AMBIO 2014, 43:1069–1081
DOI 10.1007/s13280-014-0537-4

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

REPORT

Drivers influencing adaptive management: a retrospective evaluation of water quality decisions in South East Queensland (Australia)

Leo X. C. Dutra, Nick Ellis, Pascal Perez, Cathy M. Dichmont, William de la Mare, Fabio Boschetti

Received: 14 August 2013 / Revised: 4 December 2013 / Accepted: 20 May 2014 / Published online: 28 June 2014

Abstract This article analyzes interviews with natural resource managers in South East Queensland (SEQ), Australia. The objectives of the research are (i) to apply and test deductive/inductive text analysis methods for constructing a conceptual model of water quality decision-making in SEQ, (ii) to understand the role of information in the decision-making process, and (iii) to understand how to improve adaptive management in SEQ. Our methodology provided the means to quickly and objectively explore interview data and also reduce potential subjective bias normally associated with deductive text analysis methods. At a more practical level, our methodology indicates potential intervention points if one is to influence the decision-making process in the region. Results indicate that relevant information is often ignored in SEQ, with significant consequences for adaptive management. Contextual factors (political, social, and environmental) together with effective communication or lobbying strategies often prevent evidence-based decisions. We propose that in addition to generating information to support decisions, adaptive management also requires an appraisal of the true character of the decision-making process, which includes how stakeholders interact, what information is relevant and salient to management, and how the available information should be communicated to stakeholders and decision-making bodies.

Keywords Water quality decisions · Decision attributes · Interview analysis · Information · Inductive/deductive method

Abbreviations

E&SC	Erosion and sediment control
EHMP	Ecosystem Health Monitoring Program
HWP	Healthy Waterways Partnership
IWRM	Integrated Water Resources Management
NRM	Natural Resources Management
SEQ	South East Queensland
STP	Sewage Treatment Plant

INTRODUCTION

Adaptive management has been widely recognized as a way to improve natural resource decision-making by iteratively adjusting decisions to evolving conditions based on an effective monitoring system (Walters 2007). The greater the discrepancies between apparent and desired conditions in adaptive management, the more robust the resulting actions need to be.

The literature suggests that adaptive management is essential for effective environmental management when uncertainty is high (Gregory et al. 2006; Fernandez-Gimenez et al. 2008; Gunderson et al. 2008; Huitema et al. 2009). Consequently, the approach has been applied in a variety of management settings, such as fisheries management (Fulton et al. 2007; Dichmont et al. 2008), forestry and conservation (Holling 1978; Holling and Gunderson 2002; Fernandez-Gimenez et al. 2008; Bunnefeld et al. 2011), co-management between indigenous and non-indigenous stakeholders (Robinson et al. 2005), and water quality management (Pahl-Wostl et al. 2008; Bunn et al. 2010).

Adaptive management assumes that information (i.e., data processed into a useful form (Ackoff 1989)) will improve the way decisions are made to achieve management objectives. However, when applied to adaptive management,

Electronic supplementary material The online version of this article (doi:10.1007/s13280-014-0537-4) contains supplementary material, which is available to authorized users.

there is often confusion between data profusion and usefulness (Ward et al. 1986).

The decision-making process has been widely discussed in the business, psychology, and education literature over the last 30 years (e.g., Slovic et al. 1977; Argyris and Schön 1978; Isenberg 1988; Finger and Asún 2001; Axelrod 2006; Ariely 2008). However, with a few exceptions (e.g., Gregory et al. 2006; McNie 2007), there is limited discussion on (i) the psychological, cognitive, and governance elements that affect the way decisions are made and implemented (subsequently referred to as "decision attributes") in the area of natural resource management (NRM) and (ii) how these attributes affect the successful implementation of adaptive management. Nevertheless, the literature suggests that human behavior (how we interpret data, select information to make decisions, and think about solutions to problems) and social dynamics (how we interact with each other, including power relationships) are essential to its successful implementation, because individuals involved in NRM (e.g., managers, community, industry, and politicians) tend to cooperate when making decisions about commons via the development of social relationships (van Vugt 2009).

In this paper, we adopt the definitions of decision-maker and stakeholder from McNie (2007), where "a decision-maker is any individual or group with the capacity to commit to a particular course of action. Stakeholders are individuals or groups with a vested interest in the outcome of a decision and can include just about anyone, e.g., scientists, citizens, farmers, resource managers, business, politicians, and the like." "Decision attributes" were identified by selecting semantic concepts using text analysis methods (refer to "Materials and methods"). "Concept" is defined as a word or collections of words used to describe the same general phenomenon or idea.

In this study, we interviewed resource managers from South East Queensland (SEQ), Australia, about the implementation of water quality management decisions in retrospect. The objectives of the research were (i) to apply and test deductive/inductive text analysis methods for constructing a conceptual model of water quality decision-making in SEQ, (ii) to understand the role of information in the decision-making process, and (iii) to understand how to improve adaptive management in SEQ.

In this paper, we first provide details describing decision-making processes associated with water quality management in SEQ. We then provide the methodological framework, followed by results, discussion, and conclusions.

Decisions About Natural Resources

Adaptive management follows a rational decision model as it assumes that increasing knowledge (by generating and updating information) will lead to improved decisions (Walters 2007; de Oliveira et al. 2009). Rationality is an idealized model that is suited to problems where the given are known and available (Arthur 1994). Rationality implies that the best possible scientific assessments of the natural resource are expected to play a key role in decision-making (Walters 2007).

Adaptive management explicitly deals with the uncertainty that is inherent to NRM because of natural variability in the biophysical domain, which offers great opportunities for learning (Steyaert and Ollivier 2007). However, it does not account for the uncertainty in decision-making. This is important because decisions routinely involve a person in charge or a network of people from different sectors, such as councils or state organisations. These people interact with other government departments, science providers, industry, and stakeholders. The interaction between actors (people and organizations) influences the way decision-makers gather and process information about the system they are managing (Stacey 1996, p. 196). Consequently, decision-makers are routinely under pressure from stakeholders having conflicting objectives. For example, when managing an ecological system, the objectives of industry, community, or conservation or political groups are often different. Other factors that influence decision-makers are accountability, costs of implementing decisions, and uncertainty about the outcomes of decisions on the environment and society. Additionally, vested interests, work performance, fear of failure, implicit and explicit assumptions, coalitions, leadership, conflicts, and culture also influence the process of transforming information into action (Bots et al. 1999; Stacey 2001). To complicate matters, individuals also use their values (social, cultural, economic, and environmental) to guide their objectives and decision-making (Keeney 1992:23). Consequently, stakeholders can have similar objectives but for different reasons (for practical examples in NRM refer to Robinson et al. 2005). These issues mean that even if there is an agreement within a management team on the proper course of action, local incentives, group dynamics, asymmetric information,[1] psychological issues, and private agendas combine to influence the process of making decisions, and their realization and effectiveness.

Arthur (1994) also suggests that humans alternately use deductive and inductive reasoning when they make decisions. For a problem that has a manageable number of attributes, we can create and thoroughly test all possible variables of a hypothesis in our mental models, and then generalize the answers. Computer models and tools can assist in this deductive process by allowing a larger number

[1] Asymmetric information is a situation in which one party has more or better information than the other. For example, in transactions where the seller knows more than the buyer. This is a potentially harmful situation because the former can take advantage of the latter's lack of knowledge (Hiller 1997).

of attributes, variables, and relationships to be tested. However, when the complexity of the problem and uncertainty about the effects of decisions are high, decision-makers use inductive mechanisms in their reasoning. They observe a relatively small set of events to deal with problems; they decide what to believe and which actions to choose (guided by their values) by transferring experience from other, similar problems they have faced previously. They use the new information to create or update their "mental library" to deal with the new problem, and construct hypotheses about it (Arthur 1994). Learning (a key component of adaptive management) occurs when mental models change (see Jones et al. 2011 for a review of mental models in NRM).

Natural resource managers have often become experts on the local environment. Therefore, they do not need to go through all interrelations between decision attributes influencing the problem to make decisions. They need only indications, from a relatively small number of decision attributes, to update or construct their mental models, leading to decisions and actions. Our interview analysis focuses on the identification of these attributes.

Decision Context in South East Queensland

Decision-makers in SEQ, the fastest growing region in Australia, are facing considerable challenges in accommodating a growing population (Fig. 1). The regional population is expected to grow from three million to four million people between 2010 and 2026. This means inevitable and significant changes in land use and construction of additional infrastructure. This growth will also increase demands for water, sewage treatment plants (STP), and recreational areas in waterways (Abal et al. 2005). Such changes need to be properly managed to avoid profound and adverse environmental, social, and economic consequences. Water quality management in SEQ that examines combined societal and environmental issues follows

Fig. 1 Map of South East Queensland and its catchments

approaches used in integrated water resources management (e.g., the European Union Water Framework Directives; European Parliament Council 2000; Steyaert and Ollivier 2007).

The decision process in SEQ is facilitated through the Healthy Waterways Partnership (HWP), a collaborative initiative between state and local governments, industry, researchers, and the community to improve the condition of catchments and waterways of the region. HWP has developed a long-term strategy to achieve its objectives using an adaptive management framework (Healthy Waterways 2011). An important component of the adaptive management setting in SEQ is the Ecosystem Health Monitoring Program (EHMP), an integrated aquatic monitoring program established in 2000 to assess water quality and the effectiveness of management and planning activities in the region. The EHMP provides an annual assessment of ecological health, a Report card, for each major catchment and estuary and for Moreton Bay. Report cards are graded from "A" (excellent) to "F" (fail). The EHMP is recognized as one of the most comprehensive and successful aquatic monitoring programs in Australia (Commonwealth of Australia House of Representatives 2009). It also provides both managers and researchers with the feedback required in the adaptive management cycle to better target investments to maintain or improve the health of waterways (EHMP 2008).

MATERIALS AND METHODS

We adopted a deductive/inductive methodology (Arthur 1994) to understand water quality decision-making in SEQ (Fig. 2). This choice emerges from the proposition that both deductive and inductive methods are necessary for the practical in-depth study of the interview data (Hansson et al. 2010). That is, we based the interview schedule on the literature (Supplementary Material A) and then applied it when interviewing the resource managers. We then constructed a conceptual model founded on interview data. We did this by following a logical process (deduction) derived from manually analyzing interview transcripts and synthesizing a system of hypotheses. We gained further insights and updated the conceptual model inductively by testing the various hypotheses using text analysis software (Leximancer^{TM}; for more detail on text analysis methods, see Supplementary Material B, and on hypotheses testing, refer to Figs. S1 and S3 of Supplementary Material B).

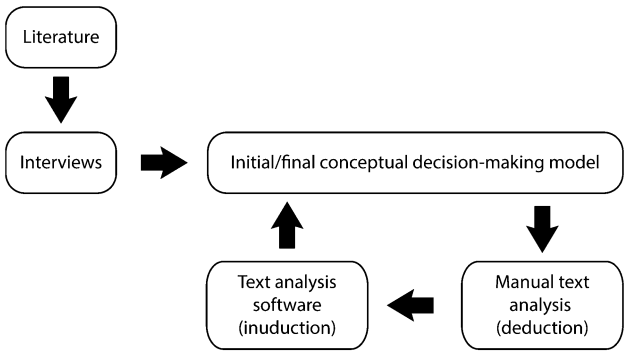

Fig. 2 Methodological framework

Interviews

Interviews were conducted in November and December 2009 with 19 regional decision-makers from SEQ, a group consisting mainly of middle to senior local government and State managers. The interviews aimed at identifying the managers' conceptions of water resource management. Each interview was related to one decision from a list of decisions identified by the HWP that led to a concrete action (Table 1). Interviews were semi-structured, lasted about 1.5 h, and used two interviewers who followed a standard set of questions; the interviews were conducted under ethical considerations (Supplementary Material A). Interviews were transcribed for manual and computer-aided text analysis.

The data from the interviews helped us understand the decision attributes and processes that predominate within the selected decision-making group. This resulted in the development of a participatory modeling technique for presenting information that was cognizant of participants' worldviews. The approach aimed at understanding learning and decision-making mechanisms by allowing participants (which included some of the interviewees) to actively manage water quality in a virtual catchment. For the participants, the objective was to improve water quality (from catchments to coastal waters), while also satisfying social and economic indicators (Dutra et al. 2011; Myers et al. 2012).

Decision Analysis

The manual content analysis helped us to identify past decisions made by interviewees in the interview transcripts (for details on methods see Supplementary Material B). The method consisted of identifying sentences in each interview that were related to a decision made, sorting information to capture patterns, and then identifying the most common keywords (based on social, institutional, spatial, geographical, and biological elements) grouped

Table 1 Decision topic and concrete actions taken by interviewees

Decision topic	Concrete action
Ripley Valley greenfield development	Planning and initial design of new development in Greenfield
Water strategy for the future (total water cycle planning)	Internal consultation and external consultation with Brisbane residents. Agreed high-level strategy
Noosa River Plan and protecting the catchment	Confining and managing urban development
Ipswich regarding the Bremer River audit and cleanup	Development of an action plan. Negotiation with developers and industry for cleanup of the river
Logan aquaculture bid on the expansion of prawn farming in the lower Logan catchment	Nutrient load limitation decision
Urban planning and the North Lake sub-divisions	Planning, developing, and implementing large-scale urban development
Upgrades of wastewater treatment plants (Oxley, Sandgate, and Luggage Point)	Upgrades of existing treatment plants
Retrofitting water sensitive urban design for Logan City	Mitigation of impacts of stormwater runoff
Western Corridor Scheme	Taking wastewater and purifying it for re-use
Waterways health improvement	Development of a recovery program and its implementation in Maroochy waters
Licence of wastewater treatment plant	Water quality guidelines for sewage treatment plants

into concepts, and finally, inferring causal relationships (Dray et al. 2006). The assessment of each decision mentioned in the interviews relied on two types of measure: (i) the level of influence of each decision attribute (derived from concepts) on the realization of the decision (attribute score) and (ii) the effectiveness of this realization (realization score). The attributes and the quality of the measures are set out in Table 2. For each decision attribute, we converted the qualitative measures to a score ranging from −2 to +2. For instance, a decision involving assumptions that are both strong and consensual would attract a score of +2, whereas in the case of both scarce and unreliable information, a score of −2 was allocated. Intermediate scores were allocated as appropriate. The strength of the relationship between these attributes and the realization was quantified using a simple Pearson's correlation between the scores. In the following, decision attributes, concepts, and keywords identified by the software are shown in *italics*.

Table 2 Attributes and the positive and negative factors we considered in the quality score

Attribute	Quality	
	Negative	Positive
Assumption	Weak and contentious	Strong and consensual
Communication	Poor and fragmented	Good and constructive
Context	Adverse and do not catalyze realization	Favorable and catalyze realization
Information	Scarce and unreliable	Plentiful and reliable
Leadership	No leadership	Strong leadership
Logistics	Inadequate and phased out	Adequate and phased in
Regulation	Conflicting	Supporting
Realization	Partial and ineffective	Complete and effective

RESULTS

Manual Text Analysis

In the initial manual content analysis of the 19 interviews, we identified 219 decisions and 105 associated keywords (Supplementary Material C). The 10 most common keywords (count >30) (Table 3) were *council, communication, funding, planner, regulation, information, community, monitoring, State*, and *developer*. Keywords such as *local knowledge, maintenance,* and *prevention* were less frequently cited as relevant to decisions.

Keywords associated with decision-making (Table S3; Supplementary Material C) allowed us to identify these decision attributes for realizing decisions: *context* (water

Table 3 Top 10 keywords related to decision-making and the number of times they were mentioned in the 219 decisions identified in the 19 interviews. Keywords were grouped into seven concepts: *context*, *information*, *regulation*, *communication*, *logistics*, *assumption*, and *leadership*. For the complete list of keywords and concepts refer to Supplementary Material C

Keyword	Concept	Count
Council	Leadership	72
Communication	Communication	44
Funding	Logistics	43
Planner	Regulation	41
Regulation	Regulation	40
Information	Information	35
Community	Leadership	34
Monitoring	Information	34
State	Regulation	34
Developer	Leadership	31

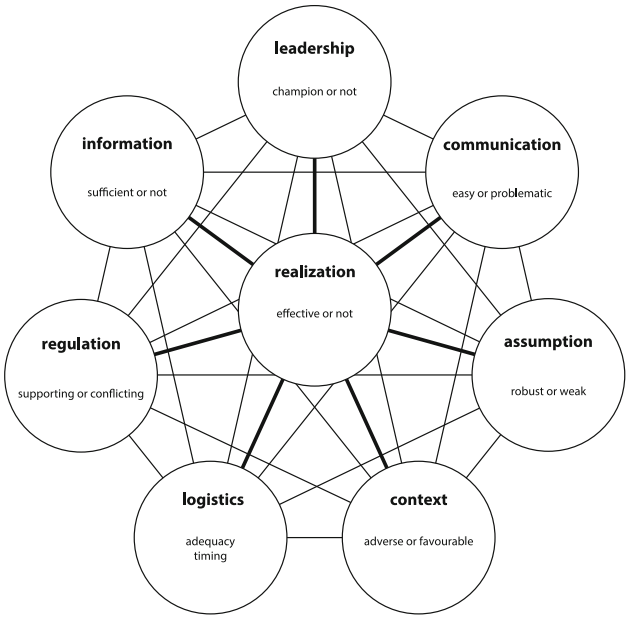

Fig. 3 Conceptual model constructed after manual content analysis indicating seven attributes involved to realize a decision

quality and development), *information* (monitoring and model), *regulation* (planner and intervention), *communication* (negotiation, coordination, and *lobbying*), *logistics* (funding and infrastructure), *assumption* (evidence and culture), and *leadership* (*council*, *community*, *State*, and *developer*). The conceptual model constructed in this initial phase uses the seven decision attributes elicited from the interviews (Fig. 3), where they equally influence each other and also the effectiveness and complete realization of decisions.

Figure 4 represents pairwise relationships between the attributes of the interview data and shows how they may affect how decisions are realized. The Pearson's correlations show that both *communication* and *logistics*, and to some extent *context* and *leadership*, are associated with *realization*. *Information* is only weakly associated with *realization*. There are strong correlations between certain pairs of attributes, especially between *realization* and *communication*.

Software-Based Text Analysis

After the manual text analysis, we used the text analysis software Leximancer^{TM} to construct an improved conceptual model of the water quality decision-making process in SEQ and also a narrative of the decisions.

Leximancer's output data are made up of concepts, frequencies, and relevance (Table 4; Supplementary Material B) related to "decision," "realization," and "effectiveness." Making decisions about water quality often involved *collaboration* and *negotiation* between the interested parties (Table 4A). *Regulation, plan*, and *negotiation* were related to realizing the decisions (Table 4B) and *negotiation, money*, and *assessment* were concepts related to the *effectiveness* of decisions (Table 4C). The flat prominence distribution shown in Table 4B suggests that realizing a decision is probably the most complex part of the process where no single critical factor can be identified. Conversely, the skewed prominence distributions in Table 4A, C suggest that critical factors consistently determine both the generation of decisions and their effectiveness. Decision attributes involved in the decision process (Fig. 3) are used to guide the results presented below.

A Conceptual Model for Water Quality Decisions in South East Queensland

The interview analysis performed with the aid of text analysis software provides a richer representation (when compared to the manual decision analysis) of how the indirect relationships between decision attributes affect how decisions are realized and their effectiveness. The analysis highlights a broad decision mechanism of vital attributes used by managers in their inductive decision-making (Fig. 5, which is an updated conceptual model based on Fig. 3). The interview material suggests that, when the *context* is compelling for a decision, opportunistic *leaders* will lobby and exercise their power to implement actions through *communication* (which includes negotiation and *lobbying*), and generally supports the findings of previous studies reported in the literature (Stacey 2001; Arvai 2003). *Information* (e.g., from science, people, and media) facilitates the process of *communication*. It is important to note that *communication* influences the *context*, thus being indirectly associated with the realization and effectiveness of decisions. The general *assumptions* (or beliefs) of people and organizations should be strong and consensual and will influence the *context* to realize a decision. Adequate *logistics* (infrastructure or the money to put them in place) will favor the *context* to realize decisions. The realization of a decision is broadly influenced by the *context*. If the *context* is favorable (e.g., unexpected floods, environmental accident, and political event), then it is more likely that the decision will be realized, indicating a reactive type of management. Supportive *regulation* is important to realize the decision, which can be effective or not. Realizing decisions and their effectiveness depends on how these attributes interplay with one another. The supporting evidence for the conceptual decision model presented in Fig. 5 was deduced from the software-aided text analysis and from the interviews presented below.

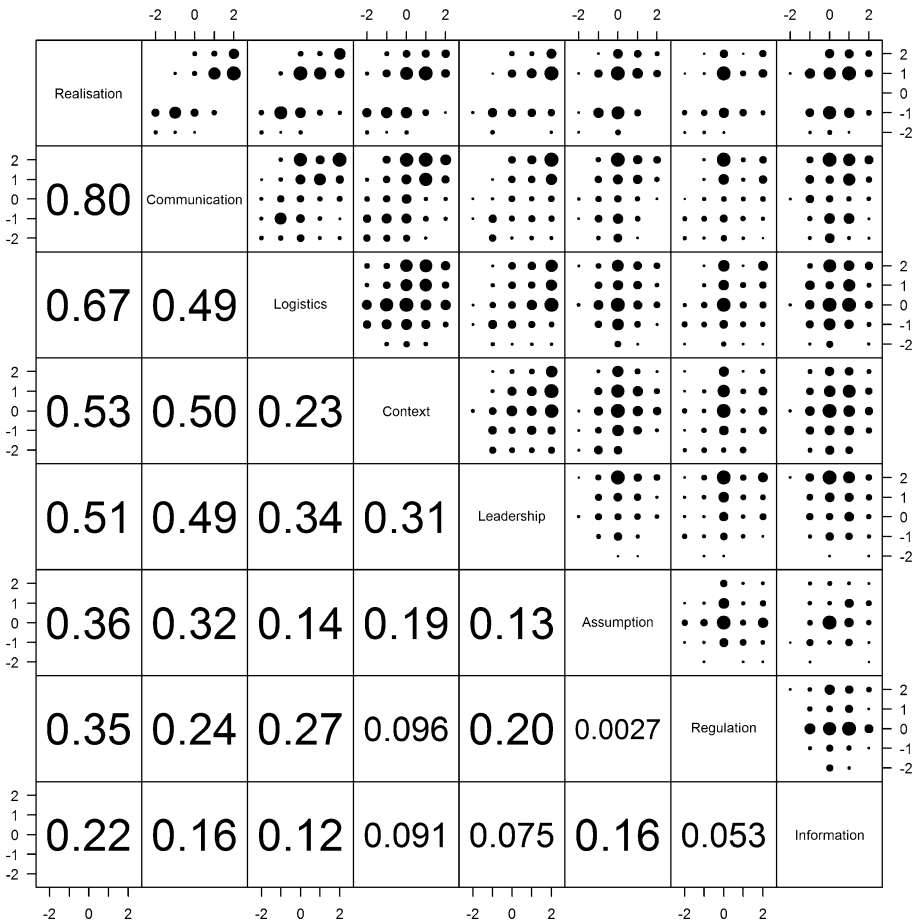

Fig. 4 Pairwise plots of the interview attribute data. *Lower triangle* Pearson's correlation coefficient. *Upper triangle* scatter bubble plots of the scores with area of bubble representing the number of observations. The attributes are ordered in decreasing order of correlation with the *Realization* attribute

Making Sense of the Decision Attributes: A Narrative of the Interviews

The computer-aided content analysis provided more in-depth insights to understand how water quality decisions were made in SEQ. We use the core decision attributes identified from interviews, as well as keywords and concepts identified in Table 4 and Figs. S1, S2, and S3 of Supplementary Material B, to support the narrative analysis about water quality decisions presented below. The analysis is supported by segments from the interviews identified with the aid of the text analysis software (for ethical reasons, these segments were modified in the description below, but we provide examples based on evidence from interviews).

Communication

People and how they interact with others play a very important part in the making and realizing of decisions. *People* are community members, and they also belong to organizations that are part of, or affected by, decisions. *People* such as managers and politicians often look at alternatives before implementing decisions. *Consultation, networking, communication*, and *conflict* all appear as related concepts, indicating the importance of people's relationships in the decision-making process.

Industry and community groups often try to persuade (lobby) *councils* to allow *development* or to avoid it. *Lobbying* clearly depends on the ability of leaders to influence decision-makers. Interviewees did mention occasions when local *governments* welcomed intervention from *State government* as it removed some of the *lobbying* pressure from industry on *councils*. This again reinforces the apparent importance of leaders to influence decision-making. Community *lobbying* also puts pressure on *councils*. For example, when the community detects problems such as over-regulation and increasing *cost*s of housing, they lobby the *council*, who then put pressure back onto *State government* to avoid or reduce *regulation.*

The interviews also revealed the need for stakeholders to *work* together closely in order to realize an effective decision (i.e., that will result in the best outcome in terms

Table 4 Concepts related to (A) making decisions, (B) realizing decisions, and (C) effectiveness of decisions in order of prominence (from Leximancer^{TM}). The quantities F, S, and P are relative frequency, strength, and prominence: F = Pr(concept | category); S = Pr(category | concept); P = Pr(concept and category)/(Pr(concept) × Pr(category))

Category: (A) making decisions				(B) Realizing decisions				(C) Effectiveness of decisions			
Concept	*F* (%)	*S* (%)	*P*	Concept	*F* (%)	*S* (%)	*P*	Concept	F (%)	S (%)	*P*
Collaboration	3	33	24.0	Regulation	6	18	3.6	Negotiation	3	8	14.1
Negotiation	3	16	12.0	Plan	25	18	3.5	Money	24	4	7.4
Assessment	8	11	8.3	Negotiation	1	16	3.2	Assessment	6	3	6.5
Assumption	14	5	3.9	Champion	2	16	3.1	Plan	32	2	4.5
Information	8	5	3.7	Government	11	15	3.0	Communication	18	2	4.3
Champion	3	4	3.4	Development	16	14	2.8	Development	24	2	4.1
Science	8	4	3.3	Lobbying	<1	14	2.8	Model	6	2	3.8
Logistics	19	3	2.7	Money	9	14	2.7	Government	9	1	2.4
Communication	10	3	2.4	Assessment	2	13	2.6	Waterways	15	1	2.4
Model	4	3	2.4	Communication	9	11	2.2	Environment	3	1	2.0
Money	8	3	2.3	Science	5	11	2.2	Context	15	1	1.9
Context	18	3	2.2	Context	16	10	2.1	Assumption	6	<1	1.7
Government	8	2	2.0	Environment	3	10	2.1	Science	3	<1	1.3
Waterways	11	2	1.8	Model	3	10	1.9	Logistics	9	<1	1.3
Development	9	2	1.5	Waterways	11	8	1.7	Lobbying	<1	<1	0.0
Regulation	3	2	1.5	Assumption	5	7	1.5	Collaboration	<1	<1	0.0
Plan	4	<1	0.5	Information	3	6	1.3	Champion	<1	<1	0.0
Lobbying	<1	<1	0.0	Logistics	8	6	1.2	Information	<1	<1	0.0
Environment	<1	<1	0.0	Collaboration	<1	<1	0.0	Regulation	<1	<1	0.0

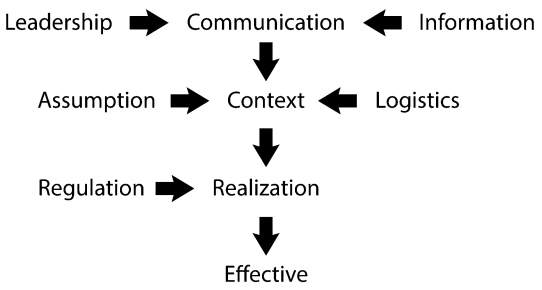

Fig. 5 Core elements of the conceptual decision-making model after analysis using the Leximancer^{TM} software

of improvement in water quality indicators). Working together also means raising the awareness of stakeholders through *education* campaigns. This is perceived to be an effective means of *communication* for changing the way people think about the influence of rural and urban management practices and their concomitant impacts on water quality. A clear message was that *education* is a powerful tool that can be used before enforcement, which appeared to work most of the time.

Communication is necessary to reinforce the context to realize decisions, in the sense that all levels of *government* and their planners should be able to *communicate* effectively with stakeholders in order to realize decisions. *Communication* is closely associated with *evidence* and *science* (*information*, see below). According to interviewees, if *communication* is based on scientific evidence, then it is easier to justify refuting or allowing development, or unpopular policies, to both developers and the wider community.

Logistics

Keywords identified in the interviews that contribute to realizing a decision are *plan*s, such as management, *catchment*, and river *plans,* or established *projects* to deal with water quality. These represent important logistical support that influences *context*. Another important concept related to *logistics* is infrastructure. For example, a mismatch between STP capacity and population growth may trigger a decision to upgrade a STP, which is easier to realize than is the decision to build a new plant.

Money is important to implementing decisions as it provides the means to put logistical arrangements (programs and infrastructure) in place, thus influencing the *context* for decisions. Another important influencing factor is that *money* is often associated with *lobbying*. An example from the interviews is that the industry puts pressure on *councils* to release land for development with the argument that if they do not, housing prices will likely increase; an unpopular outcome with negative consequences to the electorate.

Context

The interviews focused on decisions about *water* and *waterways* management, which explains their relatively high relevance; *pollution, quality*, and *system* were associated with these concepts. *Context* indicates that there were particular situations that favored (or catalyzed) a decision, where floods, drought, *development,* population *growth*, and crisis are all related to *context*. A decision was often realized when the context was appropriate. For example, interviewees identified that *pollution* provided the context to trigger decisions to reduce it. *Treatment*, *stormwater*, and *regulation* are concepts associated with *pollution*. The concept *urban* was also seen as related to context. For example, *urban* stormwater provides a context for a decision, as it is considered to be a major source of sediments and nutrients entering the waterways.

Leadership

Decisions to design and implement *plans* (part of *logistics*) will depend on strong *leadership* working in collaboration with industry, *government*, and communities. Leaders use their *negotiation* skills and *networks* as part of their *communication* strategy to influence the realization of decisions. Leaders are described as champions who establish a vision and work together with the community and other stakeholders to achieve this vision. Leaders can be politicians or members of the community or industry.

Councils are expected to *work* together and *collaborate* with *State government* (regulators), community groups, and industry to develop *programs* to improve water quality. Hence, decisions are more likely to be realized and to produce the expected results if there is a true collaboration between the interested parties.

Government was described as relating to both *State* and local *governments*. They have a responsibility to collaborate with industry and other agencies, and to intervene, educate, and regulate where necessary. *Politicians* were cited in close connection with *governments*, and their role was of collaboration with other people to make decisions and implement them. Politicians are often regarded as leaders with the power to persuade and the ability to negotiate and implement decisions. One interviewee mentioned that in some cases politicians take actions even with weak scientific evidence.

Assumption

The interviews suggested that *consultation, education* campaigns, and development of *strategies* all influence beliefs (*assumptions*), and can make it easier to realize a decision. It is reasonably easy to understand why *consultation* and *education* affect assumption as these attributes influence the way we understand the world. However, it is less straightforward to understand why *strategies* influence assumptions. This may be associated with the process of thinking through an extensive list of possible factors that may be directly and indirectly affected by decisions.

Regulation

Interviewees mentioned that *regulation* was used with *education* to underpin water quality management. Supporting *regulation* is sometimes crucial to improve water quality. For example, one interviewee mentioned that regarding erosion and sediment control (E&SC) measures undertaken in greenfield areas, some *councils* used *education* and awareness campaigns to encourage developers to implement E&SC. *Education*, however, was only partially successful.

In the interviews, *uncertainty* was associated with unclear outcomes of decisions due to bureaucratic excesses (*regulation*), or when it is unknown whether a decision really produced the expected effects. For example, one interviewee mentioned that it is uncertain whether the decision to implement the EHMP and its associated *report card* is truly influencing the decisions in SEQ or not. *Uncertainty* is, therefore, an important factor that inhibits using (science-based) *information* in decision-making.

Information

Interviewees suggested that the *management* of water quality involves people or groups of people gathering *information* and transforming it into actions to solve particular problems. The *report card* system provides snapshots of *information* describing the condition of the waterways and is used to support and justify water quality management decisions in SEQ. The *report card* was frequently related to evaluating or making decisions, such as integrated *catchment* management and *catchment rehabilitation* for improving water quality. Interestingly, interviewees from *catchments* with historical low *report card* grades seemed to be less confident in the *report card* assessments than interviewees from *councils* with higher grades. For example, one interviewee suggested that actions to improve water quality in their catchment will have little effect on their *report card* grades due to (i) natural catchment conditions (e.g., naturally turbid waterways) and/or (ii) poor water quality from upstream *councils* with predominant rural/grazing land use.

Change is linked with *strategy, regulation*, and *negotiation* and generally means a course alteration as a result of

new *information*. Relationships depicted in Table S3 and Supplementary Material C prompted further exploration of what is needed to make a *change*. After generating a table where *models* is the category of interest (not shown), we found that *models* were sometimes used to provide *information* about water quality to decision-makers. Model outputs were then used to catalyze *change* in the course of actions. One interviewee suggested that simulation models were used to plan the construction of STPs and to track the impacts of their effluents on waterways health. Quotes from interviews associated with *change* suggest that it is important that changes in strategies and regulations are well founded in *monitoring* programs (*information*) to better understand the potential effects of changing actions on the environment. *Monitoring* is also critical to evaluate whether or not a decision has achieved its objectives in terms of water quality improvements, *education* programs were effective, and an intervention produced the expected outcomes. Changes in strategies and regulations were frequently negotiated.

Even though most interviewees acknowledged the need for *information* to make decisions, it is important to note the relatively low relevance of *information* in the decision process (Fig. 3). In fact, the text analyses suggest that decisions should depend (and often they do) on *information* (Table 4), such as scientific assessments based on monitoring programs and *report cards*. However, interview data indicate that *information* is often ignored and decisions depend more on the ability of people (individuals and groups) to *communicate* their concerns or to *lobby* effectively. Our results indicate that the ability to *communicate* effectively combined with the appropriate *logistics* and the "right" context, even when there is insufficient *information* available or the quality of the *information* is poor, is more relevant to decisions than the *information* itself.

Realization and Effectiveness of Decisions

Decisions can be fully *implemented* (realized), partially realized, or not realized for various reasons. One interviewee mentioned that before implementing a decision, managers inevitably look at *alternatives* in terms of *cost*s and effectiveness. They also *look* at alternative locations where the decision can be implemented. The concept *look* was used as a synonym of investigation and was closely associated with the concepts *collaboration* and *intervention*. The managers we interviewed often looked at issues in collaboration with other interested parties before implementing a decision.

Money (as part of *logistics*) is an important keyword associated with the effectiveness of decisions. For example, if there is insufficient money to fully implement a decision, then it is likely that the decision will be only partially effective.

Summary of Results

Our results emphasized the role of key individuals (e.g., managers, politicians, and community leaders) and the relationship they have with each other to strongly influence decisions. For example, by *communicating* their views, *lobbying* and *negotiating*, key individuals can influence the decision *context*. *Information*, such as scientific *assessments*, resulting from monitoring programs and assessment tools (e.g., ecosystem health *report card*) is used only indirectly in realizing decisions by helping leaders to communicate their views and lobby. The *context* (such as sudden changes in the environment—an election, a natural disaster, and new developments) directly catalyzes or interrupts the realization of decisions and is influenced by *communication*, *assumptions*, and *logistics*. The *assumptions* (beliefs) people hold also influence the *context*, as individuals perceive problems differently depending on their *assumptions*. *Logistics* also directly affect the *context,* and supporting *regulation* will often significantly help to realize decisions.

DISCUSSION

Deductive/Inductive Methods to Construct a Conceptual Model for Water Quality Decisions in SEQ

Using deductive/inductive methodology in our research facilitated a deeper understanding about the relationships between decision attributes identified in the interview data and effective decision realization in SEQ. This constitutes a major contribution of our research. The methodology helped transform concepts and ideas elicited from interviews into a water quality decision-making model for SEQ. Text analysis software allowed us to quickly and objectively explore the data and also reduce potential subjective bias normally associated with inductive-only methods (Arthur 1994). The methodology also provided for the incorporation of the analyst's experience to classify words and concepts identified inductively (Hansson et al. 2010).

At a more practical level, our methodology indicates potential intervention points. For instance, *communication* is the most important attribute influencing the realization of water quality decisions. *Information* was the attribute that least affected water quality decisions in SEQ. This is no surprise, as the literature supports this, providing several examples both of management failures due to ineffective *communication* between *information* providers (e.g., scientists) and decision-makers (see McNie 2007; Timmerman et al. 2010) and of the influence of *communication* and *lobbying* in decision-making (Brock and Carpenter 2007).

Adaptive Management Futures in SEQ

Why is *information* not directly influencing water quality decisions in SEQ as expected in adaptive management? Cash et al. (2002) argue that the credibility, saliency, and legitimacy of *information* are normally associated with its acceptance and use by decision-makers. Our findings, supported by McNie (2007), indicate that the quantity of data, as well as the type and quality of *information* generated from data, together with psychological, relational, and political factors, all contribute to reduce the saliency of *information*. For example, some interviewees believe (*assumption*) that the *information* generated via the *report card* is not salient or credible, resulting in little influence in managing water quality.

Our results suggest that using *information* indirectly in decision-making also relates to *assumptions*. This impacts on the *realization* of decisions because the way people perceive things will influence the *context* to implement a decision. *Leadership* and *regulation* contribute in making *information* more credible and salient (and thus more useful) in water quality management. For instance, our analysis indicated that even though *information* (from models and data) shows E&SC to be one of the most effective ways of reducing *development* impacts on *waterways* health (Weber 2008) and, therefore, to improve *report card* grades, its use is limited. For example, *councils* cannot reinforce *State regulation* on roadworks on highways as it is a *State jurisdiction*. Nevertheless, interviewees frequently mentioned that *councils* are in a better position to check whether or not *developers* are *complying* with *State legislation* (with regard to E&SC), which would produce better outcomes in the realization of decisions, thus reinforcing the need for *governments* at all levels to work together.

The interviews revealed that despite huge investments in generating *information* through report cards, improvement in water quality conditions is limited to some regions, mainly estuaries (Healthy Waterways 2014). Our analysis demonstrates that we cannot simply isolate the process of generating *information* from the other psychological, relational, and political processes involved in water quality decisions in SEQ. We propose that there is space to improve adaptive management by increasing the uptake of *information* in the decision-making process. Our findings and previous research (de Geus 1994; Priscoli 2003; van den Belt 2004; Brock and Carpenter 2007) suggest that although the HWP already has a strong component of stakeholder involvement, there may be a need to increase *communication* and stakeholder involvement in water quality decisions as an effective way of making *information* more credible, salient, and legitimate. Perhaps the focus should be on *councils* in catchments with historically low *report card* grades. One way of improving *communication* and disseminating *information* is to use participatory modeling (van den Belt 2004, Dutra et al. 2011; Myers et al. 2012). This allows narratives to be built, presented, and discussed through conversations and deliberation between the participants. Individuals learn from each other and also by experimenting with models to test their underlying *assumptions*. Learning from personal experiences and using engagement and modeling as part of the existing governance/political process may help improve stakeholders' understanding about how to *manage water quality* and make decisions adaptively.

As a direction of future research, it is essential to engage management groups or individuals in their working environments (ethnography). This will capture the true character of how resource management organizations and their people operate, which in turn will contribute to a better understanding of how decisions are made in NRM, with positive effects on the development and implementation of methods to more effectively support water quality decisions via adaptive management.

CONCLUSION

Our two key research outputs were (i) the findings of a detailed review of decision-making processes in SEQ and (ii) the conceptual decision-making process established using joint deductive/inductive methods (manual and automated text analyses) that provided a deeper understanding about how decision are made in SEQ. Our research demonstrated the importance of *communication, logistics*, *context*, *leadership*, and *assumption* in making *information* more salient for water quality decisions in SEQ. It also highlighted that more coordinated activities and improved *communication* between stakeholders could deliver better regional water quality in SEQ.

Acknowledgments This project was co-funded between CSIRO Wealth from Oceans Flagship, the Healthy Waterways Partnership, and the CMAR Integrated Marine and Coastal Assessment and Management. We would like to thank Eva Abal, Di Tarte, John Bennett, Mara Wolkenhauer, Andy Steven, and Campbell Davies for their support; and interviewees from across SEQ for their participation. We also thank Sharon Tickell, Toni Cannard, Ricardo Pascual, Peter Bayliss, Olivier Thébaud, and Chris Moeseneder for their valuable work on a parallel project that supported our research. Mac Exon-Taylor provided precious support with the use of Leximancer™, and Sol Rojas-Lizana (University of Queensland) offered valuable insights on text analysis. Peter Bayliss, Olivier Thébaud, and an anonymous referee reviewed the report in which this manuscript is based, and Ingrid van Putten provided valuable comments on an earlier version of the manuscript. We are grateful to two anonymous reviewers for providing insightful criticism that improved the first draft of this manuscript.

REFERENCES

Abal, E.G., W.C. Dennison and S.E. Bunn. 2005. Setting. In *Healthy waterways healthy catchments: Making the connection in South East Queensland, Australia*, eds. E.G. Abal, S.E. Bunn and W.C. Dennison, 222 pp. Brisbane: Moreton Bay Waterways and Catchment Partnership.

Ackoff, R.L. 1989. From data to wisdom. *Journal of Applied Systems Analysis* 16: 3–9.

Argyris, C., and D.A. Schön. 1978. *Organizational learning: a theory of action perspective*. Sydney: Addison-Wesley Publishing Company.

Ariely, D. 2008. *Predictably irrational: The hidden forces that shape our decisions*. New York: Harper Collins.

Arthur, W.B. 1994. Inductive reasoning and bounded rationality. *The American Economic Review* 84: 406–411.

Arvai, J.L. 2003. Using risk communication to disclose the outcome of a participatory decision making process: Effects on the perceived acceptability of risk-policy decisions. *Risk Analysis* 23: 281–289.

Axelrod, R. 2006. *The evolution of cooperation*. New York: Basic Books.

Bots, P.W.G., M.J.W. van Twist and R. van Duin. 1999. Designing a Power Tool for Policy Analysts: Dynamic Actor Network Analysis. In: *32nd Hawaii International Conference on System Sciences*, Hawaii.

Brock, W.A., and S.R. Carpenter. 2007. Panaceas and diversification of environmental policy. *Proceedings of the National Academy of Sciences of the United States of America* 104: 15206–15211.

Bunn, S.E., et al. 2010. Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. *Freshwater Biology* 55: 223–240.

Bunnefeld, N., E. Hoshino, and E.J. Milner-Gulland. 2011. Management strategy evaluation: A powerful tool for conservation? *Trends in Ecology & Evolution* 26: 441–447.

Cash, D., W. Clark, F. Alcock, N. Dickson, N. Eckley, and J. Jäger. 2002. *Salience, credibility, legitimacy and boundaries: Linking research assessment and decision making*, 24 pp.. Harvard: John F Kennedy School of Government, Harvard University.

Commonwealth of Australia House of Representatives. 2009. *Managing our Coastal Zone in a Changing Climate: The time to act is now*, 368 pp. Canberra: House of Representatives.

de Geus, A.P. 1994. Foreword: modeling to predict or to learn? In: *Modeling for learning organizations*, eds. J.D.W. Morecroft and J.D. Sterman, 400 pp. Portland: Productivity Press.

de Oliveira, J.A.A., L.T. Kell, A.E. Punt, B.A. Roel, and D.S. Butterworth. 2009. Managing without best predictions: the management strategy evaluation framework. In *Advances in fisheries science: 50 years on from Beverton and Holt*, ed. A. Payne, J. Cotter, and T. Potter, 104–134. Oxford, UK: Blackwell Publishing Ltd.

Dichmont, C.M., et al. 2008. Beyond biological performance measures in management strategy evaluation: Bringing in economics and the effects of trawling on the benthos. *Fisheries Research* 94: 238–250.

Dray, A., P. Perez, N. Jones, C. Le Page, P. D'Aquino, I. White, and T. Auatabu. 2006. The AtollGame experience: From knowledge engineering to a computer-assisted role playing game. *Journal of Artificial Societies and Social Simulation* 9: 6.

Dutra, L.X.C., N. Ellis, F. Boschetti, C. Dichmont, W. de la Mare and P. Perez. 2011. Healthy Waterways Management Strategy Evaluation: Learning and decision making within an adaptive framework—Final Report, 76 pp. Brisbane: CSIRO Marine and Atmospheric Research Brisbane.

EHMP. 2008. *Ecosystem Health Monitoring Program—Annual Technical Report 2006–2007 on the health of the freshwater, estuarine and marine waterways of South East Queensland*, 41 pp. Brisbane: South East Queensland Healthy Waterways Partnership.

European Parliament Council. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Strasbourg: European Parliament Council.

Fernandez-Gimenez, M.E., H.L. Ballard, and V.E. Sturtevant. 2008. Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. *Ecology and Society* 13: 4.

Finger, M., and J.M. Asún. 2001. *Adult education at the crossroads: Learning our way out*. London: Zed Books.

Fulton, E.A., A.D.M. Smith, and D.C. Smith. 2007. *Alternative management strategies for Southeast Australian Commonwealth Fisheries: Stage 2: Quantitative management strategy evaluation. 378 pp*. Hobart: Australian Fisheries Management Authority Report, CSIRO Marine and Atmospheric Research.

Gregory, R., D. Ohlson, and J. Arvai. 2006. Deconstructing adaptive management: Criteria for applications to environmental management. *Ecological Applications* 16: 2411–2425.

Gunderson L., G. Peterson and C.S. Holling. 2008. Practicing adaptive management in complex social-ecological systems. In: *Complexity theory for a sustainable future*, eds. J. Norberg and G.S. Cumming, 315 pp. New York: Columbia University Press.

Hansson, T., G. Carey, and R. Kjartansson. 2010. A multiple software approach to understanding values. *Journal of Beliefs & Values* 31: 283–298.

Healthy Waterways. 2011. Healthy Waterways: working together to improve waterway health. Retrieved 12 September, 2011, from http://healthywaterways.org/home.aspx.

Healthy Waterways. 2014. Healthy e-waterways: Integrating knowledge. Retrieved 5 March, 2014, from http://www.health-e-waterways.org/reportcard.

Hiller, B. 1997. *The economics of asymmetric information*. London: MacMillan Press Ltd.

Holling, C.S. (ed.). 1978. *Adaptive environmental assessment and management*. Chichester: International Institute for Applied Systems Analysis.

Holling C.S. and L.H. Gunderson. 2002. Chapter 2: Resilience and adaptive cycles. In: *Panarchy: Understanding transformations in human and natural systems*, eds. L.H. Gunderson and C.S. Holling, 507 pp. Washington, DC: Island Press.

Huitema, D., E. Mostert, W. Egas, S. Moellenkamp, C. Pahl-Wostl, and R. Yalcin. 2009. Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecology and Society* 14(1): 26.

Isenberg, D.J. 1988. How senior managers think. In *Decision making: descriptive, normative, and prescriptive interactions*, ed. D.E. Bell, H. Raiffa, and A. Tversky, 525–539. Cambridge: Cambridge University Press.

Jones, N. A., H. Ross, T. Lynam, P. Perez, and A. Leitch. 2011. Mental models: an interdisciplinary synthesis of theory and methods. *Ecology and Society* 16(1): 46. http://www.ecologyandsociety.org/vol16/iss1/art46/.

Keeney, R.L. 1992. *Value-focused thinking*. Massachusetts: Harvard University Press.

McNie, E.C. 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environmental Science & Policy* 10: 17–38.

Myers, S., et al. 2012. Adaptive learning and coastal management in South-east Queensland, Australia. In *Sustainable coastal management and climate adaptation*, ed. E. Kenchington, and L. Sotcker, 157–176. Canberra: CSIRO Publishing.

Pahl-Wostl, C., E. Mostert, and D. Tabara. 2008. The growing importance of social learning in water resources management and sustainability science. *Conservation Ecology* 13: 24.

Priscoli, J.D. 2003. *Participation, consensus building, and conflict management training course: Tools for achieving PCCP*. Paris: Institute for Water Resources, USACE.

Robinson, C.J., D. Smyth, and P.J. Whitehead. 2005. Bush tucker, bush pets, and bush threats: Cooperative management of feral animals in Australia's Kakadu National Park. *Conservation Biology* 19: 1385–1391.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1977. Behavioral decision theory. *Annual Review of Psychology* 28: 1–39.

Stacey, R. 1996. *Complexity and creativity in organizations*. San Francisco: Berrett-Koehler Publishers.

Stacey, R.D. 2001. *Complex responsive processes in organizations: learning and knowledge creation*. London: Routledge.

Steyaert, P., and G. Ollivier. 2007. The European Water Framework Directive: How ecological assumptions frame technical and social change. *Ecology and Society* 12: 25.

Timmerman, J.G., E. Beinat, K. Termeer, and W. Cofino. 2010. Analyzing the data-rich-but-information-poor syndrome in Dutch water management in historical perspective. *Environmental Management* 45: 1231–1242.

van den Belt, M. 2004. *Mediated modeling: A systems dynamics approach to environmental consensus building*. Washington DC: Island Press.

van Vugt, M. 2009. Averting the tragedy of the commons: Using social psychological science to protect the environment. *Current Directions in Psychological Science* 18: 169–173.

Walters, C.J. 2007. Is adaptive management helping to solve fisheries problems? *AMBIO* 36: 304–307.

Ward, R.C., J.C. Loftis, and G.B. Mcbride. 1986. The data-rich but information-poor syndrome in water-quality monitoring. *Environmental Management* 10: 291–297.

Weber, T.R. 2008. *Modelling urban catchment loads—Great lakes water quality improvement plan*, 3 pp. Brisbane: BMT WBM Pty Ltd.

AUTHOR BIOGRAPHIES

Leo X. C. Dutra (✉) is a research scientist at CSIRO (Australia) within the division of Marine and Atmospheric Research. His research interests are in coastal zone management and planning, marine geology and ecology, management strategy evaluation, integrated assessments, and participatory modeling approaches.
Address: CSIRO Marine and Atmospheric Research/Wealth from Oceans Flagship, Ecosciences Precinct, 41 Boggo Road, Dutton Park, QLD 4002, Australia.
e-mail: leo.dutra@csiro.au

Nick Ellis is a mathematician at CSIRO Marine and Atmospheric Research with experience in natural resource modeling, management strategy evaluation, fleet dynamics, biodiversity modeling, photogrammetry, and statistical analysis. His background is in astrophysics and seismic data processing.
Address: CSIRO Marine and Atmospheric Research/Wealth from Oceans Flagship, Ecosciences Precinct, 41 Boggo Road, Dutton Park, QLD 4002, Australia.

Pascal Perez is a world leader in participatory modeling in complex systems currently working at the Simulation, Modeling, Analysis, Research, and Teaching (SMART) Infrastructure facility at the University of Wollongong (Australia).
Address: SMART Infrastructure Facility, University of Wollongong, Northfields Ave, Wollongong, NSW 2522, Australia.

Cathy M. Dichmont is a Senior Principal Research Scientist and Stream Leader of the Resource Use and Conservation Stream at CSIRO's Wealth from Oceans Flagship. She has a national and international reputation in stock assessment, modeling natural systems, natural resource management, shared fishery stocks, and management strategy evaluation (MSE).
Address: CSIRO Marine and Atmospheric Research/Wealth from Oceans Flagship, Ecosciences Precinct, 41 Boggo Road, Dutton Park, QLD 4002, Australia.

William de la Mare has worked on a wide range of topics in marine resource management. He has been influential in international and national conservation and management bodies, both in science and policy development and has specialized in developing management methods for marine living resources.
Address: Australian Antarctic Division, Channel Highway, Kingston, TAS 7050, Australia.

Fabio Boschetti is an applied mathematician and his main interests include modeling ecological and social processes in the management of renewable resources and bridging the gap between science and governance.
Address: CSIRO Marine and Atmospheric Research/Wealth from Oceans Flagship, Underwood Avenue, Floreat, WA 6014, Australia.
Address: School of Earth and Geographical Sciences, The University of Western Australia, Crawley, WA, Australia.