact of practices on nitrate loads. However, current monitoring initiatives in the catchment and across the GBR focus on measuring water quality at river mouths and the health of the marine ecosystem. The draft WQIP proposes monitoring and evaluation of intermediate outcomes, such as changes in adoption rates of recommended agricultural practices and paddock-scale outcomes, but the institutional responsibilities for monitoring, evaluation and reporting are unclear.

Future scenarios

The scenarios in the worked example were developed by the project team from the interview with the WQIP planner and discussions with the regional planners group. The two examples shown relate to adoption rates of new management practices not being realised (changes to program delivery are anticipated) and the difficulty in demonstrating water quality benefits as a result of changed management practices (the development of alternative management practices is anticipated). While the current strategy in the Tully WQIP relies on accelerated adoption of key management practices, the plan identifies other actions that would increase the pool of available strategies in the future. Of most interest is the prospect of new nutrient management practices in sugarcane that are expected to realise far greater water quality benefits (up to 86% reduction in nitrate loads) (Armour *et al.* 2009) than current industry standards. This appears to address

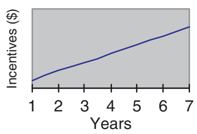
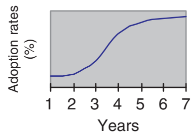
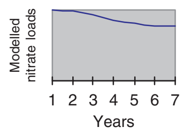
Category	Elements	Management actions	Management action targets	Resource condition targets	Aspirational targets
System understanding	Conceptual model	Actions to influence behaviour e.g. awareness, education, extension, incentives →	100% adoption of nutrient management practices within 5 years →	25% reduction in nitrate loads from rivers in 10 years →	<0.5µg L^{-1} chlorophyll *a* in coastal waters in ~50 years → Coral reef health and resilience restored in ~50 years
	Learning objectives	Effectiveness of incentives to improve uptake of new practices	Effectiveness of agricultural practices in improving water quality	Understanding influence of catchment processes	Understanding reef resilience and recovery trajectories
Measuring progress	Performance trajectories				Highly uncertain
	Feedback loops	Catchment group report actions and outputs each year	Agricultural industry partners report rates of improved practice uptake (2 years)	State government models water quality loads and impact of changed practices	Marine park authority monitors reef health and water quality impacts
Anticipating change	Scenarios	Insufficient funding to support full program	Expected adoption rates may not be realised	Investigative research determines that water quality benefits of key practices are overstated	Climate change severely impacts reef ecosystems
	Responses	Adjust performance trajectories	Adjust program delivery methods	Redirect incentives to better practices	Reconsider investment in water quality management

Fig. 2. A worked example of the adaptive management protocol applied to nitrate management in the Tully catchment.

the gap between what is achievable from the adoption of current best management practices and what is desirable to protect marine ecosystems. This is an example of anticipating iterative changes to the plan as additional actions become available for implementation.

Plans are implemented against a background of changing biophysical and socio-economic conditions. In the Tully WQIP area, the area of forestry land use is expected to expand in the future, driven by the emerging carbon trading market. The Tully WQIP identified the development of a regional forestry code of practice as important preparation for this anticipated change.

Of course, not all anticipated changes are well understood. Climate-change scenarios are being rapidly updated, and are expected to influence pressures through changes in land-use and management practices as well as ecological responses such as reduced resilience of coral reefs that may suffer increased bleaching episodes (McCook *et al*. 2007). Such changes could trigger transformative planning responses if the knowledge base and strategic responses change fundamentally. However, interrogation of models suggests that the direct impact of future climate scenarios (2030 and 2070) on the extent of sugarcane land use and the nitrate export from these lands to be negligible (Webster *et al.* 2009).

Discussion

The challenge of adaptive management

The management of water quality impacts on the GBR is characterised by high uncertainty and great urgency, highlighted by the inability of the Tully WQIP to articulate a strategy to meet the aspirational load reduction targets required to protect the GBR, and little understanding of the critical time scales in which to achieve this. WQIPs have no regulatory capacity so cannot consider or recommend complementary regulatory approaches such as land-use change. This is a common water planning experience, with Ison *et al*. (2007) characterising water management as a complex system of uncertainty and conflict between multiple stakeholders. Participation of those involved and affected throughout the planning process from conception to implementation is a fundamental principle for effective integrated planning systems (Lane and McDonald 2005; Robinson *et al.* 2009). Yet the capacity of decentralised institutions to deal with the diverse and competing interests that affect resource management priorities and activities remains a challenge. The pressure for rigorous and collaborative approaches to adaptive management is high.

Although adaptive management has been promoted as a scientific response to uncertainty, the documented failure rates are high (Gunderson 1999; Schreiber *et al.* 2004; Gunderson and Light 2006). Walters (1997) cited modelling difficulties, the costs and risks of large-scale experimentation, self-interest in research and management organisations, and fundamental value conflicts as barriers to adaptive management. Folke *et al.* (2007) suggested that the perception of failure may reflect a lack of appreciation of the social dimensions of ecosystem management, which in turn has stimulated a growing interest in the dynamics of institutional change and resilience thinking.

Planning to adapt

The protocol presented in the present paper provides the means to document and plan responses to the known uncertainties in system understanding, performance monitoring and future scenarios. Regional water quality planners in north-eastern Australia identified major uncertainties in each of these three areas. The testing of the protocol with the Tully case study demonstrated the potential benefits of its application. While the protocol plans for adaptation, the nature and timing of the responses triggered will determine whether the planning changes are iterative or transformative in nature.

Monitoring for management

The challenges associated with monitoring and evaluating changes in resource condition at the catchment scale are well documented (see Anonymous 2004; Chesson and Kingham 2005 for Australian examples). The draft Tully WQIP describes a set of objectives, and a set of actions to achieve them, without clearly articulating how monitoring will feed back into management decisions during the life of the plan or upon its review. Attributing changes in end-of-catchment loads to progressive adoption of specific agricultural practices is likely to prove difficult. Lag times and variability constrain the ability to directly measure changes in water quality at the end-of-catchment in management timeframes (Bainbridge *et al*. 2009).

The current Government monitoring programs in the Tully catchment and across the GBR focus on end-of-catchment loads and marine ecosystem health indicators, yet the protocol documentation clearly highlights that these measures are unlikely to show responses within the management timeframe of the plan (5 years), if at all. Environmental plans commonly use information from monitoring and modelling to develop objectives and strategies, but less often use these tools to investigate the consequences of uncertainty in achieving the plan's objectives (Bearlin *et al*. 2002; Schreiber *et al*. 2004). Embedding adaptation more explicitly into environmental plans entails thinking about how (and when) the results of monitoring will actually inform change in management actions. The draft Tully Plan identified the benefits of monitoring intermediate outcomes to provide timely performance feedback and allow iterative planning. Supporting the negotiation of a rigorous approach to performance measurement is the first practical benefit that emerges from the application of the protocol.

Anticipating changes

The distinction between iterative and transformative learning (Argyris and Schön 1978) proved a useful construct for adaptive management research and practice. The difference is helpful in separating the issues, responses and time scales associated with plan implementation and plan review. Actions to support implementation (iterative planning) focus on improving effectiveness by adjusting actions in response to performance feedback (described above) and short-term trial, research and investigation activities. Actions to support transformative planning will involve review and reflection on the goal, objectives and strategies of the plan. Actions in response could include developing alternate strategies, reforming key policies and anticipating significant changes that may impact on the achievement of plan objectives.

Importantly, some transformative changes can be developed early in the life of an environmental plan, and the Tully WQIP provides a number of examples where actions are initiated that may support transformative responses in the future. Gunderson *et al.* (1995) described transformative planning responses as being driven by endogenous or exogenous changes that trigger a plan crisis and adaptation. The protocol testing documented anticipated endogenous changes in system understanding, as well as exogenous changes driven by an expanding forestry sector and climate change scenarios. Maintaining an evolving strategic perspective through the plan implementation phase could contribute to the institutional flexibility that Lane and McDonald (2002) suggested is essential for effective environmental planning.

Appropriate scales

The challenges of knowledge integration associated with the development of the Tully WQIP noted by Kroon *et al.* (2009) also have implications for the adaptation of management and planning efforts. The capacity of decentralised natural resource management groups to facilitate the integration and translation of scientific and local knowledge at catchment and other scales has been questioned (Lane *et al*. 2004). In the testing of the protocol, it was evident that transformative planning efforts require knowledge feedbacks and management responses from multiple sources and scales. Many of the uncertainties identified in this case study were relevant to other regional WQIPs in the GBR, and action responses appear prohibitively expensive for individual catchment planning organisations. For example, monitoring and evaluation of outcomes, development of new agricultural industry 'best management practices', and climate change adaptation are all action responses that are relevant across scales. These findings are consistent with those of Holling *et al.* (1998) who found that environmental resource issues commonly need to be tackled simultaneously at several levels, and the potential for synergistic nesting of institutional responses described by Folke *et al.* (2007).

Government policy frameworks need to be clear and supportive for devolved planning processes to have significant influence at higher levels of governance (Koontz *et al*. 2004). The case study highlighted the lack of resolution of institutional monitoring responsibilities in the GBR, although the catchment planners' forum holds promise for cross-catchment coordination. Addressing and responding to these broader uncertainties requires the negotiation of bridges across the formal boundaries between planning systems and scales. In the GBR, this would involve a more explicit linkage of the objectives, strategy and timing between the overarching policy document (the Reef Water Quality Protection Plan) and catchment-scale WQIPs. In the double loop model (Fig. 1) used in the present paper, the inner loop of the Reef Water Quality Protection Plan would explicitly represent the sum of the planning cycles across all GBR catchments. Such an approach could support horizontal alignment across catchments through recognising and supporting their collective outcomes, as well as vertical alignment with government policy and planning processes at the larger scale. While this approach remains a theoretical proposition at this point in time, the negotiation of information inputs, learning feedbacks, management and policy actions across scales and planning boundaries is the third practical benefit that emerges from the application of the protocol. Such an approach could be considered an extension of the hierarchical approach advocated for the management of complex marine ecosystems (de la Mare 2005; Day 2008) to the wider suite of institutions and actions found on the terrestrial side of the coastline.

Conclusion

The adaptive management protocol developed through this research holds promise as a tool to negotiate the significant uncertainty associated with water quality planning at the catchment scale. Rigorous monitoring and evaluation is required to inform iterative planning. Testing assumptions and anticipating changes can be managed through proactive preparation for transformative responses. At the catchment scale, the need to negotiate planning boundaries across catchment planning and government policy domains constrains plan effectiveness. Two research priorities emerge from this work: (1) the process of applying the protocol to enable social learning needs to be tested and (2) the potential to nest adaptive management strategies across planning scales holds great promise in effectively responding to the uncertainty inherent in ecosystem management.

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