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Insight

Building resilient pathways to transformation when "no one is in charge": insights from Australia's Murray-Darling Basin

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ABSTRACT. Climate change and its interactions with complex socioeconomic dynamics dictate the need for decision makers to move from incremental adaptation toward transformation as societies try to cope with unprecedented and uncertain change. Developing pathways toward transformation is especially difficult in regions with multiple contested resource uses and rights, with diverse decision makers and rules, and where high uncertainty is generated by differences in stakeholders' values, understanding of climate change, and ways of adapting. Such a region is the Murray-Darling Basin, Australia, from which we provide insights for developing a process to address these constraints. We present criteria for sequencing actions along adaptation pathways: feasibility of the action within the current decision context, its facilitation of other actions, its role in averting exceedance of a critical threshold, its robustness and resilience under diverse and unexpected shocks, its effect on future options, its lead time, and its effects on equity and social cohesion. These criteria could potentially enable development of multiple stakeholder-specific adaptation pathways through a regional collective action process. The actual implementation of these multiple adaptation pathways will be highly uncertain and politically difficult because of fixity of resource-use rights, unequal distribution of power, value conflicts, and the likely redistribution of benefits and costs. We propose that the approach we outline for building resilient pathways to transformation is a flexible and credible way of negotiating these challenges.

Key Words: *adaptation pathways; climate change; collective action; domain shift; equity; irrigation; resilience; social conflict; transformation; wetlands*

INTRODUCTION

As the gap between the rate and impacts of climate change and efforts to mitigate that change widens, international emphasis is shifting from incremental adaptation toward pathways to transformational change (Wise et al. 2014). The easier end of a spectrum of difficulty in constructing feasible adaptation pathways is exemplified by the Thames Barrage (Reeder and Ranger 2011). The unambiguous goal of building a barrage to prevent flooding of central London by storm surges and sea level rise was relatively uncontested because sea level rise was inevitable, decision-making power was concentrated, and the project was not blocked by rules, i.e., laws, regulations, and social norms, or opposing values (Voß et al. 2007). An adaptation pathway for water management in the Rhine Delta (Haasnoot et al. 2013) is an example of a somewhat less tractable case. However, at the most difficult end of the spectrum are regions where stakeholders' values are diverse and conflicting, property rights favor some values over others, levels of uncertainty are higher than in the British and Dutch examples, fundamental changes are constrained by current rules, and different agencies regulate different parts of the system with little interagency coordination.

We outline a process for developing coherent proposals for adaptation pathways in these highly contested circumstances. We illustrate it using Australia's Murray-Darling Basin (MDB) and consider that insights gained from the MDB are likely to be generalizable to the many other regions around the world where pathways to fundamental change are needed, but for similar reasons only incremental adaptations seem currently feasible. Our proposed approach is one in which intra- and interagency learning capacity is continually built, and the preferences of each stakeholder for adaptive actions are reprioritized and reranked as new knowledge or opportunities arise, the decision-making context shifts, and shocks and drivers change. Further, we suggest seven criteria based on fundamental principles of path dependency, equity, potential for crossing thresholds, and managing uncertainty that can be used to sequence potential actions within the adaptation pathway. We anticipate our propositions could be applied and tested by practitioners and researchers alike. They have been inspired by the many publications on resilience, adaptation pathways, transitions, and transformations, such as Geels (2011), Leach et al. (2010), Pelling (2011), and Scheffer (2009). There are too many to cite within the constraints of an insight paper, but Wise at al. (2014) provide a review and synthesis.

THE MURRAY-DARLING BASIN

Background

The MDB (Fig. 1) covers 14% of Australia's surface and was populated by Aboriginal hunter-gatherers for some 40 millennia before British colonists took it in the 19th century and transformed it to commercial agriculture (Weir 2011). However, the MDB's flat topography and limited groundwater outflows make it prone to salinization after native vegetation is cleared and land irrigated, and the highly variable climate provides an uncertain supply of water (Williams 2011). Diversion of water for irrigation has reduced river flows to floodplains and wetlands and changed their species composition, structure, and functioning. "Environmental flows" have been allocated to counter this trend, but water resources are insufficient to meet the combined demands of irrigation needs and adequate

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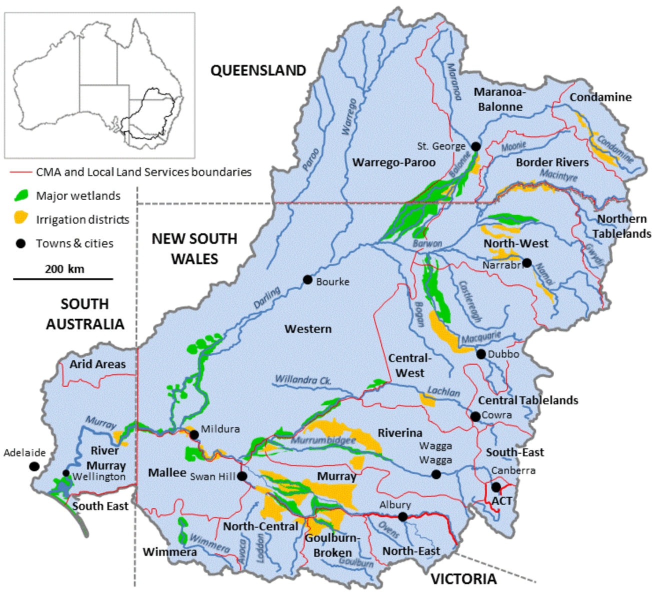
environmental flows (Williams 2011). Despite droughts, floods, and salinity, the MDB grows some 40% of Australia's agricultural production and is home to around two million people. Though its ecosystems are modified, it is still valued for its waterways, 60,000 km² of floodplains, and nationally and internationally significant wetlands, which have indigenous cultural value and support substantial tourism and recreation sectors (Hatton MacDonald et al. 2011).

Fig. 1. Map of the Murray-Darling Basin showing river systems, wetlands, boundaries of natural resource management regions, i.e., Catchment Management Authorities (CMAs) and Local Land Services, states, and the Australian Capital Territory (ACT).



Governance and contestation of land and water resources

Managing the MDB's present problems and those anticipated from climate change is politically difficult (Connell 2007). The MDB spans four states and one territory, and each state has a separate constitution that confers water rights on that state. Demands for land and water are contested among farmers, indigenous peoples, mining, environmentalists, tourism, and urban use. There is already insufficient water to supply the competing needs of these diverse stakeholders, but climate change is expected to further reduce inflows (Kirby et al. 2013; Colloff et al., *in press*). These factors combine to generate conflict even before any action to address problems can begin, but an additional handicap is the complex distribution of authority across and within scales that we summarize next.

The cross-jurisdictional Murray-Darling Basin Authority (MDBA) and was established after prolonged negotiations by federal and state governments to manage water and salinity at basin scale. The MDB is divided among 21 regional (river catchment) natural resource management organizations (NRMOs, official names vary between states; Fig. 1). These community-based organizations were established across Australia to make strategic plans for the management of land and water resources, facilitate stakeholder interactions, provide information, and disburse government funding. NRMOs have no executive authority over minerals, land, or water use. Use of private land is regulated by local governments. Farms and rangelands are privately owned or leased. State and federal government agencies manage national parks and reserves, and regulate mining. Water for consumptive use and environmental flows is allocated at basin scale under federal law through the MDBA and the Commonwealth Environmental Water Holder. Irrigators own entitlements to water that can be traded, but seasonal allocations are based on a fixed proportion of a variable flow volume. Within states, water is allocated seasonally at the scale of catchments and groundwater systems through plans made by state agencies in consultation with stakeholders.

These multiple overlapping interests, responsibilities, and powers mean that no one is in charge. Because stakeholders compete and cooperate within the mutually understood constraints on actions imposed by current values, rules, and knowledge, resource use configurations are not chaotic (Marshall et al. 2013). Agriculture is constrained by water allocations and the area of private land, while the expression of other values is checked by policy and legislative limits on environmental flows and the extent of public land. System stability is reinforced by a dominant knowledge base consistent with current resource access rights, uses, and technologies. Interactions among values, rules, and knowledge form the decision-making context, which generally constrains decisions to incremental ones that focus on proximate causes of problems and tend to reproduce the current system configuration (Leach et al. 2010, Gorddard et al. 2016). Despite this inherent conservatism and the complexity of governance, the NRMO region (catchment) is a useful scale at which to initiate adaptation pathways because many interactions among people, water, vegetation, and soils can be understood and described coherently at this scale.

LINKING RESILIENCE THINKING WITH THE ADAPTATION PATHWAYS CONCEPT

Having chosen the catchment scale for the biophysical focus, we selected NRMOs as agents of change, despite their lack of executive authority. The selection is justified by their roles in connecting stakeholders with each other and with governments. The strategic plans in ten NRMO regions were informed, at least partially, by resilience thinking. Their goals were to avoid unwanted change by keeping their regional system within key biophysical thresholds while continuing to produce the same outputs from the same resource use systems and simultaneously maintaining biodiversity (e.g., GBCMA 2013). This is consistent with resilience theory only so long as stabilizing feedbacks on a small number of slowly changing controlling variables can counter episodic shocks (Walker et al. 2009). It is represented metaphorically by the "ball-in-cup" model (Holling et al. 2002), in which the position of a moveable ball marks the current state of the system and the cup represents the stability domain within which its state can vary without shifting to another, sometimes unwanted domain (Fig. 2).

Constrained as they are by the current decision-making context, NRMOs have been advocating incremental adaptations to avoid unwanted threshold changes (e.g., by replanting native vegetation, pumping saline groundwater to counter water table rise, and managing environmental water), but these cannot alone prepare the vulnerable systems of the MDB for the magnitude of the shocks the future might bring and that will become increasingly costly to counter. Major changes are likely in variability of rainfall and temperature (Timbal et al. 2015) and stream flows across the MDB (Kirby et al. 2013). Changes will also occur in laws and policies, technologies, prices of products, energy and other inputs, the distribution and abundance of biota, and the types and incidences of crop and livestock diseases and pests. There may be irreversible shifts in drivers with unpredictable consequences at an unpredictable time in the future, e.g., crossing a temperature threshold that releases planetary carbon stores or tipping points in social values and consequential policy responses (Fisher and Le 2014). The global economy is meanwhile still carrying heavy burdens of debt incurred before the global financial crisis, yet the structural causes of indebtedness remain unresolved and future crises are expected (Mason 2015). The need to switch from conservatism to transformation is becoming clearer, but the lead time needed for major adaptations is usually long, so construction of pathways towards transformational change needs to begin now. The demands this places on the NRMOs, small and poorly resourced bridging organizations, and their diverse regional stakeholders might seem impossible to meet, but we attempt to show how adaptive actions could be prioritized and coherent adaptation pathways constructed in these circumstances.

In resilience theory intentional transformation means shifting from a system that is not expected to be able to persist in the long term to a new one with better prospects under a changing climate and a range of economic and biophysical shocks. A transformed system is defined in resilience terms as one that produces different outputs, is regulated by feedbacks on a different set of socioeconomic and biophysical controlling variables, and is bounded by different thresholds compared with the original system (Walker et al. 2012), as in a transformation from cropping to solar farming. We can expect an intentional transformation to require changes in values, rules, knowledge, redistributions of power, authority, and resources (Moore et al. 2014), and deliberate weakening of stabilizing feedbacks. A less radical adaptation is an intentional shift from one domain to another within the same system (Fig. 3), where it is restabilized by feedbacks on the same controlling variables. Unintentional, often undesirable, domain shifts and transformations can occur. An example of the latter is when leaky infrastructure, excessive rainfall, and failure to pump ground water raises a saline water table and irreversibly salinizes irrigated land, or when dairy or fruit-processing industries close down (Walker et al. 2009).

Fig. 2. The ball-in-cup metaphor showing alternative Murray-Darling Basin floodplain stability domains for what had been seasonally flooded native vegetation before the irrigation era (alternate wet/dry). The black ball shows one current state in one current domain. Gray balls represent a few of the many other feasible states in the same or other domains. The frequency and volume of flooding determine the structure, species composition, and function of floodplain vegetation (Colloff and Baldwin 2014), so a seasonally flooded site can shift to a mainly dry domain if irrigation water diversions reduce flood frequency and extent. Other sites, however, are along routes that deliver water to irrigators and can shift to a mainly wet domain.

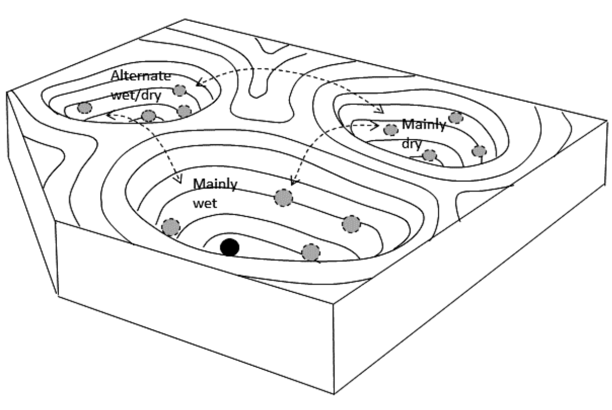
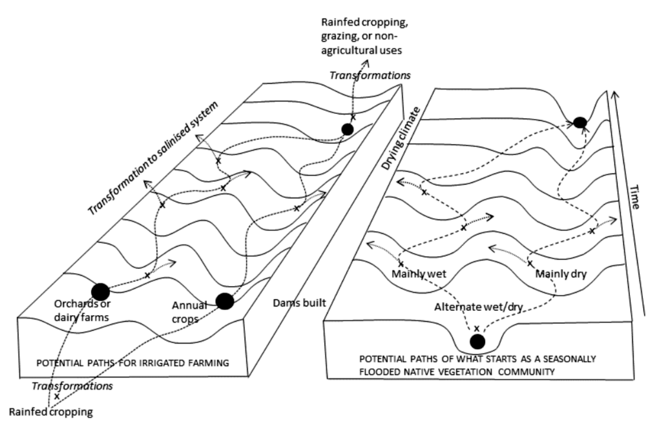


Fig. 3. Resilient pathways for coexisting resource uses on a Murray-Darling Basin floodplain—a historical and future metaphor. Ridges mark thresholds between stability domains. The depth of the cup represents its resilience. Dotted lines mark the changing states of the systems through time. Stabilizing feedbacks on controlling variables tend to maintain systems in a domain; shocks tend to shift them to alternate domains or to another system. An unintended domain shift or transformation can result from diminished resilience, an unusually severe shock, a sequence of shocks, or a new type of shock to which a system is not adapted. The x's mark decision points where, depending on the timing and appropriateness of the actions taken, a system could remain within its current domain, shift to another, or transform, intentionally or otherwise. Divergent arrows illustrate these alternatives. The right-hand diagram is explained in Figure 2, but with the time dimension added. The left-hand diagram shows that rainfed cropping was transformed to irrigated annual cropping, orchards, or dairy farms after dams were built in the last century to mitigate droughts. It caused some regions to transform to an unproductive salinized domain. Future climate change could cause domain shifts from fruit orchards and dairy farms to more resilient irrigated annual crops. Further water scarcity could transform the system back to rainfed agriculture, grazing, or nonagricultural uses.



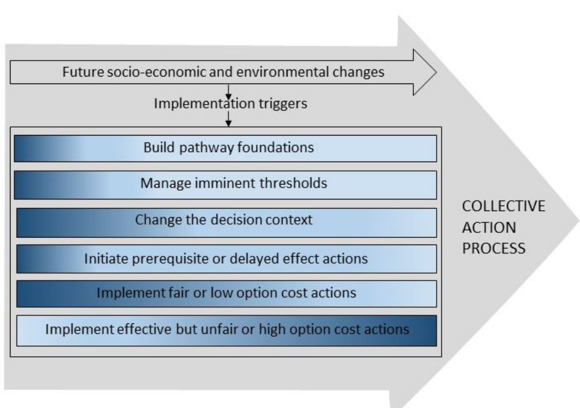
Instead of the ball-in-cup model, a more complete metaphor for resilience thinking, and one consistent with resilience theory, the adaptation pathways concept and transformational change is one in which the state of a system is channeled within an evolving stability domain, the resilience of which changes through time (Fig. 3). The figure illustrates the need to avoid shifting across a threshold to an undesirable domain, e.g., salinized land, while following an adaptation pathway. It also shows an intentional shift from a domain in which resilience is declining to a more resilient domain (e.g., irrigated orchards to annual crops), or to another system, such as a solar energy farm.

A resilience-based approach to resource use conflicts has been criticized because it treats humans and their environment as systems with equilibria, feedbacks, and thresholds; promotes the property of self-organization while ignoring human agency, conflict, and power; and regards societies as being essentially cooperative and equilibrial (Olsson et al. 2015). Our own experiences in applying systems thinking and resilience theory with indigenous, farming, and conservation stakeholders justify in our minds the usefulness of the concepts of systems, equilibria, feedbacks, and thresholds. Moreover, the collective action process we advocate should not, would not, and could not impose this approach on unwilling stakeholders. We believe this paper addresses the other criticisms.

ADAPTATION PATHWAYS FOR TRANSFORMATIONAL CHANGE

Our proposals for building pathways are about what actions stakeholders, industries, local governments, nongovernmental organizations (NGOs), state agencies, and the NRMOs could take to facilitate regime shifts or transformations (Fig. 4). The suggestions are of two kinds: path-building actions within the region (e.g., Siebentritt et al. 2014) and cross-scale actions to change the decision-making context that currently constrains effective adaptation (Gorddard et al. 2016).

Fig. 4. Action types, sequencing, and implementation triggers. The level of investment in an action type is proportional to the darkness of the bar. The figure only shows the expected future pattern of investment in action types from today's perspective to an arbitrary time in the future. The pattern and the implementation triggers will shift as learning and circumstances change. Unlike project-based investments, there are no final outcomes and no agreed end date for an adaptation pathway.



Collective action processes for building pathways

We propose that a series of regionally focused cross-scale collective action processes that enable debate and negotiation among multiple stakeholders is a necessary foundation for adaptation pathways (Ratner et al. 2013, Moore et al. 2014). Participants would include irrigators, indigenous peoples, mining and energy industries, tourism and other rural industries, environmentalists, recreational users, and researchers. Each group would bring different values, goals, knowledge, levels of power and influence, and political strategies to the process. Though the arena is a region, state and federal government departments, some industries, environmentalists, and recreational users are not resident but are legitimate participants.

The collective action processes would generate and play a part in implementing sets of stakeholder actions for shifting systems to other and preferred stability domains, or for avoiding transgression of thresholds to unwanted domains. Each stakeholder group would develop a set, while the collective action processes would address conflicts and synergies among them and the equity of outcomes. The processes also decide which actions are feasible within the current decision context and which require supplementary actions to change the context. Thereafter, the sequencing of actions would be enabled by six criteria:

1. the role of the actions in paving the pathway for other actions;
2. the probability of an action averting transgression of a threshold;
3. the actions' resilience or robustness to a wide range of shocks;
4. the actions' effect on other adaptive options;
5. the time between action initiation and effect, and;
6. the consequences for equity.

A collective action process is likely to have lower transaction costs and may produce more effective adaptation pathways than change imposed from above (Syme et al. 1999), although changes to the decision context would require extraregional support and actions. We envisage processes in which knowledge, actions, rules, values, and social relationships coevolve as tensions among them are encountered and resolved where possible. The aim is not to generate a single adaptation pathway for a region, as in Reeder and Ranger (2011), but a set of stakeholder pathways that can coevolve while minimizing their negative impacts on each other. Although the processes and criteria are focused on building the pathways, stakeholders would be making parallel decisions aimed variously at earning a living, conserving fauna and flora, or maintaining cultural values. We envisage that the stakeholder groups themselves would integrate these shorter term decisions into their group's pathway and that learning and the collective action processes would address conflicts among the pathways and foster synergies.

The processes would be inserted into stakeholders' long-held and strongly established environmental discourses, each one representing the continuing values, understanding, and aspirations of a particular group (Robbins 2012). The processes are intended to develop and expand debates and negotiations among those groups and lead toward transformations, but there can be no set completion date. Rather, there would be starts, pauses, reversals, and changes of direction as circumstances and actors learn and change. There is no guarantee that the processes would result in shifts onto sustainable and equitable pathways, but they could identify and describe those pathways and show the magnitude and scope of actions needed to begin stakeholders' journeys along them.

Based on the authors' experiences of participative development of resilience-based regional plans in the MDB and elsewhere (e.g., GBCMA 2013), we favor a process that engages stakeholders in the following:

- negotiating a collective vision for the region.
- identifying the values the region generates and who holds them.
- eliciting stakeholders' mental models of the socioeconomic and biophysical processes that generate these values so as to promote debate, understanding, compromise, synergy, and synthesis.
- identifying the relatively small number of socioeconomic and biophysical controlling variables and feedbacks that maintain current stability domains.
- identifying trends in controlling variables, threshold levels, and the probability of crossing them.
- listing shocks and drivers that could push controlling variables across thresholds.
- identifying potential alternate domains, some desirable, some to be avoided; what is desirable to some stakeholders will be unwanted by others.
- coming to accept the need for change, transformational or otherwise.
- developing actions to avoid unwanted thresholds, and building pathways to "preferred" domains.
- addressing the uncertainty and assumptions associated with each of these steps.
- implementing the pathways, learning from this implementation, and adapting to changing circumstances.

We propose that to achieve these aims the collective action process should so far as possible include these elements (Ratner et al. 2013):

- the NRMO as a bridging organization (Wyborn 2015);
- finance, knowledge, time, and other resources (Butler et al. 2015);
- a mix of participants that collectively brings leadership, lobbying, research, innovation, negotiation, conflict resolution, facilitation, and managerial abilities;
- bonding networks that link individuals within stakeholder groups;
- inter- and intrascale networks to connect stakeholder, government agencies, NGOs, and industries;
- a willingness to experiment and learn by doing, and a capacity to foster novelty, and protect it from suffocation by conservatism;
- internal and external information sharing systems;
- monitoring, evaluation, and commitments to learning by doing and the coproduction of knowledge (Wyborn 2015).

NRMOs already run similar processes to develop their catchment plans and interact with local, state, and federal governance processes (e.g., GBCMA 2013). The Goulburn Broken Catchment Management Authority has already begun to develop adaptation pathways with stakeholders in six subregions, and Siebentritt et al. 2013 have published a pathway for a region outside the MDB.

NRMOs have reported that tensions arise if objectives depart from government policy, and NRMOs can be overruled or their objectives left unfunded; thus is conservatism maintained. This emphasizes the need to influence formal governance processes and prompts the next question.

Is the action feasible within the current decision-making context?
Resilience theory proposes that any complex system at a defined focal scale is set within other, broader-scale systems in a nested panarchy (Gunderson and Holling 2002). The broader scale systems provide the context within which decisions are made at the focal scale. This context includes the current set of rules (regulations, laws, and policies; society's dominant norms and values), the stock of local and scientific knowledge (Gorddard et al. 2016), and the consequent distribution of power and authority. Resilience theory's four-stage adaptive-cycle concept (Holling and Gunderson 2002) holds that the decision-making context will change with time regardless of specific efforts to change it. Adaptations not possible in the conservative stage of the cycle may become so when conservatism ends in a crisis that leads to the release of resources, opening of new opportunities, reorganization, and renewal as values shift, rules change, and new knowledge is generated. This puts the system on a growth path, but constraints reappear as the system evolves through the growth stage and enters a new period of conservatism dominated by a relatively narrow set of values backed by highly focused knowledge and strong rules. Systems can become locked into path dependency if values, rules, and knowledge do not adapt to changing circumstances (Abel et al. 2011). Repeated phases of drought and recovery in the MDB are broadly analogous to the phases of the adaptive cycle (Helman 2009), whereas Abel et al. 2006 have applied it to the history of indigenous peoples and pastoralists in the basin's rangelands.

An adaptation pathway is therefore likely to proceed through alternating incremental and transformational changes (Park et al. 2012). During the conservative stage, transformational actions are not socially acceptable or legitimate because the prevailing values, rules, distribution of power, and knowledge of the system favor the current stability domain, which may be considered by many stakeholders to be sustainable. Uncertainty about the benefits of change understandably leads to incremental actions aimed at stabilizing the system in its current domain.

In 2015 the MDB's decision context is in a conservative stage of the adaptive cycle. Policies are aimed at maintaining irrigation communities by improving efficiency and diverting water saved to environmental flows, supplemented by buying irrigation water entitlements. However, public belief in the benefits and sustainability of current domains can be eroded by shocks. The MDB was hit by the 2008 global financial crisis during a 13-year drought, and the combined impacts may have raised the imperative for stakeholders to consider radical adaptations. However, reducing the constraints on major regional scale change does require strategies to change this conservative decision context.

Major changes in resource use can be imposed and subsidized by a government if it has sufficient resources, authority, power, and intent. The separation of water entitlements from land ownership and the initiation of water trading is an MDB example (Connell 2007). Major bottom-up changes are usually constrained by lack of power and authority, but covert strategies can be effective (Marshall et al. 2013). Thus, an NRMO that is formally powerless to implement transformational pathways can align with groups with common interests at same or a higher scale and seek funding for projects that serve the needs of allies, current opponents, and the NRMO.

Is the action a prerequisite for the whole pathway?
Some actions will be prerequisites for others, such as acquiring resources, reforming out-of-date rules, coordinating fragmented governance, and establishing the collective action process, its operating rules, social learning, and communication processes (Wyborn 2015). Beyond this is the need to develop a common vision (Park et al. 2012, GBCMA 2013, Varela-Ortega et al. 2014), with the potential to align stakeholders' values, understand opposing positions, and make compromises. Visions can be better imagined if supported by metaphors such as Figure 3, although over-specification could prove maladaptive if circumstances change. Instead, the vision might be derived from attributes of general resilience: the capacity of a system to cope with a wide range of shocks, including novel ones (Carpenter et al. 2012). An example that leaves room for a range of potential stakeholder pathways might be "We are working towards a future in which our community participates in the governance of our region as we strive to improve our understanding of how to navigate pathways through socioeconomic, climatic, and other shocks, while taking up new opportunities, abandoning unsustainable activities, promoting economic diversity, and wisely conserving the many options in our well-functioning landscapes."

What is the probability of crossing an unwanted threshold?
The collective action processes establish for stakeholders the relative importance of each controlling variable. However, the sequencing of actions to manage those variables depends on the risk of crossing a threshold. Examples include the likelihood of a saline water table rising into the root zone, farms falling below critical financial viability thresholds (Walker et al. 2009), or the flood regime of wetlands failing to maintain the current domain. Actions can be sequenced by ranking them according to the subjective probability of crossing an unwanted threshold within a specified period. However, controlling variables are interconnected, so one threshold transgression might trigger a cascade resulting in domain change (Kinzig et al. 2006). For example, Walker et al. (2009) showed the strong connections among water table rise and farm and local industrial economic viability. The estimated strength of linkages among controlling variables should therefore also influence the sequencing of actions.

Is the action robust or resilient under a wide range of shocks?
Optimizing a strategy to cope with one potential future is unwise because the ranges of potential socioeconomic and environmental shocks are highly uncertain. An iterative approach using multiple scenarios can identify robust actions that are unaffected by a wide variety of uncertainties under a broad range of conditions (Hallegate 2009), or resilient actions that are adaptable to diverse circumstances (Walker et al 2009). This approach minimizes the regret felt when unexpected circumstances occur, which they will. For example, wetland ecosystems and their biota are more likely to persist despite climate change if they (1) have high response diversity to extremes of flood and drought; (2) have drought-resistant lifecycle stages and long-lived propagules; (3) have rapid growth and regeneration during wet periods; (4) sequester carbon and nutrients produced during wet phases for use during dry phases; and (5) have aquatic connectivity for propagule transport and recolonization (Colloff et al. *in press*). Wetlands with these attributes are resilient to drought but retain potential to form new ecological communities that could be valued by future generations. Such areas are already highly valued for the benefits they supply, and their conservation should be a priority in an adaptation pathway. Other areas may not be valued now but should be maintained because of their potential option value for flood mitigation, water filtration, landscape stabilization, propagule sources, drought refuges, and provision of shade and shelter. Actions to maintain areas with low chances of persistence should have lower priorities.

Will the action reduce the range of future adaptive options?
Actions that reduce future options diminish resilience because an option suited to a novel circumstance many no longer be available when needed. We are often uncertain about what resources will be needed as conditions change, so maintaining options conserves resilience. Actions of one stakeholder group may reduce options for others, for example, where farm-scale practices have adverse impacts on the broader floodplain. This criterion is aimed toward the generation of multiple, somewhat compatible pathways by diverse stakeholder groups. It incorporates the risk-management strategies of portfolio diversification and option value, and like the previous criterion, prioritizes "no-regrets" actions over those with potential adverse future impacts. It also addresses the problem of path dependency that tends to emerge in a stability domain as it matures.

This criterion is also aimed towards intergenerational equity. Current generations have a strong propensity to compromise future options by meeting immediate needs and leaving future generations to carry the costs. Actions such as the building of infrastructure or the clearance of native vegetation for farming have indefinite consequences (Stafford Smith et al. 2011). This criterion helps identification of no-regrets decisions, which yield benefits under any future conditions (Hallegatte 2009, Stafford Smith et al. 2011). Actions that reduce future options but rate well on other criteria can be reserved for implementation when changing circumstances makes their contribution to a pathway critically important.

Is the lead time long?
Lead time is the period between the initiation of an action and the time when it takes effect (Stafford Smith et al. 2011). For example, there may be a long lag between the release of new

knowledge, its broad acceptance, and its effectiveness in changing management, as with fossil fuels and climate change. Or there may be a long lag between a decision to build new infrastructure and its completion. Uncertainty about the merits of an action may delay implementation while more data are collected or pilot projects implemented (real options; Sanderson et al. 2015), e.g., exploring the consequences of removing water control structures. This criterion prioritizes actions with long lead times over other actions, running counter to human preferences that discount future benefits and costs.

What is the effect on equity?

Implementation of pathways will depend on social cohesion, which is favored by equity (Syme et al. 1999). Assessing the effects of a proposed action on future options takes account of intergenerational equity, but accounting for its consequences for contemporary equity means estimating impacts on current land and water allocations and their socioeconomic flow-on effects. The current distributions of benefits and costs of resource use depend in large part on the distribution of property rights, so some transformations would require changes to laws, perhaps backed by taxpayer funded compensation. The federal government has shown this can happen by buying out some irrigators to release significant volumes of water for environmental flows. Times of major social change are opportunities for some interest groups to drive rule changes that secure and further their own interests, thereby reducing the common good. Both procedural and distributive justice are necessary components of an equitable pathway (Syme et al. 1999) and can be prerequisites for implementation.

Sequencing actions

The ratings of proposed actions against the six criteria should help stakeholder groups set provisional implementation sequences for actions through multicriteria analysis and debate. Uncertainty means it is rarely useful to set an implementation date, but it is useful to set decision criteria that show when the circumstances are right for implementation. e.g., the proximity of a controlling variable, such as river flow volume, to a threshold. These criteria are implementation triggers for actions along the time path (Fig. 4). We envisage an iterative process in which potential actions are resequenced and preferences are reranked as learning from implementation creates new knowledge, and rules, values, opportunities, shocks, and drivers change. Initial selection of actions that are robust to or resilient in changing circumstances will reduce the magnitude and frequency of the changes needed, but some previous investments in the pathway will inevitably prove to have been inappropriate. In such cases it will be politically difficult to apply the economic principle that sunk costs should be ignored and that no investment, no matter how costly, should remain in use just because it exists, but the principle is nevertheless right in advocating the redirection of resources from maladapted to adaptive and transformative measures. The costly irrigation infrastructure upgrades now being built may provide future test cases for this principle.

BASIN-WIDE IMPLICATIONS OF ADAPTATION PATHWAYS

The MDB catchments are tightly interconnected socioeconomically and biophysically. Concurrent regional and MDB-wide path-building processes could therefore improve the mutual compatibility of pathways and exploit synergies. This is consistent with the MDBA's roles in coordinating actions to manage salinity, distribute water, disseminate information, and engage with communities. Tensions among catchment and basin-scale pathways would be exposed by this cross-scale process. It will be necessary to trade-off particular functions in some regions, such as certain kinds of land use, to maintain functionality in the basin as a whole. It is already accepted that some MDB wetlands have a greater chance than others of persisting under climate change for a given volume and frequency of flooding, and should therefore be favored to the detriment of other sites (Barnett et al. 2015). For example, the persistence of the estuarine Coorong Lagoon at the mouth of the River Murray will require increasing volumes of environmental water at the expense of upstream wetlands and irrigation communities (Fig. 1), and the relative value of the alternative sacrifices is already highly contested. Resilience theory advocates that some fine-scale systems should be allowed to collapse if that is necessary for the broad-scale system to persist (Walker and Salt 2012). The public demonstrations and burning of copies of the new draft plan for MDB water allocation foreshadow the enormous social cost and political difficulty of applying this in practice to the farms, businesses, and households of whole irrigation regions, but this does not negate the potentially high long-term net benefit of doing so.

CONCLUSIONS AND PROPOSITIONS

We have observed that the ball-in-cup metaphor for a stability domain can be interpreted by NRMOs as a rationale to manage the resilience of the current domain and avoid a domain shift or transformation. Introducing a time dimension changes the metaphor to one in which alternative domains are represented as channels from now into the future, their resilience varying through time. Some channels will be preferable to others; some should be avoided. This metaphor could encourage exploration of potential domain shifts or transformations, and it provides a link between resilience and pathways thinking.

We have proposed that the construction of pathways for the MDB should be founded on regional collective action processes that generate, appraise, and sequence adaptive actions, reappraising and resequencing them as new opportunities arise, or as the decision-making context and shocks and drivers change. Seven criteria would enable potential adaptive actions to be sequenced: (1) the feasibility of the action within the current decision-making context; (2) the role of the action in paving the path for other actions; (3) its role in averting transgression of a critical threshold; (4) its robustness or resilience under diverse shocks; (5) its effect on the range of future options; (6) the length of its lead time; (7) and its effects on equity. We propose that these criteria make it possible to lay out coherent proposals for mutually compatible stakeholders' pathways even when stakeholders' values are contested, power is dispersed, and structural change is blocked by current rules. By acting to change the decision-making context when it blocks domain shifts or transformations, an adaptation pathway acknowledges the need to address both agency and structure to enable systemic change.

Though multiple collective action processes provide a means to develop compatible and evolving pathways at regional scale, a basin-wide process would be needed to realize interregional compatibility. That would reveal the need to curtail or transform resource uses in some regions to maintain basin-wide functionality. Though the social costs of doing so will be painful, we would expect the intergenerational benefits to justify it, because climate change interacting with deep socioeconomic uncertainty will dictate the need to move from incrementalism to transformation.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/8422

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