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Review

Key issues and drivers affecting coastal and marine resource decisions: Participatory management strategy evaluation to support adaptive management

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1. Introduction

Changes in the landscape and seascape to accommodate and support human development worldwide are known to be eroding natural resources with flow-on effects on socio-cultural and economic values (Boulding, 1966; Costanza et al., 1995; Holling, 2001; Holling and Meffe, 1996). Because of the feedbacks and inherent uncertainty in social-ecological systems, it is generally difficult to provide one 'best' (or optimal) policy to improve the condition of the resource (Rittel and Webber, 1973).

However, decision frameworks that assist decision-makers on a course of action to regulate natural resource-use have been successfully developed and implemented to improve natural resources management (NRM) issues in coasts and oceans. This includes adaptive management, a decision framework that has been mainly applied to marine fisheries management (Walters, 2007) and a subsequent but related approach, management strategy evaluation (MSE) (Smith, 1994), a framework that accounts for multiple objectives by comparing the trade-offs of alternative management strategies. Improving socio-economic wellbeing and environmental conditions are expected outcomes of successful adaptive management and MSE initiatives. It is recognized that 'success' in NRM depends not only on improving our understanding about the resource dynamics (e.g. population dynamics, harvest efforts, and physio–chemical drivers) but also of governance and behavioral components; i.e. the way actors make decisions, develop rules to mediate resources-use, and implement and enforce these rules (Dutra et al., 2014; Fulton et al., 2013; Gutierrez et al., 2011; Westgate et al., 2013).

There are limited studies identifying decision-making drivers in coastal and marine NRM settings. These studies mostly look at specific aspects of decision making, such as leadership, engagement and scales of governance (Dale et al., 2013; Fulton et al., 2013; Gutierrez et al., 2011). The objectives of this paper are therefore: (1) to review the literature to identify and understand the key drivers affecting NRM decisions, and (2) to use the key learnings from this review and the experience from the authors to examine how formal participatory approaches used in MSE can assist in addressing these drivers. The focus of the review and analyses is on coastal and marine management issues, which includes water, fisheries, biodiversity conservation, and multiple-use management. In what follows, based on a selective review of the literature on organizational learning, adaptive management, and decision-making, we (i) describe key issues affecting NRM decisions, (ii) relate adaptive management and MSE as 'rational' decision frameworks, (iii) present the methods used to review the literature and to identify decision-making drivers, (iv) identify key drivers influencing decision-making about NRM using examples from coastal and marine MSE applications, and (v) examine limitations to the validity of adaptive management and MSE as a rational decision-making model. Understanding these limitations is important in order to contextualize how decision-making frameworks can be more effectively used by managers and stakeholders. Finally, we conclude the manuscript with key findings from our review.

1.1. Key issues affecting NRM decisions

Maintaining or improving the condition of underlying resources and ecosystem services in coasts and oceans is difficult for many reasons. Firstly, resource use and exploitation frequently lead to a polarization between the need for economic development and the need to preserve or conserve the resource base of this development in the long-term, often because the beneficiaries are different groups to those that are impacted by development (Lichatowich, 1992). Secondly, decision-making often involves a diverse set of government organizations (local, state, federal) that control or regulate access to or use of the resource (e.g. fisheries, forestry, land for urban development, agriculture and conservation) (Acheson, 2006; Bella, 1992). This control in turn influences the decisions of resource users who derive economic benefits from harvesting or using natural assets, with impacts on others who use resources for recreational, social and cultural purposes. Thirdly, because of the diverse stakeholder groups affected by coastal and marine NRM decisions and involved in the decision-making process, values and management objectives (environmental, socio-economic and cultural) are often divergent, not well articulated, or not made explicit to the wider society (Burt, 2011; de Geus, 1988; Ludwig, 2001; Walters, 2007). This can lead to tensions within and between stakeholder groups due to lack of transparency in the decision-making process, which also affects the way actions are chosen and implemented.

1.2. Adaptive management and management strategy evaluation as 'rational decision' frameworks

Adaptive management treats policy choices as deliberate, large-scale scientific experiments (Walters, 1997, 2007), for which the decision-making process generates relevant and reliable information about the natural resource system. Adaptive management requires a set of objectives (what managers and stakeholders want to achieve and by when), as well as an effective monitoring protocol to evaluate the consequences of decisions – in relation to objectives – to adjust actions based on the feedback received via the monitoring protocol. In principle, adaptive management can help managers understand the current state, and make explicit the desired states of the resource, also considering uncertainty and a limited understanding of key underlying processes (Bennett et al., 2005; Cinner et al., 2006; Sainsbury et al., 2000).

MSE supports the design and implementation of adaptive management by enabling experimentation with alternative management strategies in a 'safe' computer environment rather than in the real world. The approach has been assisting coastal and fisheries managers in dealing with uncertainty and multiple objectives by allowing the comparison of (often conflicting) social, environmental and economic trade-offs, while testing multiple management strategies (Bunnefeld et al., 2011; Dichmont et al., 2006b, 2013a; Fulton et al., 2013; Fulton et al., 2011b; McDonald et al., 2006; Moeseneder et al., 2015; Smith, 1994).

The presumed effectiveness of adaptive management and MSE is based on the assumption that a manager acts as a single agent that manipulates a set of regulatory levers to achieve objectives, with more or less well-known consequences on the natural resource system being managed, and does so in response to the information (and uncertainties) received from the system via monitoring and assessment models (mental or computer-based models). Adaptive management regards decision-making as 'rational'. That is, it assumes that improved information necessarily leads to improved decisions, and that the aim is to identify and adapt pre-determined courses of action depending on the feedbacks received about the system's response to past actions (refer to Arthur, 1992 for more on 'rational decision-making').

Under the paradigm of rationality, it is expected that scientific recommendations on resource use should seek to provide the best possible assessments of the natural resource, which is expected to play a key role in decision-making (de Oliveira et al., 2009; Walters, 2007). However, coastal and marine decision-making usually involves a number of complex drivers related to governance structures and group dynamics, including leadership (Dutra et al., 2014; Gutierrez et al., 2011), stakeholder engagement (Fulton et al., 2013; Triantafillos et al., 2014), values (Armitage, 2005; Dutra et al., 2015; Failing et al., 2013), and institutions (Gutierrez et al., 2011; Herrfahrdt-Pahle and Pahl-Wostl, 2012), which also influence which management decisions are chosen and how they are implemented (Dutra et al., 2014). In addition, decisions are depending less and less on information alone, and individuals often appear at first glance to decide in 'irrational' ways (see for example Ariely, 2008). This can be explained by cognitive and psychological factors. Hence individual-level responses may themselves have strong driving influences on collective decision-making.

Even though adaptive management principles have been widely referred to in coastal and marine NRM, their practical implementation is still limited (Westgate et al., 2013). The MSE approach has been successfully implementing adaptive management in complex settings, such as fisheries (e.g.Butterworth et al., 2010; Dichmont et al., 2006b, 2013a; Mapstone et al., 2008; Pascoe et al., 2013; Plagányi et al., 2012a, 2012b; Punt et al., 2001; Smith, 1994), environmental conservation (Bunnefeld et al., 2011), coastal water management (de la Mare et al., 2012; Dutra et al., 2014; Moeseneder et al., 2015; Myers et al., 2012) and coastal multiple-use management (Fulton et al., 2013; McDonald et al., 2008; van Putten et al., accepted). Given the limited practical applications of adaptive management and the successful history of MSE in operationalizing adaptive management principles we use MSE as the framework for our analysis.

2. Methods

Our review focuses on literature from adaptive management (as defined in Section 1), organizational learning, and decision-making to identify drivers that function as enablers of effective coastal and marine management. Organizational learning (OL) is defined as an information management strategy designed to detect and correct errors and transfer knowledge and learnings throughout organizations (Argyris and Schön, 1978; Spector and Davidsen, 2006). Identifying enablers of effective management and understanding how they operate within NRM organizations is therefore a significant contribution of our study. Decision-making is an important aspect of organizational learning but it goes beyond the OL domain. The identification of formal decision-making processes (in particular structured decision-making) draws on principles from decision analysis theory (Failing et al., 2013; Keeney and Raiffa, 1976) and has strong commonalities with adaptive management (Failing et al., 2013). Both encompass a process that includes problem definition, description of objectives, strategy development, estimation of consequences, implementation of actions, trade-off evaluation based on a monitoring system, and re-definition of objectives (Failing et al., 2013). Hence, there is an explicit link in our review between decision-making, adaptive management and OL.

The literature reviewed describes a number of drivers that contribute to decision-making, which we aggregated into categories based on their similarities. These are: (i) governance structures, (ii) power and leadership, (iii) psychological processes and (iv) cognitive processes.

3. Results

3.1. Categorizing decision-making drivers

Decision-making drivers identified in the literature were aggregated into four broad categories (Table 1). These are:

Governance structures: refers to organizational drivers affecting the process of making and implementing decisions, such as well defined roles and responsibilities, flexible institutions and management processes, explicit jurisdictions and mandates over ecological boundaries, cooperation, engagement and collaboration between actors, organizational incentives, integration of knowledge, and time delays between problem identification and action implementation..

Power and leadership: refers to drivers related to how leaders interact with other actors to make and implement decisions. Drivers identified in the literature are leadership, politics and power relations, trust, transparent decision-making and management processes, communication, and resources (human and financial).

Psychological processes: involves drivers affecting decision-making at the individual level, such as anxiety and unconscious defenses, values, individual attitudes and group dynamics.

Cognitive processes: refers to how individuals perceive, store and structure information, thus influencing their way of making decisions (Boschetti et al., 2012).

The detailed description of categories and drivers identified in the literature are presented in section 3.2.

3.2. Drivers affecting individual and collective decisions

The existence of multi-stakeholders involved in decision-making processes may be the cause of many of the practical limitations of the standard adaptive management framework. Examples from fisheries management suggest that adaptive management provides insights about how decisions ought to be made when based on new information (Dichmont et al., 2013b; van Vugt, 2009). Where the decision-maker can be seen as (a) a single agent with a consistent and stable set of objectives, (b) able to consistently seek to achieve these objectives, but (c) likely to experience a degree of uncertainty as to what the potential impacts of alternative courses of action might be, a rational, adaptive management approach should strengthen the decision-making process by allowing managers to learn from experience in a reinforcing feedback cycle ('the more I know the better decisions I can make') (Stacey, 1996:196). However, people operating within coastal and marine management organizations are influenced by other people, they often use emotions in their decisions, and unconscious motivations drive the way they interpret information and make decisions (Arthur, 1994; Keeney and Raiffa, 1976:11; Stacey, 2007; Sterman, 2000:26; Tversky and Kahneman, 1974, 1983; Walters, 2007). Below, we present a brief review of how each of the above drivers (Table 1) is expected to affect the process of making NRM decisions in coastal and marine settings. The review provides important insights as to how MSE could be applied to address each category of drivers.

3.2.1. Governance structures

Management problems in coasts and oceans are fundamentally governance problems (Acheson, 2006; Brondizio et al., 2009;

Table 1
Decision-making drivers identified in the literature and corresponding categories used for analysis.

Category	Driver	References
Governance structures	Well defined roles and responsibilities	Borrini-Feyerabend et al. (2006); Hajer (2003)
	Explicit mandates and jurisdictions over ecological boundaries	Acheson (2006); Clarke et al. (2013); Fidelman et al. (2013); Folke et al. (2007); Hajer (2003); Izurieta et al. (2011); Pauly (2007); Smith (2004)
	Cooperation, collaboration and engagement between actors	Adger et al. (2005); Axelrod (2006); Brede et al. (2008); Brondizio et al. (2009); Clarke et al. (2013); Dale et al. (2013); Douglass (2002); Dutra et al. (2015); Fulton et al. (2013); Leith et al. (2012); Meinzen-Dick (2007); Selnes et al. (2006); Stocker et al. (2012b); van Vugt (2009); Vollan and Ostrom (2010)
	Organisational incentives to filter out negative information about the status of natural resources	Bella (1992:19); Buchanan (1983); Tollison (1982)
	Knowledge integration	Costanza (1991); Folke et al. (1998); Folke et al. (2005); Leith et al. (2012); Roberts and Jones (2013)
	Time delays between identification of problem and implementation of decisions	Pister (1992:7); Sterman (2000)
Power and leadership	Leadership	Dale et al. (2013); Dutra et al. (2014); Fidelman et al. (2013); Folke et al. (2005); Gutierrez et al. (2011); Lockwood et al. (2012); O'Keeffe (2002); Walters (2007)
	Power relations	Arvai (2003); Dutra et al. (2015); Kothari (2006:544); Stacey (2001); Van Vugt (2002)
	Trust	Bainbridge et al. (2011); Berkes (2009); Borrini-Feyerabend et al. (2006); Leith et al. (2012); Leith et al. (2014); Mackelworth et al. (2013); Ostrom (2010); Sneed (1997)
	Transparency in decision-making and management processes	Herrfahrdt-Pahle and Pahl-Wostl (2012)
	Communication	Arvai (2003); Brock and Carpenter (2007); Dutra et al. (2015); Dutra et al. (2014); Folke et al. (2005); Gutierrez et al. (2011); McNie (2007); Stacey (2001); Timmerman et al. (2010)
	Human and financial resources	Cundill (2010); Dutra et al. (2015); Stocker et al. (2012b:30); Walters (2007)
Psychological processes	Anxiety and unconscious defences	(Argyris (1991); Stacey (2007).
	Values	Argyris (1999); Bardi and Schwartz (2003); Bottom (1992:1); Keeney (1992:4); Maio (2010); O'Keeffe (2002); Schwartz and Bilsky (1990); Stacey (1996); Stacey (2007:285–287)
	Individual attitudes and group dynamics	Argyris and Schön (1978); Ariely (2008); Axelrod (2006); Boschetti et al. (2012); Bots et al. (1999); Finger and Asún (2001); Isenberg (1988); Slovic (2007); Stacey (2001); Stacey (2007:89)
Cognitive processes	Cognitive styles	Boschetti et al. (2012); Dutra et al. (2014); Failing et al. (2013)
	Worldviews	Bainbridge et al. (2011); Boschetti et al. (2012); Innocenti and Albrito (2011); Simpson and Gill (2007); Stocker and Kennedy (2009)

Dichmont et al., 2013b; Folke et al., 2005; Ludwig, 2001; Olsen, 2003; Ostrom, 2009; Selnes et al., 2006). Governance refers to processes related to decision-making and power sharing where actors (e.g. non-governmental organizations (NGO), government, industry) and market, education and regulation incentives work together to guide society towards desirable outcomes (Brondizio et al., 2009; Folke et al., 2005; Hajer, 2003; Jones, 2013; Selnes et al., 2006).

Governance consists of two interacting components: institutions (rules) and organizations (people) (Dutra et al., 2015). Institutions are the laws, policies, regulations, norms, and customs that shape human action and define opportunities and constraints in which organizations operate. Organizations are the actors, or an organised body of people with a particular purpose, where its members develop the rules for collective decision delegation and membership (Argyris and Schön, 1978:28). A coastal community, or fisheries management bodies are examples of organizations, which may shape and alter institutions (Hodgson, 2006). The focus of this paper is restricted to organizational aspects related to governance. Consequently, 'governance' and 'organizations' are used as synonyms.

Coastal and marine organizations can often be represented as nodes in networks operating at multiple levels (e.g. international, national, state, local) (Brondizio et al., 2009). They consist of many centers linking many levels of government (e.g. national, state, local, departments/sectors), industry, community and NGO, each with its own jurisdictions, interests, goals and means. Few of the nodes are capable of solving NRM problems in isolation (Selnes et al., 2006). For example, at a national level, NRM commonly involves a lead agency (e.g. ministries of fisheries) that operates within a management/development plan or Act (Pauly, 2007). A ministry of the environment, or a similar organization, is also usually indirectly involved in resource management. It is often surrounded by NGOs, industry groups and civil society who influence (or lobby) individuals and agencies involved in decision-making (Dutra et al., 2014). In most cases this structure places stakeholders in various influencing positions, resulting in hierarchical structures or polycentric networks of governance in which power is dispersed leaving areas of responsibility unspecified (Hajer, 2003). Other examples of network governance systems relevant to coastal management include indigenous/traditional systems, which emphasize the intertwined distribution and exercise of a group's decision-making and leadership to achieve collective goals. These traditional nodal governance arrangements seem to be more responsive and effective in terms of NRM (Smith, 2004), but there is no guarantee that these structures will achieve the intended management goals, especially if these are part of or embedded in different governance systems (Acheson, 2006; Izurieta et al., 2011).

Governance structures in place to manage coastal and marine resources often lack the power to deliver the required or requested policy results on their own because of the multiple levels or nodes of governance. This results in leaders with limited power and/or jurisdiction over the resource. This is characterized as an ‘institutional void’, where ‘there are no clear rules and norms according to which politics is to be conducted and policy measures are to be agreed upon’ (Hajer, 2003). One consequence of the ‘institutional void’ associated with the often ill-defined multi-nodal governance structures usually encountered in coastal NRM is that there is no clear process to define what kind of information is required for management, and how or whether the information should be used and acted upon (Dutra et al., 2014). A second consequence is that there may be a long delay (years to decades) between problem recognition and the gathering of financial and administrative support from governments to address NRM problems (Pister, 1992:7). The third consequence is that these governance structures may become dysfunctional, as they tend to filter out negative information and use only favorable assessments about the status of the resources (Bella, 1992:19). According to Bella (1992), this happens for two reasons:

- The norm can be for individuals on management teams or their leaders to take decisions to advance their welfare and career development, thus impeding changes in management and governance that may be necessary in coastal and marine management (this is further examined in section ‘Power and leadership’ below).
- Completing the tasks for changing governance systems when such tasks are outside the norm can be seen as lacking the prospect of reward (on the nature and consequences of such incentives in organizations see also Buchanan, 1983; Tollison, 1982).

Consequently, organizations tend to have a self-sustaining structure with a reinforcing feedback loop. This can only be disturbed when leaders consciously make additional personal effort to promote the necessary changes, and/or when there is a change in political leadership (Walters, 2007). This may lead to a high level of resistance to change, which will only be beneficial if the existing structure effectively deals with NRM problems.

Enabling adaptive management systems to respond quickly to NRM problems and avoid filtering out negative information would seem to entail a strong need for incentives that encourage, rather than deter, innovation and risk taking. At a management level, coastal and marine NRM organizations are bound by the existing legislation, but the actual decision-making processes are not always explicit (Dutra et al., 2014). They are also influenced by power relations and leadership styles and are affected by the behavior of decision-makers when facing management challenges. This in turn affects how decision-makers choose and interpret the information available to them.

3.2.2. Power and leadership

Empirical evidence suggests that making and implementing decisions about coastal and fisheries issues is often related to strong leadership and/or to the influence of power groups (Dutra et al., 2014; Gutierrez et al., 2011; O'Keeffe, 2002; Walters, 2007). Strong leadership has also been associated with successful management initiatives in catchment-to-coast (water quality), fisheries, and marine biodiversity management (Dutra et al., 2015, 2014; Gutierrez et al., 2011; Lockwood et al., 2012). For our discussion, we define leaders as middle-level staff from a regulatory agency who have the power to persuade as well as the ability to negotiate and implement decisions (Dutra et al., 2014; Walters, 2007). These leaders are expected to source funds to build teams to deal with coastal and marine problems under the existing legislation and organizational structures. Not surprisingly, leaders and the management teams they create often share beliefs, values and objectives, resulting in decisions that conform with the values of the leader (this is similar to organizational culture, see Argyris, 1999; O'Keeffe, 2002; Stacey, 1996).

Walters (2007) suggests that changes in management processes or structure in fisheries organizations are only possible when a leader creates additional work for themselves ‘in terms of setting up new regulations and enforcement procedures, designing and staffing (funds, equipment, people) new monitoring initiatives, and organizing the oversight processes (committees, administrative procedures) typically required for any new management program in today's highly bureaucratized management systems'. The way leaders interpret information and act upon these is critical in the process of choosing decisions when management objectives conflict or when it is not clear whether the management actions will achieve desired objectives (i.e. managing under uncertainty).

In the absence of complete information and certainty, the choices of the management team are often based on support from the existing leadership (Folke et al., 2005; Gutierrez et al., 2011; Stacey, 1996:196). Vested interests are part of this process and are unlikely to be disturbed if leaders and the individuals in their team share similar beliefs about how the management system should work. This may be another reason for stability in governance structures, which may be beneficial if the coastal/marine resource is being managed adequately. However, instability may be created when individuals keep moving within and outside the organizational structure as this is sometimes the only way for civil servants to get promoted.

Implementing decisions often depend on how well leaders communicate issues and decisions with their teams (Folke et al., 2005; McNie, 2007; Timmerman et al., 2010) and how much team members trust their leaders (Berkes, 2009; Ostrom, 2010). Transparency in management decisions (Herrfahrdt-Pahle and Pahl-Wostl, 2012) and adequate resourcing (human and financial) (Cundill, 2010; Walters, 2007) are also important factors identified in the literature that support leadership.

3.2.3. Psychological processes

When there is a change in leadership and the management team no longer shares beliefs with the new leader, team members (or the new leader) may experience internal conflicts and contradictions in the form of unconscious defenses against anxiety and uncertainty (Argyris, 1991; Stacey, 2007). For example, a ‘green’ politically oriented leader working with a ‘pro-development’ team will most likely become anxious if she/he chooses to implement decisions that do not conform to the team's and/or higher level leadership values and beliefs. Values are important because they reflect ‘what’ stakeholders want the system to be and ‘how’ they want to implement it. Values provide the principles that underlie decisions as well as the metrics to evaluate progress (for more comprehensive definitions of values refer to Bardi and Schwartz, 2003; Bottom, 1992:1; Keeney, 1992:4; Maio, 2010; Schwartz and Bilsky, 1990). According to Stacey (2007:285–287), anxiety resulting from a conflict in values may influence a person's perception of future opportunities and management strategies. In other words, contradictions and the consequent anxiety due to differences in values and beliefs may limit individuals' capacity to identify a problem and also their ability to choose and implement management decisions.

Even though clearly defined management objectives are key to NRM, their articulation can be difficult, especially in coastal management problems where the trade-offs between alternative objectives are difficult to avoid (Mackenzie et al., 2006; Rittel and Webber, 1973). Defining management objectives in NRM settings results from negotiations between interested parties and forms part of the purpose and outcome of activities such as modeling and data analysis that support NRM (Boschetti, 2007). As a result, decision-makers often need to surmise the likely behavior of others to filter and choose which information to use and also which objectives to achieve.

Another psychological factor influencing decision-making is how individual attitudes and group processes respond to the risk of failure (Stacey, 2007:89). Individuals tend to ignore recognized deficiencies and uncertainties in the management and/or biophysical systems to maintain control, which leads to the development of defensive routines[1]. Stacey (2007) suggests that under these circumstances it is common for the management team to be aware of the problem but all agree, tacitly, not to discuss it. Fear of failure is noted as a strong influence on the willingness of individuals to act, which has been reported in coastal Australia (Dutra et al., 2014). Individuals may apply ‘organizational defensive routines’ to constrain the process of making and implementing decisions by not acting due to the fear that these actions will not produce the expected results (Stacey, 2007).

3.2.4. Cognitive processes

Context, personal preferences, time delays, values and cognitive styles all have strong influences on decision-making. The context for the decision is highly relevant because it influences decision-makers' judgments about the available information (Dutra et al., 2014). The acceptance of decisions also appears to be highly contextual, depending on the type of problem, the social, political and economic implication of the message; the type of audience, and the charisma and reputation of the messenger (Boschetti et al., 2012). For instance, for environmental decisions people tend to accept certain options (e.g. nuclear power) better when these are described as being the result of wide public consultation (Arvai (2003) calls this ‘context dependence’). Empirical results (e.g. Dutra et al., 2014) support the context dependence hypothesis, where certain types of controversial water quality management decisions (e.g. the construction of infrastructure to recycle water in coastal Australia) have greater chances of being implemented when the context (e.g. long drought) is favorable. Context dependence leads to the possibility, for example, that individuals ignore information and base their choices on transitory perceptions influenced by their current context.

Individuals assess problems and make decisions based on their expectations of the performance of a choice, when compared to the performance of alternative choices. In particular, certain outcomes will usually be given greater weight in decision-making than others, despite appearing ‘irrational’. This is the case, for example, with options which carry small expected probabilities of sustaining extremely high losses or making extremely high gains. Individuals have also been shown to grant greater weight in their decisions to perceived losses than to the equivalent gains (Kahneman and Tversky, 1979). Interestingly, these general results regarding human behavior were validated in the context of environmental management decisions, where ‘losses’ were presented as a need for ‘restoration’, while ‘gains’ were framed as a possibility for ‘improvements’ in environmental conditions (Gregory et al., 1993). Prospect theory asserts that the way the information (on regulations, on incentives, on political decisions and also from data and models) is communicated to the public and leaders can strongly influence the actual decisions. This implies that communication methods—as applied in examples on biodiversity conservation and water quality management in the coastal zone (Dutra et al., 2014; Westgate et al., 2013)—are critical to adequately present information necessary to anticipate such cognitive reactions of stakeholder groups.

Time delays in the interactions between management and natural resource systems also influence the process of making decisions. Resource management decisions always involve time delays between a decision made to improve the resource condition, its implementation and when it actually produces the desired outcomes. For example, the revegetation of riparian zones or reduction in catches of a certain fish species involves the decision itself, the planting of trees or the reduction in catches, and when these actions actually start producing desired outcomes (e.g. reduction in sediment runoff or increase in fish stocks). Accounting for these time delays is important because managers often continue to intervene (e.g. planting more trees, implementing actions to reduce or increase fish catches) even after sufficient actions have been implemented. This happens simply because they did not account for the inertia between action implementation and response and also because of the belief that by repeating the action it would eventually work as anticipated (Arvai et al., 2006). This not only wastes resources (human and financial) but in management situations, Sterman (2000:23) suggests that such behavior leads to ‘overshoot and oscillation, which reduce the ability of managers to control for confounding variables and discern cause and effect, further slowing the rate of learning’.

Cognitive styles influence the way individuals perceive, store and structure information, thus influencing their decision-making (Boschetti et al., 2012). Consequently, they have a direct influence on how individuals decide which information is true and how this is used to make choices. Cognitive styles affect the process of making decisions because they determine what kind of information decision-makers want, how much information they wish to receive, how they want to receive it, how much effort they dedicate to understanding the details, how willing they are to change their attitudes and opinion in the light of new information and how comfortable they are to account for uncertainty in their decision-making (Boschetti et al., 2012). This means that decision-making for coastal and marine management should explicitly consider the diversity of cognitive styles (and values) from the various stakeholder groups in a transparent manner (Failing et al., 2013; Simpson and Gill, 2007). This view acknowledges that, for example, economic prosperity is just as much, if not more, a part of people's cognitive styles and preferred visions of the future as is the sustenance of natural systems (van den Belt, 2004:2).

3.3. MSE as a participatory decision support approach

MSE requires the representation of two systems to assess management strategies: the resource system and the management strategy system (Fig. 1). The resource system is usually represented by an operating model (OM) (which includes an observation model represented as ‘data’ in Fig. 1), which simulates plausible hypotheses about how the resource system works and how it is impacted by resource use (Dichmont et al., 2006b). The OM is used to test the robustness of management strategies given current knowledge and what can and cannot be controlled. The management strategy system usually includes an assessment sub-model from which to derive estimates of performance measures or system state, based on simulated observations, as well as a set of decision rules or heuristics which modify the controls imposed on components of the OM. Outputs from the assessment model inform these decision rules (Dichmont et al., 2006b; Kell et al., 2007). Typically, the

[1] Organisational defensive routines are the policies or actions individuals put in place to prevent them from experiencing embarrassment or threat. For example, individuals can make a decision and not implement it to avoid the risk of it going wrong and being ridiculed by their team Argyris, C., 1991. Teaching smart people how to learn. Reflections 4, 1–15.

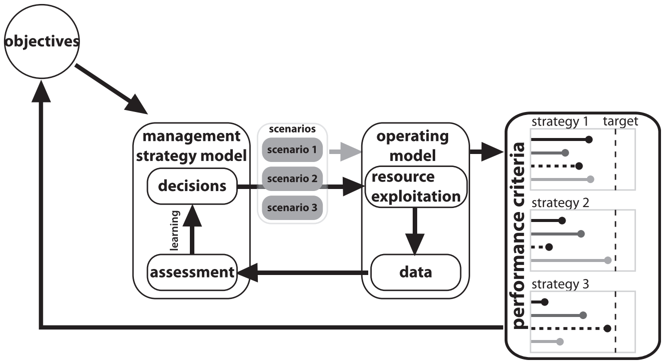

Fig. 1. Management Strategy Evaluation (modified from Dichmont (2006b)), which contains management strategy and operating models. Based on objectives decisions are implemented and these will affect the operating model. An assessment sub-model presents the results of selected performance indicators, which will then influence decisions using simple heuristics ("if this happens than apply that action"), and can potentially lead to changes in the management objectives.

management model may also include a degree of what has often been described as 'implementation uncertainty', that is, processes leading to a divergence between a planned course of action and the management actions effectively implemented (Fulton et al., 2011a). With such components included, it is expected that MSE increases the knowledge base on the consequences of management actions, ultimately improving management.

MSE and the associated approach of management procedures have been applied worldwide to fisheries management based on the theoretical background of system dynamics and its control. Somewhat contrary to the intuitive idea of controlled dynamic systems, from the early days these applications have included a strong stakeholder participation component (Smith et al., 1999). Although this may be the result of the intuition of researchers or fisheries managers in the early applications, the importance of participatory approaches incorporated in MSE has increasingly been formally acknowledged. The objectives of engaging and interacting with coastal and marine stakeholder groups is seen as a key to success in fostering learning about NRM issues (Boschetti et al., 2011a; Dutra et al., 2014; Fulton et al., 2013, 2011a). This has even led to dedicated efforts to improve the interactivity of MSE tools, which requires the underlying simulation models to run faster (e.g. de la Mare et al., 2012; Moeseneder et al., 2015). In what follows, we examine why MSE as an adaptive management approach has progressively involved increasing stakeholder participation. We relate this back to the observations of limitations to the rational adaptive management metaphor when applied to NRM, as discussed in Section 1.2 and, based on recent examples of MSE, we present a staged and formalized description of how MSE can be considered as a participatory decision-support approach (Fig. 1 and Table 2). In particular, we consider how the approach

Table 2
Description of participatory MSE stages and selected methods that can be used in each stage.

MSE stage	Methods	References
Understanding governance structures	Engage with representative NRM organizations, stakeholder committee or bridging organization	Dichmont et al. (2013a); Dutra et al. (2010); Fulton et al. (2013); Fulton et al. (2011a); Fulton et al. (2011b); Smith et al. (1999)
	Institutional analysis	Bainbridge et al. (2011); Fidelman et al. (2012); Hajer (2003); Ostrom (1986); Ostrom et al. (1994)
	Assessment of the legal framework	Sporne and Dale (2009)
	Interviews and workshops	Dichmont et al. (2014); Dutra et al. (2014); Horigue et al. (2012); van der Heijden (1996); Woodward et al. (2010)
Identification of key management objectives and values to guide decisions	Literature review	Horigue et al. (2012); van Putten et al. (accepted)
	Interviews and surveys	Pommeranz et al. (2012); van Putten et al. (accepted)
	Analytical hierarchical process	Dichmont et al. (2014); Dichmont et al. (2013b); Pascoe et al. (2013); Saaty (1980, 2003)
Methods to synthesize the available information	Scenario planning	Burt (2011); Morecroft and van der Heijden (1994); van der Heijden (1996); Wack (1985)
	Co-construction of conceptual models	Barker (1990); Dambacher et al. (2007); Dambacher et al. (2003a); Dutra et al. (2011b); Hayes et al. (2012); Levins (1966); Özesmi and Özesmi (2004)
	Ethnographic studies	Dray et al. (2006a); Dray et al. (2006b); Pommeranz et al. (2012)
	Photo elicitation	Harper (2002); Pommeranz et al. (2012)
Avenues for choice under uncertainty	Participatory modeling to allow exploratory analysis	Boschetti et al. (2011b); Brugnach et al. (2008); Dutra et al. (2011a); Fulton et al. (2011a); Myers et al. (2012); Senge and Sterman (1994); Sterman (2000:34); Woodward et al., 2010)
	'Simple' models (Bayesian belief networks)	Hosack et al. (2008); Kuhnert et al. (2010); Lynam et al. (2010); Metcalf et al. (2014); Pestes et al. (2008)
	'Simple' models (system dynamics)	Dutra et al. (2011b); Forrester (1961); Fulton et al. (2011a); van den Belt (2004); Vennix (1996); Vennix et al. (1994)
	'Simple' models (qualitative modeling)	Dambacher et al. (2007); Dambacher et al. (2012); Dambacher et al. (2003a); Dambacher et al. (2003b); Hayes et al. (2012)
	Role-playing games	Barreteau (2003); D'Aquino et al. (2003); Dray et al. (2006a); Dray et al. (2006b); Dutra et al. (2011a); Janssen and Ostrom (2006); Woodward et al. (2010)
	Quantitative models fitted to data	Moore et al. (2009); Plaganyi and Butterworth (2012); Plagányi et al. (2012a)
	Full ecosystem models	Fulton (2010); Fulton et al. (2011b); Fulton et al. (2005); McDonald et al. (2006); McDonald et al. (2008)

allows managers to (i) identify and deal with governance structures, (ii) identify key values and management objectives held by stakeholders and how they impact the ranking of alternative performance measures, (iii) develop methods which fully consider the available information, (iv) recognize avenues for choice under uncertainty that limit the sources of individual biases, and (v) provide incentives to respond to perceived changes in performance.

3.3.1. *Dealing with governance structures*

Solutions for coping with governance issues and therefore sustainability in NRM require stakeholder-driven approaches to accommodate the differences in values, cognitive styles, and perspectives of the resource managers, as well as to promote social learning (Akkerman et al., 2004; Fidelman et al., 2012; Folke et al., 2002; Gunderson et al., 1995; Stocker et al., 2012a).

Values are the principles or standards that guide the definition of objectives, which in turn determine the goals to be achieved. Values and objectives are sometimes used interchangeably in the literature, so we clarify our definitions in the following example. An initial objective of a hypothetical marine park might be to increase coral trout populations by 50 per cent. The reason (or value) underlying this might be to increase larval dispersal to areas outside the park, thus increasing the potential catch and the wellbeing of fishers who depend on the resource. Another reason might be to increase biodiversity within the park. These reasons (or values) are much more fundamental principles than the objectives: they relate to concerns of the national park for human wellbeing and biodiversity. How the objectives are to be achieved will therefore depend on stakeholder values held. Permanent or temporary spatial closures and change in target species are potential management actions that could achieve the objective of increasing coral trout populations; but the choice will depend on values.

Lessons learned from MSE projects applied in fisheries and coasts (Dichmont et al., 2014, 2013b; Dutra et al., 2011a; Fulton et al., 2011a; Fulton et al., 2011b; Smith et al., 1999; van Putten et al., accepted) suggest that using stakeholder-driven committees or bridging organizations (defined as organizations that bring together science and local knowledge, also providing an arena for knowledge co-production, trust building, sense making, learning, vertical and horizontal collaboration, and conflict resolution, Berkes, 2009) is critical to MSE. This is the case because the membership of such committees/organizations already contains key stakeholders and leaders to help direct MSE activities and developments. In addition, stakeholder committees and/or bridging organizations can help identify and engage with other key actors, including the general public. Examples of representative stakeholder committees and bridging organizations are the Healthy Waterways Partnership in South East Queensland (Australia) (Myers et al., 2012), local marine advisory committees (Great Barrier Reef, Australia) (Great Barrier Reef Marine Park Authority, 2013), and resource assessment groups under the Australian Fisheries Management Authority model (AFMA, Smith et al., 1999). These organizations were critical to the development of MSE because: (a) they help build social capital and allow participants to build or maintain reciprocity and trust, also facilitating vertical and horizontal collaboration (Berkes, 2009; Brondizio et al., 2009; Fulton et al., 2013), and (b) the broader stakeholder group and possibly the general public will perceive the decisions that come out of the MSE process and models supported by representative bodies as credible, salient and legitimate for management.

Failure to use stakeholder committees (or establish one for MSE projects) or bridging organizations may well result in a model-building exercise that can produce credible information. However, the lack of legitimacy and limited salience of modeling outputs will most likely result in no or very limited application of MSE results in real-world decisions (Fulton et al., 2011b). The application of MSE in the coastal zone of the Great Barrier Reef Marine Park (Australia) suggests that creating a 'steering committee' of decision-makers and stakeholders as well as the (lead) MSE analyst is a good practice when seeking to engage effectively with decision-makers and stakeholders (Dichmont et al., 2014).

In addition to working closely with stakeholders, MSE researchers must understand: (1) 'What are the institutional arrangements, legislation and jurisdiction boundaries in place to manage the natural resource?' This helps identify who will use the MSE tool (which actors are involved in decision-making), and (2) how the decisions are actually made at the management/operational level This is a more practical question that aims to identify how MSE can be used in the existing governance structure.

Methods previously applied to identify the above include engagement with NRM organizations and stakeholders (Smith et al., 1999), institutional analysis (Fidelman et al., 2012; Hajer, 2003; Ostrom, 2009) and assessments of the legal framework in place (Sporne and Dale, 2009). MSE projects are often initiated through some pre-existing defined management process where the initiators are likely to brief the MSE practitioners on the governance context (Dichmont et al., 2014; Dutra et al., 2010; Smith et al., 1999). It is often the case that practitioners want to test the advice by discussing it with likely stakeholders if they are not already familiar with the system being investigated and its management structures. This approach helps identify the main institutional drivers, key actors and stakeholders affected by the decisions, and existing collaborative institutional initiatives that can be used to support the development and use of MSE models and methods, thus avoiding duplication of management processes (Table 1 provides MSE stages and selected methods with references that have been or have the potential to be used in various instances of implementing MSE).

Institutional analysis can identify the behavior of and relationships between the norms and rules for managing the resource. This can help, for example, identify the governance network, the power distribution in the network as well as any existing formal decision-making process. An assessment of the legal framework helps identify the existing relevant legislation and its physical and institutional boundaries and overlaps. The legal framework assessment can also support the identification (and may be the establishment) of management boundaries, responsibilities, roles and rules to manage the natural resource (i.e. the identification of 'institutional voids'). This will guide development of MSE models for identifying spatial boundaries and management rules, as well as how MSE will be used to manage the resource and by whom.

Interviews, surveys and consultations with relevant stakeholders and decision-makers can help elucidate the decision-making process and identify key actors/institutions involved in decision-making (Dutra et al., 2014; Horigue et al., 2012). Engaging with key actors in the early stages of MSE development facilitates organizational collaboration when jurisdictions overlap or are not well defined, or when 'institutional voids' are identified. Methods to identify and characterise governance structures have been used in coastal and fisheries MSE projects (Dichmont et al., 2014; Dutra et al., 2011a, 2014; Fulton et al., 2011a).

3.3.2. *Identification of key values and management objectives to guide decisions*

The most common techniques for eliciting management values and objectives are interviews, questionnaires, literature reviews and surveys (Fig. 2). A literature review can help identify an initial list of implicit and explicit objectives from government, industry, and community groups (see Boschetti et al., 2012; Dichmont et al., 2014, 2013b; Pascoe et al., 2013; van der Heijden, 1996; van Putten

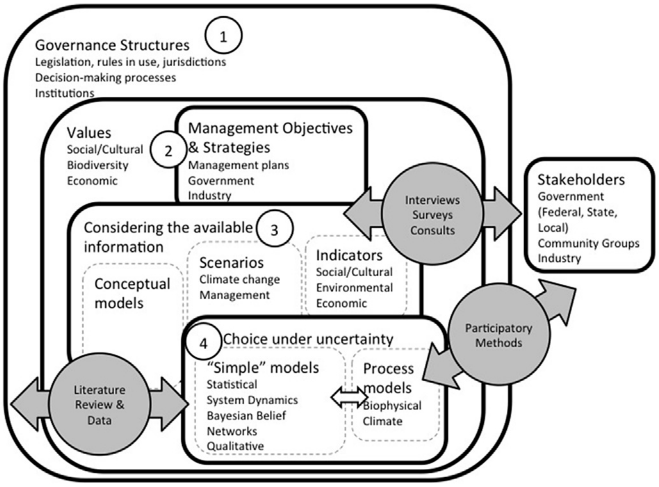

Fig. 2. Graphical representation of the methodological MSE framework. The framework considers the following stages: (1) dealing with governance; (2) identification of key management objectives and values to guide decisions; (3) methods to synthesize the available information; and (4) avenues for choice under uncertainty. The investigation of governance structures (1) is informed by all the other stages: values, management objectives and strategies (2), consideration of available information (3) and choice under uncertainty (4) are the proposed stages to develop participatory MSE. The dashed-line boxes are the necessary activities, such as the construction of conceptual models, elicitation of scenarios and indicators for use in the MSE, as well as the construction of "simple", quantitative and process models. Note that all stages/activities are connected. Each stage has its specific methods (in grey; see also Table 2), such as scenario planning and participatory modeling under "Participatory Methods", questionnaires and interviews under "Interviews, Surveys and Consults".

et al., accepted; Zander et al., 2010). Stakeholders can then help refine this list via interviews (Dutra et al., 2014; van Putten et al., accepted), surveys (Dichmont et al., 2014; Zander et al., 2010), and workshops (Dichmont et al., 2014, 2013b; Pascoe et al., 2013) and also identify and prioritize values for designing and evaluating management strategies before these are discussed with the wider community. The analytical hierarchical process (AHP) (Saaty, 1980, 2003) is one method that has successfully elicited and prioritized NRM management objectives (Dichmont et al., 2013b). As part of the AHP, management objectives are elicited and refined and potential courses of action to address management objectives are ranked according to participants' expectations on how these actions will perform against objectives. These evaluations may include both qualitative and quantitative assessments depending on data availability and time (Dichmont et al., 2013b; Pascoe et al., 2013).

3.3.3. Methods for synthesizing information

Methods for synthesizing available information are used to deal with uncertainty and limited data and also to address the leadership, psychological and cognitive processes involved when selecting which information to use to make decisions.

Scenario planning has been used to examine and incorporate the uncertainty that may have developed over many years in businesses organizations (Bohensky et al., 2011; Burt, 2011; Morecroft and van der Heijden, 1994; van der Heijden, 1996; Wack, 1985). It aims to broaden the thinking among members of organizations and requires an intensive process of structuring and restructuring of perceptions, based on negotiation and agreement of meaning between participants, while also accommodating their diverse cognitive styles and worldviews (Eden, 1992). The process helps participants understand differing perceptions about resource use (without necessarily reaching consensus), and facilitates individuals and group cooperation and commitments, thus improving the group's social capital.

Information generated through scenario planning can be used to construct conceptual models to inform the design of the operating models and tools used in MSE (refer to Barker, 1990; Checkland, 1999; Dutra et al., 2011b; Levins, 1966; Özesmi and Özesmi, 2004). The clustering outcomes from the conceptual models are the negotiated representation of emerging concerns and help identify information that is perceived by the group to be credible, salient and legitimate. The output of the scenario planning exercise is a storyline on how participants perceive the future and includes detailed information on the major events (e.g. climate change, politics, status of the resource) that led to the future scenario. Management scenarios from previous MSE applications have used elements of the scenario planning approach along with biophysical scenarios (e.g. climate change) as part of model simulations. These scenarios assess the effectiveness of different management strategies against objectives and values under uncertainty (Dutra et al., 2010; Fulton et al., 2011a, 2014; Pantus et al., 2008; Woodward et al., 2010). MSE models, both conceptual and operational, can therefore be used as effective communication tools to support stakeholder discussions and engagement.

Other methods for considering the available information include ethnographic studies and photo elicitation, which can be used in isolation or in conjunction with the scenario planning exercise. Ethnographic methods are used to gain detailed insights about the resource management through observing what people do in their work and by interviewing them in a social group (Pommeranz et al., 2012). For example, researchers may participate over a long period in the daily activities of NRM organizations to gather personal experiences about how individuals in this organization interact with other stakeholders, and how they consider the information available in individual and organizational decision-making processes. In the case of fisheries, researchers were already deeply embedded in management processes (e.g. as members of advisory groups in AFMA) and were also involved in similar arrangements in coastal MSE applications (Dichmont et al., 2014; Dutra et al., 2014; Fulton et al., 2013, 2014). The method helps identify internal organizational processes that affect the psychological and cognitive processes of leaders or management groups, which may hinder decision-making.

Photo elicitation techniques have been successfully used in participatory modeling projects to gather further information about a resource and its use (Dray et al., 2006a). Compared to ethnographic surveys, this technique may be a quicker and less expensive solution. Photo elicitation involves using photographs to discuss management issues with managers and/or stakeholders to determine the aspects of the natural resource they find important, what they value, what they consider as salient and credible information and how they should go about producing and sharing information (Dray et al., 2006a; Harper, 2002; Pommeranz et al., 2012).

3.3.4. Avenues for choice under uncertainty

Multiple modeling approaches used in MSE projects have helped stakeholders choose informed courses of action (Fulton et al., 2011a; Moeseneder et al., 2015). The aim is to try to identify solutions that are robust to known uncertainties using the available information. Coastal and fisheries MSE applications have used a range of methods that help tackle a number of the difficulties of collective decision-making under uncertainty, as depicted in Table 2 and Fig. 2. These methods are: (1) the construction of 'simple' and interactive models as 'learning laboratories' for decision-makers to observe possible system trajectories and/or detect extreme changes (Brugnach et al., 2008), and (2) the development and trial runs of full ecosystem models with refined spatial and temporal scales. These two methods can operate as parallel processes, each informing the other.

3.3.4.1. Using 'simple' models. Conceptual models represent people's understanding about cause–effect relationships in the managed system, and may also include individual perceptions and understanding on how the management system operates. As a result, multiple conceptual models with various structures are expected to be constructed as part of the process to 'consider the available information'. Qualitative modeling techniques have been used to assess if the different structures of the management system are relevant to manage the resource (Dambacher et al., 2003a; Fulton et al., 2011a; Metcalf et al., 2014). For example, do the management strategies perform similarly (despite the uncertainties) no matter how the conceptual model is structured? Qualitative modeling also enables participants to both test a range of management actions and/or strategies as well as to qualitatively assess the effectiveness of management decisions against objectives by quantifying the interactions of positive and negative feedback loops on the variables of interest (end points) (Dambacher et al., 2007, 2003a). Other examples of 'simple' models include system dynamics techniques (Boschetti et al., 2011b; Dutra et al., 2011b; Forrester, 1961; Meadows et al., 1974; van den Belt, 2004; Vennix, 1999), and Bayesian beliefs networks (Hosack et al., 2008; Lynam et al., 2010; Pestes et al., 2008). The exercise of constructing and showing these models to stakeholders is itself a critical step to elicit understanding, communicate research findings and explore possible future directions under different management actions and scenarios. The MSE team can also discuss ways to better communicate results from the model as it develops over time.

Allowing stakeholders to help develop MSE models strongly supports the model building exercise and the stakeholder learning experience (Dutra et al., 2010; Fulton et al., 2011a; Myers et al., 2012). This is similar to the concept of the 'learning laboratory' (Senge and Sterman, 1994), also used in experimental economics (Gintis, 2000; Tisdell, 2007), where participants can conduct experiments to assess the effects of decisions on their objectives. Simulating the system to be managed allows time and space to be compressed or dilated and management actions can be repeated under the same or different conditions (scenarios and model structures). One can stop the action and reflect about doing things differently in order to learn more about possible outcomes. Learning laboratories provide an environment in which decisions that are dangerous, impractical, or too costly in the real system can be taken in a computer simulation (Sterman, 2000:34). Interactions between individuals via group dynamic processes used as part of the 'learning laboratory' may affect the way individuals and groups select and use information to make decisions and also affect commitments and cooperation towards issues learned in the exercise with potential practical applications to real-world coastal management (Dutra et al., 2011a). This reinforces the potential of using MSE in a participatory setting to build social capital by facilitating social learning.

Some previous MSE projects with 'learning laboratories' use simulation models to allow participants to explore the range of available management options and their impacts on both stakeholders and the natural resource without fear of negative consequences, and then discuss the issues learned (e.g. Boschetti et al., 2011a; Dutra et al., 2011a; Fulton et al., 2011a). In 'learning laboratories' participatory modeling techniques can be also used to elicit, change and communicate values. However, care must be taken not to push individuals or groups into provocative situations that risk undermining the engagement process and trust between and among stakeholders and researchers.

Role-playing game techniques (D'Aquino et al., 2003; Dray et al., 2006a) have been used in previous MSE projects (Dutra et al., 2011a; Woodward et al., 2010) to allow participants to acknowledge the challenges faced by those in positions other than their own. This helps stakeholders understand how their behavior and interaction with other stakeholders affect the process of making and implementing decisions. In previous coastal MSE projects, such understanding led to the discussion of potential solutions on how to overcome the issues identified with governance, leadership, behavioral and cognitive barriers. In this context, MSE has been used successfully to communicate the existing knowledge, to promote shared understanding about the system, and to mediate and encourage stakeholder engagement and dialogue (Dutra et al., 2011a; Fulton et al., 2011a; Myers et al., 2012; Woodward et al., 2010). MSE is therefore effective in nurturing a learning culture within management groups and organizations by fostering experimentation and innovation within the (virtual) management system and by collaboratively reframing concerns (O'Keeffe, 2002).

3.3.4.2. Using quantitative models fitted to data. Quantitative models fitted to data are used to support fisheries decision-making either strategically ('big picture', direction-setting and contextual) or tactically (focused on management actions on short to medium timescales), with some strategic models informing the development of tactical models (Plagányi et al., 2012a; Punt and Smith, 1999). Such models are referred to as 'models of intermediate complexity for ecosystem assessment' (MICE), examples of which exist worldwide (e.g. Moore et al., 2009; Plagányi et al., 2012b). These models are context- and question-driven. They limit complexity by restricting the focus to the components of the ecosystem needed to address the main effects of the specific management question. Similar to other model applications used in MSE, developing MICE involves extensive stakeholder participation and dialogue (Plagányi et al., 2012a). These quantitative models fitted to data are able to address many of the impediments to greater use of ecosystem models in strategic and particularly tactical decision-making for marine resource management and conservation, but they have not yet been successfully applied to tactical decision-making (Plagányi et al., 2012a)

3.3.4.3. Using process-oriented MSE models. Depending on requirements, data availability, and time and budget of the MSE projects, end-to-end models with refined spatial and temporal resolution have been successfully developed for fisheries and multiple-use coastal MSE (see Dichmont et al., 2013a; Fulton, 2010; Fulton et al., 2005; McDonald et al., 2006; Plagányi et al., 2011). These models represent entire systems by coupling physical, biological and human components to more explicitly evaluate the performance of various strategies against social, environmental and economic indicators (e.g. ecological, hydrodynamic, human and biogeochemical models). Process models are useful in dealing with uncertainties, such as climate change, because of their fairly rigorous approach tailored to represent the key physical and chemical processes of concern (Plagányi et al., 2011). However, process-based models have relatively long (years) development periods and run times in the order of hours to days to simulate a single year (e.g. Dichmont et al., 2006b; Fulton et al., 2007; Pantus et al., 2008). Running these models requires an experienced team of scientists who can make recommendations to management bodies or provide potential system trajectories (and their uncertainty) according to the tested strategies under different scenarios (Dichmont et al., 2008, 2006a; Fulton et al., 2011b). Due to time constraints (days to weeks) to run full ecosystem models, it is not possible to perform live trials with them. However, selected strategies previously trialed with 'simple' models can be tested in the full ecosystem models. This provides the management body with further information on possible system trajectories and improved spatial and temporal resolution to allow for a better assessment of the impacts of management actions and therefore their policy recommendations for a range of fisheries and coastal management issues (Fulton et al., 2011a, 2007; Mapstone et al., 2008; McDonald et al., 2006; Pantus et al., 2011; Stoeckl et al., 2013). Interactive videos of process-oriented models are often used to communicate outputs to stakeholders (e.g. Wild-Allen et al., 2010). Outputs from full ecosystem models can also be used to refine the 'simple' models and vice versa.

4. Conclusions

Our research suggests that coastal and marine management decisions are influenced by a limited number of drivers related to governance structures, power and leadership, and cognitive processes. Personal motivations and institutional constraints affect both individual and collective (organizational) decision-making processes, thus influencing the way natural resources are exploited and managed. Effective management of coastal and marine resources is complex not only because of challenges in biophysical data collection and analysis. Its complexity also results from intense negotiations between stakeholders from multiple organizations with different, divergent and often overlapping mandates. Leaders of such organizations have varied cognitive styles, perceptions and expectations about the current and future state of the resource. We found that their motivations may go beyond their formal mandates and, as a result, necessary changes in resource management are the result of personal, rather than organizational, efforts.

The literature reviewed suggests that improving the information base about the natural resource, its dynamics and its use alone is necessary but will have limited effect on the way decisions are made and implemented. A formal participatory MSE approach supports resource management in coasts and oceans by combining modeling techniques, cognitive aspects of human decision-making and behaviour and stakeholder engagement to facilitate social learning and shared understanding. In addition, participatory approaches used in MSE strongly support stakeholder negotiation processes by helping participants make their values and objectives explicit and clarifying the inevitable trade-offs involved in coastal and marine management decisions. Actively engaging with and interviewing stakeholders, analyzing institutions and the legal framework in which they operate, and prioritizing management objectives help unravel and address governance processes, political and socio-economic drivers, and power influences. These, combined with the identification of values and management objectives and integrated biophysical and socio-economic assessments, provide a strong basis for decision-making with respect to coastal and marine resource management. It also allows for more transparency in the management process, thus promoting acceptance and support from the broader stakeholder group.

Participatory MSE approaches can also clarify some of the underlying assumptions and reduce internal conflicts and contradictions at the individual level as it allows for policy testing via modeling before it is implemented. This is important to evaluate whether the outcomes of these decisions match their intended purposes. This may also reduce anxiety among leaders and decision-makers, thus reducing the risk that they adopt defensive positions.

There are, however, challenges to participatory approaches, especially if the engagement approaches are not adequately designed. Stakeholders may suffer from 'consultation fatigue' when there is 'too much' consultation around management issues with the same groups or individuals (Jackson et al., 2008). This may result in lack of interest from key participants and consequently limited input and representation in MSE projects.

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References

Acheson, J.M., 2006. Institutional failure in resource management. Annu. Rev. Anthropol. 35, 117–134.
Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., Rockström, J., 2005. Social-ecological resilience to coastal disasters. Science 309, 1036–1039.
Akkerman, T., Hajer, M., Grin, J., 2004. The interactive state: democratisation from above? Polit. Stud-London 52, 82–95.
Argyris, C., 1991. Teaching smart people how to learn. Reflections 4, 1–15.
Argyris, C., 1999. On Organizational Learning, second ed. Blackwell Publishers Ltd, Oxford.
Argyris, C., Schön, D.A., 1978. Organizational Learning: a Theory of Action Perspective. Addison-Wesley Publishing Company, Sydney.
Ariely, D., 2008. Predictably Irrational: The Hidden Forces that Shape Our Decisions. Harper Collins, New York, NY.
Armitage, D., 2005. Adaptive capacity and community-based natural resource management. Environ. Manag. 35, 703–715.
Arthur, W.B., 1992. On Learning and Adaptation in the Economy. Santa Fe Institute, Stanford, p. 27.
Arthur, W.B., 1994. Inductive reasoning and bounded rationality. Am. Econ. Rev. 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 Anal. 23, 281–289.
Arvai, J.L., Bridge, G., Dolsak, N., Franzese, R., Koontz, T., Luginbuhl, A., Robbins, P., Richards, K., Smith Korfmacher, K., Sohngen, B., Tansey, J., Thompson, A., 2006. Adaptive management of the global climate problem: bridging the gap between climate research and climate policy. Clim. Change 78, 217–225.
Axelrod, R., 2006. The Evolution of Cooperation, Revised Edition Ed. Basic Books, New York.
Bainbridge, J.M., Potts, T., O'Higgins, T.G., 2011. Rapid policy network mapping: a new method for understanding governance structures for implementation of marine environmental policy. Plos One 6.
Bardi, A., Schwartz, S.H., 2003. Values and behavior: strength and structure of relations. Pers. Soc. Psychol. B 29, 1207–1220.
Barker, R., 1990. CASE Method – Entity Relationship Modelling. Addison-Wesley Publishing Company, Workingham.
Barreteau, O., 2003. The joint use of role-playing games and models regarding negotiation processes: characterization of associations. JASS 6.
Bella, D.A., 1992. Ethics and the credibility of applied science. In: Reeves, G.H.B., Daniel, L., Brookes, Martha H. (Eds.), Ethical Questions for Resource Managers. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, pp. 19–32.
Bennett, J., Lawrence, P., Johnstone, R., Shaw, R., 2005. Adaptive management and its role in managing great Barrier reef water quality. Mar. Pollut. Bull. 51, 70–75.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manage 90, 1692–1702.
Bohensky, E., Butler, J.R.A., Costanza, R., Bohnet, I., Delisle, A., Fabricius, K., Gooch, M., Kubiszewski, I., Lukacs, G., Pert, P., Wolanski, E., 2011. Future makers or future takers? A scenario analysis of climate change and the great Barrier reef. Glob. Environ. Change-Human Policy Dimensions 21, 876–893.
Borrini-Feyerabend, G., Johnston, J., Pansky, D., 2006. Governance of protected areas. In: Lockwood, M., Worboys, G.L., Kothari, A. (Eds.), Managing Protected Areas: a Global Guide. Earthscan, London, Sterling, VA, pp. 116–145.
Boschetti, F., 2007. Improving resource exploitation via collective intelligence by assessing agents' impact on the community outcome. Ecol. Econ. 63, 553–562.
Boschetti, F., Fulton, E.A., Bradbury, R.H., Symons, J., 2011a. What is a model, why people don't trust them and why they should. In: 2011 International Congress on Modelling and Simulation (MODSIM 2011), Perth.
Boschetti, F., Hardy, P., Grigg, N., Horwitz, P., 2011b. Can we learn how complex systems work? Emergence Complex. Organ. 13, 47–62.
Boschetti, F., Richert, C., Walker, I., Price, J., Dutra, L., 2012. Assessing attitudes and cognitive styles of stakeholders in environmental projects involving computer modelling. Ecol. Model. 247, 98–111.
Bots, P.W.G., van Twist, M.J.W., van Duin, R., 1999. Designing a power tool for policy analysts: dynamic actor network analysis. In: 32nd Hawaii International Conference on System Sciences, Hawaii.
Bottom, D.L., 1992. Introduction. In: Reeves, G.H.B., Daniel, L., Brookes, Martha H. (Eds.), Ethical Questions for Resource Managers. UR Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, pp. 1–4.

Boulding, K.E., 1966. The economics of the coming spaceship earth. In: Jarret, H. (Ed.), Environmental Quality in a Growing Economy. John Hopkins University Press, Baltimore, pp. 3–14.
Brede, M., Boschetti, F., McDonald, D., 2008. Strategies for resource exploitation. Ecol. Complex 5, 22–29.
Brock, W.A., Carpenter, S.R., 2007. Panaceas and diversification of environmental policy. Proc. Natl. Acad. Sci. U. S. A. 104, 15206–15211.
Brondizio, E.S., Ostrom, E., Young, O.R., 2009. Connectivity and the governance of multilevel social-ecological systems: the role of social capital. Annu. Rev. Environ. Resour. 34, 253–278.
Brugnach, M., Pahl-Wostl, C., Lindenschmidt, K.E., Janssen, J.A.E.B., Filatova, T., Mouton, A., Holtz, G., van der Keur, P., Gaber, N., 2008. Complexity and uncertainty: rethinking the modelling activity. In: Jakeman, A.J., Voinov, A.A., Rizzoli, A.E., Chen, S.H. (Eds.), Environmental Modelling, Software and Decision Support. State of the Art and New Perspectives Elsevier, Amsterdam, pp. 49–68.
Buchanan, J.M., 1983. Rent seeking, non-compensated transfers, and laws of succession. J. Law Econ. 26, 71–85.
Bunnefeld, N., Hoshino, E., Milner-Gulland, E.J., 2011. Management strategy evaluation: a powerful tool for conservation? Trends Ecol. Evol. 26, 441–447.
Burt, G., 2011. Towards the integration of system modelling with scenario planning to support strategy: the case of the UK energy industry. J. Operational Res. Soc. 62, 830–839.
Butterworth, D.S., Bentley, N., de Oliveira, J.A.A., Donovan, G.P., Kell, L.T., Parma, A.M., Punt, A.E., Sainsbury, Keith J., Smith, A.D.M., Stokes, T.K., 2010. Purported flaws in management strategy evaluation: basic problems or misinterpretations? ICES J. Mar. Sci. 67, 567–574.
Checkland, P., 1999. Systems Thinking, Systems Practice (New Edition, Including a 30-year Retrospective), New Edition. John Wiley & Sons, Chichester.
Cinner, J., Marnane, M.J., McClanahan, T.R., Almany, G.R., 2006. Periodic closures as adaptive coral reef management in the Indo-Pacific. Ecol. Soc. 11. Article 31 [online].
Clarke, B., Stocker, L., Coffey, B., Leith, P., Harvey, N., Baldwin, C., Baxter, T., Bruekers, G., Galano, C.D., Good, M., Haward, M., Hofmeester, C., de Freitas, D.M., Mumford, T., Nursey-Bray, M., Kriwoken, L., Shaw, J., Shaw, J., Smith, T., Thomsen, D., Wood, D., Cannard, T., 2013. Enhancing the knowledge–governance interface: coasts, climate and collaboration. Ocean. Coast. Manage 86, 88–99.
Costanza, R., 1991. Ecological Economics: the Science and Management of Sustainability. Columbia University Press, New York, Chichester, West Sussex, p. 525.
Costanza, R., Kemp, M., Boynton, W., 1995. Chapter 3: scale and biodiversity in coastal and estuarine ecosystems. In: Perrings, C., Mäler, K.-G., Folke, C., Holling, C.S., Jansson, B.-O. (Eds.), Biodiversity Loss: Economic and Ecological Issues. Cambridge University Press, pp. 84–125.
Cundill, G., 2010. Monitoring social learning processes in adaptive comanagement: three case studies from South Africa. Ecol. Soc. 15.
D'Aquino, P., Le Page, C.,F.,B., Bah, A., 2003. Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: the selfcormas experiment in senegal. JASS 6, 3.
Dale, A., Vella, K., Pressey, R.L., Brodie, J., Yorkston, H., Potts, R., 2013. A method for risk analysis across governance systems: a great Barrier reef case study. Environ. Res. Lett. 8.
Dambacher, J.M., Brewer, D.T., Dennis, D., Macintyre, M., Foale, S., 2007. Qualitative modelling of gold mine impacts on Lihir Island's socioeconomic system and reef-edge fish community. Environ. Sci. Technol. 41, 555–562.
Dambacher, J.M., Hayes, K.R., Hosack, G.R., Lyne, V., Clifford, D., Dutra, L.X.C., Moeseneder, C.H., Palmer, M.J., Sharples, R., Rochester, W.A., Taranto, T.J., Smith, R., 2012. Project summary: national marine ecological indicators. A report prepared for the australian government department of sustainability, environment, water, population and communities. CSIRO Wealth from Oceans Flagship, Hobart.
Dambacher, J.M., Li, H.W., Rossignol, P.A., 2003a. Qualitative predictions in model ecosystems. Ecol. Model. 161, 79–93.
Dambacher, J.M., Luh, H.K., Li, H.W., Rossignol, P.A., 2003b. Qualitative stability and ambiguity in model ecosystems. Am. Nat. 161, 876–888.
de Geus, A.P., 1988. Planning as learning. Harv. Bus. Rev. March-April 70–74.
de la Mare, W., Ellis, N., Pascual, R., Tickell, S., 2012. An empirical model of water quality for use in rapid management strategy evaluation in southeast Queensland, Australia. Mar. Pollut. Bull. 64, 704–711.
de Oliveira, J.A.A., Kell, L.T., Punt, A.E., Roel, B.A., Butterworth, D.S., 2009. Managing without best predictions: the management strategy evaluation framework. In: Payne, A., Cotter, J., Potter, T. (Eds.), Advances in Fisheries Science: 50 Years on from Beverton and Holt. Blackwell Publishing Ltd., Oxford, UK, pp. 104–134.
Dichmont, C.M., Deng, A., Punt, A.E., Ellis, N., Venables, W.N., Kompas, T., Ye, Y., Zhou, S., Bishop, J., 2008. Beyond biological performance measures in management strategy evaluation: bringing in economics and the effects of trawling on the benthos. Fish. Res. 94, 238–250.
Dichmont, C.M., Deng, A.R., Punt, A.E., Venables, W., Haddon, M., 2006a. Management strategies for short lived species: the case of Australia's Northern prawn fishery: 2. Choosing appropriate management strategies using input controls. Fish. Res. 82, 221–234.
Dichmont, C.M., Deng, A.R., Punt, A.E., Venables, W., Haddon, M., 2006b. Management strategies for short-lived species: the case of Australia's Northern prawn fishery 1. Accounting for multiple species, spatial structure and implementation uncertainty when evaluating risk. Fish. Res. 82, 204–220.
Dichmont, C.M., Dutra, L.X.C., Thébaud, O., Putten, I.v., Deng, R., Pascual, R., Dambacher, J., Owens, R., Read, M., Thompson, C., Wachenfeld, D., Jebreen, E., Quinn, R., Dunning, M., Davies, J., Garland, A., Warne, M., Playford, J., Bennett, J., 2014. Design and Implementation of Management Strategy Evaluation for the Great Barrier Reef Inshore (MSE-gbr) - Progress Report. National Environmental Research Program, Cairns.
Dichmont, C.M., Ellis, N., Bustamante, R.H., Deng, R., Tickell, S., Pascual, R., Lozano-Montes, H., Griffiths, S., 2013a. Evaluating marine spatial closures with conflicting fisheries and conservation objectives. J. Appl. Ecol. 50, 1060–1070.
Dichmont, C.M., Pascoe, S., Jebreen, E., Pears, R., Brooks, K., Perez, P., 2013b. Choosing a fishery's governance structure using data poor methods. Mar. Policy 37, 123–131.
Douglass, M., 2002. From global intercity competition to cooperation for livable cities and economic resilience in Pacific Asia. Environ. Urbanization 14, 53–68.
Dray, A., Perez, P., Jones, N., Le Page, C., D'Aquino, P., White, I., Auatabu, T., 2006a. The AtollGame experience: from knowledge engineering to a computer-assisted role playing game. JASS 9, 6.
Dray, A., Perez, P., LePage, C., d'Aquino, P., White, I., 2006b. AtollGame: a companion modelling experience in the Pacific. In: Perez, P., Batten, D. (Eds.), Complex Science for a Complex World: Exploring Human Ecosystems with Agents. ANU E Press, Canberra, pp. 255–282.
Dutra, L.X.C., Bustamante, R.H., Sporne, I., van Putten, I., Dichmont, C.M., Ligtermoet, E., Sheaves, M., Deng, R.A., 2015. Organizational drivers that strengthen adaptive capacity in the coastal zone of Australia. Ocean. Coast. Manage 109, 64–76.
Dutra, L.X.C., de la Mare, W., Perez, P., Ellis, N., Tickell, S., Cannard, T., Thebaud, O., Pascual, P., Bayliss, P., Moeseneder, C., Dichmont, C., Boschetti, F., Pascoe, S., 2010. Healthy Waterways Management Strategy Evaluation: Scoping Study for the Development of a 'catchment-to-coast' MSE in SE Queensland - Phase 2 – Final Report. CSIRO Marine and Atmospheric Research, Cleveland, p. 131.
Dutra, L.X.C., Ellis, N., Boschetti, F., Dichmont, C., de la Mare, W., Perez, P., 2011a. Healthy Waterways Management Strategy Evaluation: Learning and Decision Making within an Adaptive Framework – Final Report. CSIRO Marine and Atmospheric Research, Brisbane, p. 76.
Dutra, L.X.C., Ellis, N., Perez, P., Dichmont, C.M., de la Mare, W., Boschetti, F., 2014. Drivers influencing adaptive management: a retrospective evaluation of water quality decisions in south East Queensland (Australia). Ambio 43, 1069–1081.
Dutra, L.X.C., Haworth, R.J., Taboada, M.B., 2011b. An integrated approach to tourism planning in a developing nation: a case study from Beloi (Timor-Leste). In: Dredge, D., Jenkins, J. (Eds.), Stories of Practice: Tourism Policy and Planning. Ashgate, Farnham, pp. 269–293.
Eden, C., 1992. Strategy development as a social process. J. Manag. Stud. 29, 799–811.
Failing, L., Gregory, R., Higgins, P., 2013. Science, uncertainty, and values in ecological restoration: a case study in structured decision-making and adaptive management. Restor. Ecol. 21, 422–430.
Fidelman, P., Evans, L., Fabinyi, M., Foale, S., Cinner, J., Rosen, F., 2012. Governing large-scale marine commons: contextual challenges in the coral triangle. Mar. Policy 36, 42–53.
Fidelman, P.I.J., Leitch, A.M., Nelson, D.R., 2013. Unpacking multilevel adaptation to climate change in the great barrier reef, Australia. Glob. Environ. Change-Human Policy Dimensions 23, 800–812.
Finger, M., Asún, J.M., 2001. Adult education at the crossroads: learning our way out. Zed Books, London.
Folke, C., Berkes, F., Colding, J., 1998. Ecological practices and social mechanisms for building resilience and sustainability. In: Berkes, F., Folke, C. (Eds.), Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge,UK, pp. 414–436.
Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio 31, 437–440.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473.
Folke, C., Pritchard, L., Berkes, F., Colding, J., Svedin, U., 2007. The problem of fit between ecosystems and institutions: ten years later. Ecol. Soc. 12.
Forrester, J.W., 1961. Industrial Dynamics. MIT Press, Cambridge.
Fulton, E., Jones, T., Boschetti, F., Chapman, K., Little, R., Syme, G., Dzidic, P., Gorton, R., Sporcic, M., de la Mare, W., 2013. Assessing the impact of stakeholder engagement in management strategy evaluation. Int. J. Econ. Manag. Eng. 3, 83–99.
Fulton, E.A., 2010. Approaches to end-to-end ecosystem models. J. Mar. Syst. 81, 171–183.
Fulton, E.A., Jones, T., Boschetti, F., Sporcic, M., de la Mare, W., Syme, G., Dzidic, P., Gorton, R., Little, L.R., Dambacher, G., Chapman, K., 2011a. A multi-model approach to stakeholder engagement in complex environmental problems. In: 2011 International Congress on Modelling and Simulation (MODSIM 2011), Perth.
Fulton, E.A., Link, J.S., Kaplan, I.C., Savina-Rolland, M., Johnson, P., Ainsworth, C., Horne, P., Gorton, R., Gamble, R.J., Smith, A.D.M., Smith, D.C., 2011b. Lessons in modelling and management of marine ecosystems: the Atlantis experience. Fish Fish. 12, 171–188.
Fulton, E.A., Smith, A.D.M., Punt, A.E., 2005. Which ecological indicators can robustly detect effects of fishing? ICES J. Mar. Sci. 62, 540–551.
Fulton, E.A., Smith, A.D.M., Smith, D.C., 2007. Alternative Management Strategies for

Southeast Australian Commonwealth Fisheries: Stage 2: Quantitative Management Strategy Evaluation. Australian Fisheries Management Authority Report, CSIRO Marine and Atmospheric Research, Hobart.
Fulton, E.A., Smith, A.D.M., Smith, D.C., Johnson, P., 2014. An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. Plos One 9.
Gintis, H., 2000. Beyond *Homo economicus*: evidence from experimental economics. Ecol. Econ. 35, 311–322.
Great Barrier Reef Marine Park Authority, 2013. Local Marine Advisory Committees. Australian Government, Townsville.
Gregory, R., Lichtenstein, S., Slovic, P., 1993. Valuing environmental resources: a constructive approach. J. Risk Uncertain. 7, 177–197.
Gunderson, L.H., Holling, C.S., Light, S.S., 1995. Barriers and Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York, p. 593.
Gutierrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470, 386–389.
Hajer, M., 2003. Policy without polity? Policy analysis and the institutional void. Policy Sci. 36, 175–195.
Harper, D., 2002. Talking about pictures: a case for photo elicitation. Vis. Stud. 17, 13–26.
Hayes, K.R., Dambacher, J.M., Lyne, V., Sharples, R., Rochester, W.A., Dutra, L.X.C., Smith, R., 2012. Ecological Indicators for Australia's Exclusive Economic Zone: Rationale and Approach with Application to the South West Marine Region. A Report Prepared for the AustraliaN Government Department of Sustainability, Environment, Water, Population and Communities. CSIRO Wealth from Oceans Flagship, Hobart.
Herrfahrdt-Pahle, E., Pahl-Wostl, C., 2012. Continuity and change in social-ecological systems: the role of institutional resilience. Ecol. Soc. 17.
Hodgson, G.M., 2006. What are institutions? J. Econ. Issues 40, 1–25.
Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4, 390–405.
Holling, C.S., Meffe, G.K., 1996. Command and control and the pathology of natural resource management. Conserv. Biol. 10, 328–337.
Horigue, V., Alino, P.M., White, A.T., Pressey, R.L., 2012. Marine protected area networks in the Philippines: trends and challenges for establishment and governance. Ocean. Coast. Manage 64, 15–26.
Hosack, G.R., Hayes, K.R., Dambacher, J.M., 2008. Assessing model structure uncertainty through an analysis of system feedback and Bayesian networks. Ecol. Appl. 18, 1070–1082.
Innocenti, D., Albrito, P., 2011. Reducing the risks posed by natural hazards and climate change: the need for a participatory dialogue between the scientific community and policy makers. Environ. Sci. Policy 14, 730–733.
Isenberg, D.J., 1988. How senior managers think. In: Bell, D.E., Raiffa, H., Tversky, A. (Eds.), Decision Making: Descriptive, Normative, and Prescriptive Interactions. Cambridge University Press, Cambridge, pp. 525–539.
Izurieta, A., Sithole, B., Stacey, N., Hunter-Xenie, H., Campbell, B., Donohoe, P., Brown, J., Wilson, L., 2011. Developing indicators for monitoring and evaluating joint management effectiveness in protected areas in the northern territory, Australia. Ecol. Soc. 16.
Jackson, S., Stoeckl, N., Straton, A., Stanley, O., 2008. The changing value of australian tropical rivers. Geogr. Res. 46, 275–290.
Janssen, M.A., Ostrom, E., 2006. Empirically based, agent-based models. Ecol. Soc. 11. Article 37 [online].
Jones, P.J.S., 2013. A governance analysis of the galapagos marine reserve. Mar. Policy 41, 65–71.
Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47, 263–291.
Keeney, R.L., 1992. Value-focused Thinking. Harvard University Press, Massachusetts.
Keeney, R.L., Raiffa, H., 1976. Decisions with Multiple Objectives: Preferences and Value Trade-offs. John Wiley & Sons, Inc., New York.
Kell, L.T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., Scott, F., Scott, R.D., 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES J. Mar. Sci. 64, 640–646.
Kothari, A., 2006. Collaboratively managed protected areas. In: Lockwood, M., Worboys, G.L., Kothari, A. (Eds.), Managing Protected Areas: a Global Guide. Earthscan, London, Sterling, VA, pp. 528–548.
Kuhnert, P.M., Martin, T.G., Griffiths, S.P., 2010. A guide to eliciting and using expert knowledge in Bayesian ecological models. Ecol. Lett. 13, 900–914.
Leith, P., Coffey, B., Haward, M., O'Toole, K., Allen, S., 2012. Improving science uptake in coastal zone management: principles for science engagement and their application in south-eastern Tasmania. In: Kenchington, R., Stocker, L., Wood, D. (Eds.), Sustainable Coastal Management and Climate Adaptation. CSIRO Publishing, Collingwood, pp. 135–156.
Leith, P., Ogier, E., Pecl, G., Hoshino, E., Davidson, J., Haward, M., 2014. Towards a diagnostic approach to climate adaptation for fisheries. Clim. Change 122, 55–66.
Levins, S., 1966. The strategy of model building in population biology. Am. Sci. 54, 421–431.
Lichatowich, J., 1992. Managing for sustainable fisheries: some social, economic, and ethical considerations. In: Reeves, G.H.B., Daniel, L., Brookes, Martha H. (Eds.), Ethical Questions for Resource Managers. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, pp. 11–17.
Lockwood, M., Davidson, J., Hockings, M., Haward, M., Kriwoken, L., 2012. Marine biodiversity conservation governance and management: regime requirements for global environmental change. Ocean. Coast. Manage 69, 160–172.
Ludwig, D., 2001. The era of management is over. Ecosystems 4, 758–764.
Lynam, T., Drewry, J., Higham, W., Mitchell, C., 2010. Adaptive modelling for adaptive water quality management in the great Barrier reef region, Australia. Environ. Modell. Softw. 25, 1291–1301.
Mackelworth, P., Holcer, D., Fortuna, C.M., 2013. Unbalanced governance: the Cres-Losinj special marine reserve, a missed conservation opportunity. Mar. Policy 41, 126–133.
Mackenzie, A., Pidd, M., Rooksby, J., Sommerville, I., Warren, I., Westcombe, M., 2006. Wisdom, decision support and paradigms of decision making. Eur. J. Operational Res. 170, 172–191.
Maio, G.R., 2010. Mental representations of social values. Adv. Exp. Soc. Psychol. 42, 1–43.
Mapstone, B.D., Little, L.R., Punt, A.E., Davies, C.R., Smith, A.D.M., Pantus, F., McDonald, A.D., Williams, A.J., Jones, A., 2008. Management strategy evaluation for line fishing in the great Barrier reef: balancing conservation and multi-sector fishery objectives. Fish. Res. 94, 315–329.
McDonald, A.D., Fulton, E., Little, L.R., Gray, R., Sainsbury, K.J., Lyne, V.D., 2006. Multiple-use management strategy evaluation for coastal marine ecosystems using InVitro. In: Perez, P., Batten, D. (Eds.), Agents, Icons and Idols. ANU E Press, Canberra, pp. 283–297.
McDonald, A.D., Little, L.R., Gray, R., Fulton, E., Sainsbury, K.J., Lyne, V.D., 2008. An agent-based modelling approach to evaluation of multiple-use management strategies for coastal marine ecosystems. Math. Comput. Simul. 78, 401–411.
McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environ. Sci. Policy 10, 17–38.
Meadows, D.L., Behrens III, W.W., Meadows, D.H., Naill, R.F., Randers, J., Zahn, E.K.O., 1974. Dynamics of Growth in a Finite World. Wright-Allen Press, Cambridge, Massachusetts.
Meinzen-Dick, R., 2007. Beyond panaceas in water institutions. Proc. Natl. Acad. Sci. U. S. A. 104, 15200–15205.
Metcalf, S.J., van Putten, E.I., Frusher, S.D., Tull, M., Marshall, N., 2014. Adaptation options for marine industries and coastal communities using community structure and dynamics. Sustain. Sci. 9, 247–261.
Moeseneder, C., Dutra, L., Thébaud, O., Ellis, N., Boschetti, F., Tickell, S., Dichmont, C., de la Mare, W., Pascual, R., Cannard, T., 2015. A simulation interface designed for improved user interaction and learning in water quality modelling software. Environ. Modell. Softw. 70, 86–96.
Moore, S., Wallington, T., Hobbs, R., Ehrlich, P., Holling, C., Levin, S., Lindenmayer, D., Pahl-Wostl, C., Possingham, H., Turner, M., Westoby, M., 2009. Diversity in current ecological thinking: implications for environmental management. Environ. Manag. 43, 17–27.
Morecroft, J.D.W., van der Heijden, K.A.J.M., 1994. Modeling the oil producers: capturing oil industry knowledge in a behavioral simulation model. In: Morecroft, J.D.W., Sterman, J.D. (Eds.), Modeling for Learning Organizations. Productivity Press, Portland, pp. 147–174.
Myers, S., Thomsen, D.C., Tarte, D., Dutra, L.X.C., Ellis, N., Thébaud, O., Nursey-Bray, M., Smith, T.F., 2012. Adaptive learning and coastal management in south east queensland, Australia. In: Kenchington, R., Stocker, L., Wood, D. (Eds.), Sustainable Coastal Management and Climate Adaptation. CSIRO Publishing, Collingwood, pp. 157–176.
O'Keeffe, T., 2002. Organisational learning: a new perspective. J. Eur. Industrial Train. 26, 130–141.
Olsen, S.B., 2003. Frameworks and indicators for assessing progress in integrated coastal management initiatives. Ocean. Coast. Manage 46, 347–361.
Ostrom, E., 1986. A method of institutional analysis. In: Majone, F.X.K., Ostrom, V. (Eds.), Guidance, Control, and Evaluation in the Public Sector: the Bielefeld Interdisciplinary Project. Walter de Gruyter, New York.
Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325, 419–422.
Ostrom, E., 2010. Analyzing collective action. Agr Econ-Blackwell 41, 155–166.
Ostrom, E., Gardner, R., Walker, J., 1994. Rules, Games, and Common-pool Resources. University of Michigan Press, Ann Arbor.
Özesmi, U., Özesmi, S.L., 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecol. Model. 176, 43–64.
Pantus, F., Barton, C., Bradford, L., Stroet, M., 2011. Integrated Science Support for Managing Australia's Tropical Rivers: a Case Study in the Daly River Catchment. TRaCK, Darwin, p. 148.
Pantus, F.J., Abal, E., Pearson, L., Steven, A., 2008. Healthy waterways management strategy evaluation: science support for catchment-to-coast water quality management. CSIRO Wealth from Oceans and Water for a Healthy Country National Research Flagships, Cleveland, p. 79.
Pascoe, S., Dichmont, C.M., Brooks, K., Pears, R., Jebreen, E., 2013. Management objectives of Queensland fisheries: putting the horse before the cart. Mar. Policy 37, 115–122.
Pauly, D., 2007. The *sea Around Us* project: documenting and communicating global fisheries impacts on marine ecosystems. Ambio 36, 290–295.
Pestes, L.R., Peterman, R.M., Bradford, M.J., Wood, C.C., 2008. Bayesian decision analysis for evaluating management options to promote recovery of a depleted Salmon population. Conserv. Biol. 22, 351–361.
Pister, E.P., 1992. A pilgrim's progress from group A to group B. In: Reeves, G.H.B., Daniel, L., Brookes, Martha H. (Eds.), Ethical Questions for Resource Managers. US Department of Agriculture, Forest Service, Pacific Northwest Research

Station, Portland, pp. 5–10.
Plagányi, É.E., Bell, J.D., Bustamante, R.H., Dambacher, J.M., Dennis, D.M., Dichmont, C.M., Dutra, L.X.C., Fulton, E.A., Hobday, A.J., van Putten, E.I., Smith, F., Smith, A.D.M., Zhou, S., 2011. Modelling climate change effects on Australian and Pacific aquatic ecosystems: a review of analytical tools and management implications Mar. Freshw. Res. 62, 1132–1147.
Plaganyi, E.E., Butterworth, D.S., 2012. The Scotia sea krill fishery and its possible impacts on dependent predators: modeling localized depletion of prey. Ecol. Appl. 22, 748–761.
Plagányi, E.E., Punt, A.E., Hillary, R., Morello, E.B., Thébaud, O., Hutton, T., Pillans, R.D., Thorson, J.T., Fulton, E.A., Smith, A.D.M., Smith, F., Bayliss, P., Haywood, M., Lyne, V., Rothlisberg, P.C., 2012a. Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish Fish. 15, 1–22.
Plagányi, É.E., Skewes, T.D., Dowling, N.A., Haddon, M., 2012b. Risk management tools for sustainable fisheries management under changing climate: a sea cucumber example. Clim. Change 1–17.
Pommeranz, A., Detweiler, C., Wiggers, P., Jonker, C., 2012. Elicitation of situated values: need for tools to help stakeholders and designers to reflect and communicate. Ethics Inf. Technol. 14, 285–303.
Punt, A.E., Smith, A.D.M., 1999. Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri*). ICES J. Mar. Sci. 56, 860–875.
Punt, A.E., Smith, A.D.M., Cui, G., 2001. Review of progress in the introduction of management strategy evaluation (MSE) approaches in Australia's south East Fishery. Mar. Freshw. Res. 52, 719–726.
Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in general theory of planning. Policy Sci. 4, 155–169.
Roberts, T., Jones, P.J.S., 2013. North East Kent European marine site: overcoming barriers to conservation through community engagement. Mar. Policy 41, 33–40.
Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill International Book Co., New York and London.
Saaty, T.L., 2003. Decision-making with the AHP: why is the principal eigenvector necessary. Eur. J. Operational Res. 145, 85–91.
Sainsbury, K.J., Punt, A.E., Smith, A.D.M., 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES J. Mar. Sci. 57, 731–741.
Schwartz, S.H., Bilsky, W., 1990. Toward a theory of the Universal content and structure of values – Extensions and cross-cultural replications. J. Pers. Soc. Psychol. 58, 878–891.
Selnes, T.A., van Bavel, M.A.H.J., Rheenen, T., 2006. Governance of Biodiversity, p. 119. Working Document 42., Wageningen.
Senge, P.M., Sterman, J.D., 1994. Systems thinking and organizational learning: acting locally and thinking globally in the organization of the future. In: Morecroft, J.D.W., Sterman, J.D. (Eds.), Modeling for Learning Organizations. Productivity Press, Portland, pp. 195–216.
Simpson, R., Gill, R., 2007. Design for development: a review of emerging methodologies. Dev. Pract. 17, 220–230.
Slovic, P., 2007. If I look at the mass I will never act: psychic numbing and genocide. Judgm. Decis. Mak. 2.
Smith, A.D.M., 1994. Management strategy evaluation – the light on the hill. In: Hancock, D.A. (Ed.), Population Dynamics for Fisheries Management. Australian Society for Fish Biology, Perth, pp. 249–253.
Smith, A.D.M., Sainsbury, K.J., Stevens, R.A., 1999. Implementing effective fisheries-management systems - management strategy evaluation and the Australian partnership approach. ICES J. Mar. Sci. 56, 967–979.
Smith, D.E., 2004. From gove to governance: reshaping indigenous governance in the northern territory. In: Altman, J. (Ed.), CAEPR Discussion Paper Series. Centre for Aboriginal Economic Policy, Canberra, p. 43.
Sneed, P.G., 1997. National parklands and northern homelands: toward co-management of national parks in Alaska and the Yukon. In: Stevens, S. (Ed.), Conservation through Cultural Survival: Indigenous People and Protected Areas. Island Press, Washington, D.C. and Covelo, California, pp. 135–154.
Spector, J.M., Davidsen, P.I., 2006. How can organizational learning be modeled and measured? Eval. Program Plan. 29, 63–69.
Sporne, I., Dale, P., 2009. Vegetation management in Queensland: Integration assessment of the legal framework. Natl. Environ. Law Rev. 4, 40–49.
Stacey, R., 1996. Complexity and Creativity in Organizations. Berrett-Koehler Publishers, San Francisco.
Stacey, R.D., 2001. Complex Responsive Processes in Organizations: Learning and Knowledge Creation. Routledge, London and New York.
Stacey, R.D., 2007. Strategic Management and Organisational Dynamics, fifth ed. Pearson Eduction Limited, Essex.
Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill, Boston.
Stocker, L., Burke, G., Kennedy, D., Wood, D., 2012a. Sustainability and climate adaptation: using google Earth to engage stakeholders. Ecol. Econ. 80, 15–24.
Stocker, L., Kennedy, D., 2009. Cultural models of the coast in Australia: towards sustainability. Coast. Manag. 37, 387–404.
Stocker, L., Kennedy, D., Kenchington, R., Merrick, K., 2012b. Sustainable coastal management? In: Kenchington, R., Stocker, L., Wood, D. (Eds.), Sustainable Coastal Management and Climate Adaptation. CSIRO Publishing, Collingwood, pp. 29–55.
Stoeckl, N., Jackson, S., Pantus, F., Finn, M., Kennard, M.J., Pusey, B.J., 2013. An integrated assessment of financial, hydrological, ecological and social impacts of 'development' on Indigenous and non-Indigenous people in northern Australia. Biol. Conserv. 159, 214–221.
Timmerman, J.G., Beinat, E., Termeer, K., Cofino, W., 2010. Analyzing the data-rich-but-information-poor syndrome in Dutch water management in historical perspective. Environ. Manag. 45, 1231–1242.
Tisdell, J., 2007. Bringing biophysical models into the economic laboratory: an experimental analysis of sediment trading in Australia. Ecol. Econ. 60, 584–595.
Tollison, R.D., 1982. Rent seeking – a survey. Kyklos 35, 575–602.
Triantafillos, L., Brooks, K., Schirmer, J., Pascoe, S., Cannard, T., Dichmont, C., Thebaud, O., Jebreen, E., 2014. Final Report - 2010-040-DLD – Developing and Testing Social Objectives for Fisheries Management. Fisheries Research and Develoment Corporation.
Tversky, A., Kahneman, D., 1974. Judgment under uncertainty: heuristics and biases. Science 185, 1124–1131.
Tversky, A., Kahneman, D., 1983. Extensional versus intuitive reasoning: the conjuctive fallacy in probability judgment. Psychol. Rev. 90, 293–315.
van den Belt, M., 2004. Mediated Modeling: a Systems Dynamics Approach to Environmental Consensus Building. Island Press, Washington DC.
van der Heijden, K., 1996. Scenarios: the Art of Strategic Conversation. John Wiley & Sons Ltd., Chichester.
van Putten, I.E., Dichmont, C.M., Dutra, L.X.C., Thébaud, O., Deng, R.A., Jebreen, E., Owens, R., Pascual, R., Read, M., Thompson, C., accepted. Articulating objectives for local management of a coastal socio-ecological system. Reg. Environ. Change.
van Vugt, M., 2009. Averting the tragedy of the commons: using social psychological science to protect the environment. Curr. Dir. Psychol. Sci. 18, 169–173.
Van Vugt, M., 2002. Central, individual or collective control? social dilemma strategies for natural resource management. Am. Behav. Sci. 45, 783–800.
Vennix, J.A.M., 1996. Group Model Building: Facilitating Team Learning Using System Dynamics. John Wiley & Sons Ltd., West Sussex.
Vennix, J.A.M., 1999. Group model-building: tackling messy problems. Syst. Dyn. Rev. 15, 379–401.
Vennix, J.A.M., Andersen, D.F., Richardson, G.P., Rohrbaugh, J., 1994. Model building for group decision support: issues and alternatives in knowledge elicitation. In: Morecroft, J.D.W., Sterman, J.D. (Eds.), Modeling for Learning Organizations. Productivity Press, Portland, pp. 29–49.
Vollan, B., Ostrom, E., 2010. Cooperation and the commons. Science 330, 923–924.
Wack, P., 1985. Scenarios: uncharted waters ahead. In: Harvard Business Review September-october, pp. 72–89.
Walters, C., 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conserv. Ecol. 1, 1–22 [online].
Walters, C.J., 2007. Is adaptive management helping to solve fisheries problems? Ambio 36, 304–307.
Westgate, M.J., Likens, G.E., Lindenmayer, D.B., 2013. Adaptive management of biological systems: a review. Biol. Conserv. 158, 128–139.
Wild-Allen, K., Herzfeld, M., Thompson, P.A., Rosebrock, U., Parslow, J., Volkman, J.K., 2010. Applied coastal biogeochemical modelling to quantify the environmental impact of fish farm nutrients and inform managers. J. Mar. Syst. 81, 134–147.
Woodward, E., Bayliss, P., Dray, A., Perez, P., 2010. Participatory Modelling Workshop for Feral Animal Management in Kakadu National Park, p. 119. Darwin.
Zander, K.K., Garnett, S.T., Straton, A., 2010. Trade-offs between development, culture and conservation - willingness to pay for tropical river management among urban Australians. J. Environ. Manage 91, 2519–2528.