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RESEARCH ARTICLE

Integrating social and ecological knowledge for planning sustainable land- and sea-scapes: experiences from the Great Barrier Reef region, Australia

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Abstract The integration of social and ecological knowledge has been identified as one of the key issues and research priorities in landscape ecology. However, research into the tools and processes that support knowledge integration for planning sustainable land- and sea-scapes is largely lacking. To fill this gap, Bohnet and Smith (Landsc Urban Plan 80:137–152, 2007) developed a social-ecological planning framework based on a holistic landscape concept which I applied in the Tully–Murray basin to test the framework's transferability and effectiveness for knowledge integration in a water quality improvement planning context in the Great Barrier Reef (GBR) region, Australia. In this paper I present the context in which the Tully Water Quality Improvement Plan (WQIP) was developed, the tools and processes applied during the three planning stages to achieve knowledge integration, and the results from this exercise. I then discuss the transferability and effectiveness of the framework using criteria identified to assess collaborative planning processes, outputs and outcomes, such as collaborative science and social and political capital. While many social outcomes such as the creation of partnerships between multiple-stakeholders, including Traditional Owners, local farmers, industry, government, community groups, schools, and the wider public, have been achieved, the research also highlights some of the challenges related to multiple-stakeholder relations. Further research into the roles and responsibilities of multiple-stakeholders for knowledge integration in developing and managing sustainable land- and sea-scapes is recommended.

Keywords Community engagement · Environmental values · Scenario planning · Participatory research · Sustainable development · Transdisciplinary · Interdisciplinary · Adaptive co-management

Introduction

Since the term and goal of Landscape Ecology was first introduced by the German geographer Carl Troll in 1939 (Troll 1939), landscape ecological research has made significant advances in the development of theory and application related to biophysical patterns and processes in landscapes (e.g. Forman 1995; Zonneveld 1995; Turner et al. 2001). However, the understanding of how to influence decisions about landscapes that bring about environmental improvements and more sustainable and resilient landscapes is largely lacking (e.g. Antrop 2006, 2007; Wu 2006, 2007; Opdam 2007; Nassauer and Opdam 2008).

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Since environmental degradation and the loss of ecosystems and landscapes is continuing more rapidly than ever (e.g. Ehrlich 2009), some scholars have argued to refocus the research agenda of Landscape Ecology to better understand nature-society relationships and the environmental, social, cultural and economic values represented in landscape patterns and processes (e.g. Tress et al. 2001, 2005; Hatfield-Dodds et al. 2006; Potschin and Haines-Young 2006a; Bohnet 2008a; Termorshuizen and Opdam 2009). Others have advocated that only with the introduction of a 'social layer' in the superposition of thematic maps, which are generally used in planning processes, can the interests and needs of different landscape users be taken into account as professionally as the mapping of vegetation, soils or land-use (e.g. Luz 1993, 2000; Gravsholt Busck 2002; Botequilha Leitao et al. 2006).

To affect decisions about landscapes Nassauer and Opdam (2008) propose to extend the landscape ecology paradigm to include design. They suggest that by explicitly incorporating intentional landscape change (through design) scientific understandings of pattern: process: design relationships can affect landscape planning (Nassauer and Opdam 2008). In this sense landscape planning can make a useful contribution to the goals of Landscape Ecology by providing alternative landscape designs (e.g. Steinitz et al. 2003; Hulse et al. 2004; Nassauer and Corry 2004; Bohnet and Smith 2007) that fulfil multiple functions and are based on landscape ecological principles (Haines-Young 2000; Steiner 2000; Ahern 2002). However, to achieve successful implementation of planning projects, Luz (2000) and others (e.g. Hatfield-Dodds et al. 2006; Hophmayer-Tokich and Krozer 2008) have demonstrated that communication and collaboration between scientists from different disciplinary backgrounds, planners, administrators and local stakeholders is essential and supports the integration of social and ecological information. Adding to this debate, Mostert (2003) suggests that public participation and collaboration can become an exercise in sharing responsibility and social learning, but that it requires an entirely different mode of governance and therefore should not be treated as a mere technique.

Based on the notion that the development of sustainable land- and sea-scapes (the main goal of Landscape Ecology) requires integration of social and ecological knowledge at the landscape scale (Blaschke 2006; Potschin and Haines-Young 2006b; Wu and Hobbs 2007) and collaboration between multiple stakeholders that supports social learning (Pahl-Wostl 2002; Mostert 2003) through discussion and negotiation about intentional landscape change (Luz 2000), Bohnet and Smith (2007) developed a social-ecological framework for sustainable landscape planning. In essence, their framework operationalises a holistic concept of landscape (e.g. Swanwick and Land Use Consultants 2002), builds on existing planning frameworks (e.g. Steinitz 1990; Steiner 2000; Botequilha Leitao and Ahern 2002) and calls for sustainable landscape planning to be goal oriented and capable of solving practical problems (Naveh 1988; Luz 2000). While the framework proposes three broad stages of research, no participatory tools or processes are prescribed. However, the use of spatially-explicit landscape scenarios as a means of linking social and ecological information with communication and collaboration between stakeholders is central to the framework (Fig. 1).

In contrast to other key frameworks that integrate social and ecological information, for example the Ecosystem Approach to implement the Convention on Biological Diversity (Smith and Maltby 2003), Bohnet and Smith's (2007) social-ecological planning framework focuses on biophysical landscapes and people's perceptions, uses and values associated with landscape at the basin/landscape scale. Their framework shares many similarities with Musacchio's (2009) conceptual framework for landscape sustainability, which is characterised by the six Es: Environment, Economics, Equity, aEsthetics, Experience, and Ethics. In contrast, the Ecosystem Approach focuses on biodiversity at the national or sub-national scale, is primarily concerned with the protection of ecosystems and based on 12 abstract principles (Table 1; Hartje et al. 2003). Since the social-ecological framework seemed generic and focused on outcomes at the landscape/basin scale it was considered appropriate to be adapted to a water quality improvement planning context.

This paper reports on how the social-ecological framework (Bohnet and Smith 2007) was applied to water quality improvement planning in the Tully–Murray basin of the GBR region, Australia (Kroon 2009). Throughout the three stages of research, a range of tools and processes were tested aiming to

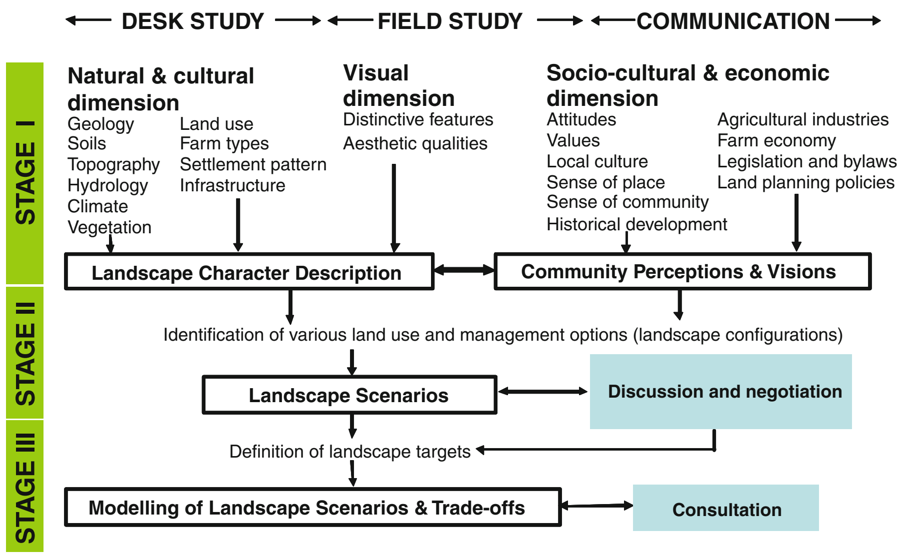

Fig. 1 Social-ecological framework for sustainable landscape planning (*Source*: Bohnet and Smith 2007)

Table 1 Key characteristics of and differences been the social-ecological framework for sustainable landscape planning (Bohnet and Smith 2007) and the UN Ecosystem Approach to implement the Convention on Biological Diversity (Hartje et al. 2003; Smith and Maltby 2003)

Concept name	Social-ecological framework for sustainable landscapes planning (Bohnet and Smith 2007)	Ecosystem Approach to implement the Convention on Biological Diversity (Smith and Maltby 2003)
Scale	Basin, landscape	National, sub-national
Main focus	Landscape	Biodiversity
Conceptual foundation	Holistic landscape	Holistic natural resource management
Associated concepts	Values, sense of place, identity	Protection of ecosystems
Emphasis of the framework	Trade-offs between different values (e.g. conservation, production, aesthetic) in landscapes	Valuation of ecosystem goods and services (e.g. flood prevention, pollination, clean water)
Associated governance structure	Decentralised	Centralised
Operational principles and guidance	Concrete, based on outcomes and outputs from three stages of planning	Abstract, based on 12 principles and five points of operational guidance

(i) achieve knowledge integration and (ii) foster collaboration amongst stakeholders to achieve the desired outcomes for the Tully Water Quality Improvement Plan (WQIP). The results suggest that the development of Landscape Ecology as a trans-disciplinary science (Tress et al. 2004) without methodological boundaries (Jaeger and Scheringer 1998) has influenced the development of the social-ecological framework and supports its application to different contexts, such as water quality improvement planning. Diverse tools (e.g. face-to-face interviews and landscape scenarios) and processes (e.g. community workshops, presentations and discussion forums) for knowledge integration and stakeholder collaboration were applied, demonstrating that besides the collection of social data many other social outcomes were achieved. However, the experience with the development of the Tully WQIP also highlighted some challenges related to multiple stakeholder collaborations (Lane and Robinson 2009), in particular the lack of a clear policy and delivery framework for WQIPs that clarifies the roles and responsibilities of key stakeholders in the process.

Methods

The Tully–Murray basin study area

The Tully–Murray basin (2780 km^2) is located in far-north Queensland, Australia and one of 35 basins discharging into the GBR World Heritage Area (Fig. 2). The dominant land uses in the Tully–Murray basin comprise natural forest (71%), sugarcane (13%), grazing (5%), plantation forestry (4%), banana and other horticulture (3%) and urban (1%), with the remaining areas occupied by waterways (3%) (Armour et al. 2009). World Heritage-listed rainforest occupies approximately 64% of the basin in the higher elevation and upper reaches of the rivers and creeks, whereas cleared cultivated land and remnant patches of rainforest are found on the alluvial plains, and wetlands and estuaries near the

Fig. 2 Location of the Tully–Murray basin in far-north Queensland in relation to other basins discharging their waters into the Great Barrier Reef (*Source*: Great Barrier Reef Marine Park Authority)

Fig. 3 Sugarcane is the dominant agricultural land use on the Tully–Murray floodplain with remnant patches of rainforest remaining mainly along rivers and creeks. Extensive views to the World Heritage listed rainforest are a common landscape feature (*Source*: Damon Sydes)

sandy coast (Fig. 3). The basin's landscape, in particular the floodplain, has been altered extensively since European settlement reflecting exploitation for grazing and timber, and clearing for agricultural development and associated changes in hydrology and drainage (Furnas 2003). The marine area influenced by discharging waters from the Tully–Murray basin ($\sim$2000 km^2) (Devlin and Schaffelke 2009) represents five of 70 bioregions within the GBR Marine Park (GBRMPA 2001).

Context and background to the development of the Tully Water Quality Improvement Plan (WQIP)

To protect the GBR from land-based sources of pollution, the Australian and Queensland Governments jointly launched the Reef Water Quality Protection Plan in 2003 (the Reef Plan; State of Queensland and Commonwealth of Australia 2003; Baker 2003). This Plan aims to reverse the decline in water quality entering the Reef within 10 years, and supports development and implementation of WQIPs for individual coastal catchments (Fig. 2). These WQIPs are concerned with reducing anthropogenically sourced sediment, nutrient and pesticide loads in the waters entering the GBR lagoon. The development of a WQIP for the Tully–Murray basin was identified as a high priority under the Reef Plan.

The Australian Federal Government has contracted the development of WQIPs in the GBR region to the regional Natural Resource Management (NRM) organisations. Agreement and support for WQIP development and implementation is required from relevant local stakeholders, including State and Local Governments, thereby forming an agreed approach to achieving pollutant reductions (Kroon et al. 2009).

In the case of the Tully WQIP, Terrain NRM (the regional NRM organisation) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) instigated the establishment of the Tully–Murray Floodplain Program (TMFP) to coordinate the WQIP (see Kroon et al. 2009 for more detail). The TMFP formed a partnership between Traditional Owners, council, primary industry groups, State and Federal government agencies, the regional NRM board, research organisations, and community groups. In addition, three action teams, focusing on biodiversity, agricultural production and socio-cultural capital, were established to support the work of the TMFP. Throughout the development of the Tully WQIP, the TMFP met regularly and was used for inclusive knowledge presentation and integration, as well as for debate. The three action teams met regularly too and served as sounding boards for researchers and managers involved in locally based projects informing the development of the Tully WQIP.

The overall process for developing the Tully WQIP was adapted from the National Water Quality Management Strategy (NWQMS) and is described in detail in the Tully WQIP (see Kroon 2008). The NWQMS considers community participation in water management critical to (i) identify the preferred uses and values of local water bodies, and (ii) develop community acceptance in relation to the costs associated with improved water quality (ANZECC 1994, 1998). These two requirements formed the basis for testing transferability and effectiveness of the social-ecological framework in a water quality improvement planning context.

Application of the social-ecological framework to water quality improvement planning

Figure 4 provides an overview of how the social-ecological framework (Fig. 1) has been adapted and operationalised to water quality improvement planning in the Tully–Murray basin.

Identification of community uses and values of waters and visions for the future (Stage I)

Identification of Environmental Values (EVs), i.e. the community uses and values of local water bodies, was critical social information that together with the water quality guidelines (ANZECC 2000) informed the setting of the draft Water Quality Objectives (WQOs) for the Tully WQIP (Kroon 2008). To identify the community's water uses and values, individual community members were interviewed face-to-face during Stage I of the research to identify their preferred uses and values of local water bodies (Bohnet et al. 2006). Interviewees were purposely selected based on their particular connection to the basin (Silverman 2000). This included primary producers from different locations within the basin who, were considered to, depend on the basin waters for their livelihoods, and Traditional Owners who, were thought to, have a cultural obligation to look after particular areas of country. Potential interviewees were approached through industry representatives, agricultural extension officers and Traditional Owners involved in the TMFP or the socio-cultural action team. To reach community groups and the wider community, a project flyer was distributed in the study area and an article published in the local newspaper to invite local participation in the Tully WQIP. In addition, a 'snowballing' technique (Miles and Huberman 1994) was used where one person introduces the interviewer to others, which provided the interviewer with access to interviewees that may have otherwise not participated.

Interviews were semi-structured and tailored towards the different stakeholder groups in the basin to ensure that the researcher covered all potential EVs, i.e. aquatic ecosystems, primary industries, recreation and aesthetics, drinking water, industrial uses, and cultural and spiritual values (EPA 2005). Questions were open-ended to allow (i) follow-up prompts and to encourage deeper exploration of the EVs identified by the respondents, (ii) exploration of additional water uses and values, and (iii) discussion about past water uses and values that had been lost over time, and conflicts between current and potential future uses and values. All interviews were tape-recorded, transcribed verbatim and analysed using the qualitative software package ATLAS.ti (Muhr 1997). All information related to EVs in the basin and associated coastal and marine environments was coded according to the EV classification provided by the Environmental Protection Agency (EPA 2005). Links between codes, known as nodes, were established to gain a deeper and contextualised understanding of the issues and conflicts related to EVs. Information related to the future based on interviewees' values and assumptions was also coded and preliminary qualitative visions for the future of the Tully–Murray basin were developed for 2025.

The research approach, methods and preliminary results were presented to and discussed by both the socio-cultural action team and the TMFP in their regular meetings. These meetings were also used to discuss how data integration and translation could best be achieved.

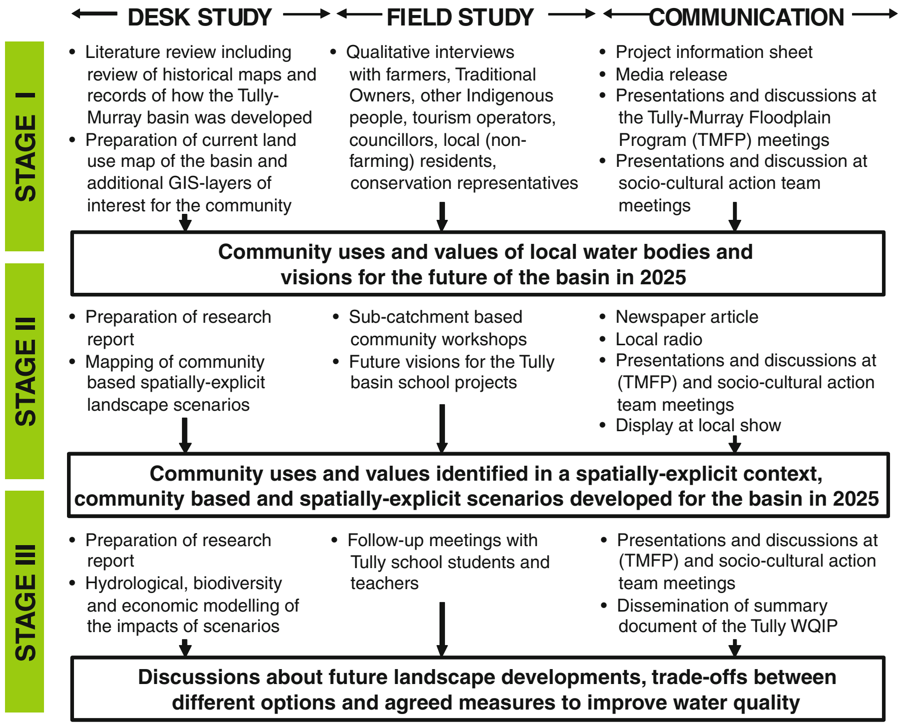

Fig. 4 Operationalisation of the social-ecological framework to water quality improvement planning in the Tully–Murray basin. A wide range of tools and processes have been used in the three stages of research during development of the Tully WQIP. The process is not unidirectional as illustrated in the figure, there is potential for many feedback loops and reasons for iterative processes within and between different stages. Desk studies, field studies and communication are not always distinct tasks as shown in the figure; they often inform each other and may overlap depending on the task

To validate the results gathered from the qualitative interviews in Stage I and to start a process that develops community acceptance in relation to the costs associated with improved water quality, one of the main goals of the NWQMS, a number of activities were carried out during Stage II of the research (Beierle and Cayford 2002; Renn 2006).

Identification of community uses and values of water in a spatially-explicit context (Stage II)

Community workshops were held in different sub-basins to determine past, present and preferred future water uses and values and associated spatial locations within the basin and river reaches (Bohnet et al. 2007). In addition, the workshops were used to find out what changes, for example in land use and/or management practices, could lead to water quality improvement and seemed achievable and acceptable to the participant.

To inform and invite the community to participate in one of the workshops, the workshops were promoted in the local newspaper and radio and individual invitations were sent out to the interviewees. To stimulate discussion and learning about the diversity of water uses and values amongst participants, which is a prerequisite for communities to adapt and respond to change (Barker 2005; Mostert et al. 2007, 2008), the workshop groups were composed of individuals representing potentially different views and interests within the sub-basins (Denzin and Lincoln 2007). A series of basin maps and key questions guided the community workshops.

The workshops were tape-recorded and the transcripts, along with the participants' annotations of basin maps and notes, provided the raw data for input into ATLAS.ti (Muhr 1997). Data were analysed and coded according to EVs and spatial locations of EVs. In addition, the workshop and interview data were also triangulated to validate the EVs (sensu Denzin 2006).

Development of future visions for the Tully–Murray basin by local primary schools (Stage II)

To engage young people in the research besides adults all primary schools in the basin were invited to contribute to the Tully WQIP (Bohnet et al. in review). The idea was for teachers to develop visions for the future of the Tully–Murray basin, with particular emphasis on water, with their students. This was seen as an important opportunity to support students' critical thinking about the future (e.g. Fien 2001, 2005; Evans 2005). The outcomes from the school projects were displayed at a local show to increase community awareness of the Tully WQIP. In addition, the intention was to stimulate community debate about likely changes to land use and management practice and their potential to improve water quality.

Development of community-based spatially-explicit scenarios for the Tully–Murray basin in 2025 (Stage II)

All information gathered during the face-to-face interviews, the community workshops, the primary schools' projects and meetings that related to changes in land use and management practices in the Tully–Murray basin was summarised and translated into spatially-explicit scenarios for the future of the area (e.g. Hulse et al. 2002). The resulting normative scenarios (Nassauer and Corry 2004) are those that make sense to locals and reflect their aspirations and assumptions, in contrast to forecasts and scenarios developed by researchers. These community-based scenarios were developed to serve two purposes: (i) to form a bridge which links biophysical landscape patterns (developed by and of interest to the local community) with social learning and capacity building for adaptive co-management (e.g. Measham 2007) and (ii) to be used as boundary objects that can facilitate stakeholder discussion about trade-offs between different landscape scenarios and their potential for water quality improvement (Cash et al. 2003; Hulse and Gregory 2004).

Similar to Stage I, research activities, approaches and methods applied during Stage II as well as preliminary results of the various activities were presented to and discussed by the socio-cultural action team and the TMFP in their regular meetings.

Discussion about future landscape developments, trade-offs between different options and agreed measures to improve water quality (Stage III)

To progress development of community acceptance in relation to the costs associated with improved water quality or more broadly to develop the community's adaptive capacity to deal with change, presentations and discussions of the research results were the main task during Stage III. Special emphasis was placed on the local schools that participated in the research and the socio-cultural action team with whom a close working relationship was established. Presentations to schools involved an overview of the diversity of ideas contributed to the visions for the future project (Bohnet et al. in review). Meanings of individual student contributions were clarified by the students and trade-offs between environmental, social and economic goals discussed. Presentations to the socio-cultural action team focused on planning for the future of the basin; discussions focused on identification of long-term goals, potential trade-offs between different future scenarios and steps towards achieving improvements in water quality flowing out to the Reef based on collaborative research and adaptive management (Fischer 2000; Pahl-Wostl et al. 2007).

Evaluation of the effectiveness of the social-ecological framework to water quality improvement planning

In order to evaluate the tools and processes applied during the three stages of research I used Sheppard's (2005) process criteria for participatory decision-support methods. To assess the outcomes achieved through the application of the social-ecological framework I employed Mandarano's (2008) performance criteria for collaborative environmental planning outputs and outcomes.

Results

Application of the social-ecological framework to water quality improvement planning

Social data were collected from 41 qualitative interviews with 49 respondents (Stage I), three community workshops with 29 participants (Stage II), and five local school projects, involving five teachers/principals and more than 100 students (Stage II) during Stage I and II of the research. Interviewees and workshop participants included a diversity of local community members, including Traditional Owners, other Indigenous people, primary producers, tourism operators, councillors, local (non-farming) residents and conservation representatives (Table 2, 3). All primary producers, Traditional Owners and other Indigenous people approached by local representatives from the TMFP agreed to be interviewed, indicating their willingness to collaborate. Sixteen of the 29 workshop participants also contributed to the research via an interview, demonstrating their commitment to the research process (Sheppard 2005).

The interview and workshop results highlighted that conflicts exist between 'consumptive' (e.g.

Table 2 Participants in face-to-face interviews for the identification of community uses and values of waters in the Tully–Murray basin

Interview participants	Total
Primary producers in the Tully–Murray basin	
Sugarcane growers	15
Sugarcane and banana growers	3
Sugarcane/banana growers and graziers	1
Graziers	1
Graziers and sugarcane growers	2
Graziers and sugarcane growers, small crops	2
Tropical fruit growers	2
Forest growers	1
Tully–Murray residents (not involved in primary production)	
Traditional Owners from the Tully–Murray basin	10
Other indigenous people (i.e. Traditional Owners from other areas living in the Tully–Murray basin)	3
Non-indigenous people	6
Shire councillors	1
Tourism operators in the Tully–Murray basin	
Sea based tourism operators	2

Source: Bohnet and Kinjun 2009

Table 3 Workshop participants by location for the identification of community uses and values of waters in the Tully–Murray basin

Workshop participants	Workshops by location			Total
	South Mission Beach	Euramo	Cardwell	
Traditional Owners	2	0	1	3
Councillors	1	1	1	3
Local residents	2	1	1	4
Sugarcane farmers	2	3	1	6
Tropical fruit growers	1	1	0	2
Banana growers	0	1	1	2
Graziers	1	2	1	4
Foresters	0	0	1	1
Conservationists	2	0	2	4
Total number of participants	11	9	9	29

Source: Bohnet and Kinjun 2009

irrigation) and 'non-consumptive' (e.g. recreational and cultural) uses. The main consumers of water in the basin are primary producers and industry (e.g. banana growers, Koombooloomba Dam, Tully sugar mill). In contrast, all other user groups including local residents, Traditional Owners, other Indigenous people, and conservation groups value the basin waters primarily for their recreational opportunities and aesthetic values, as well as for cultural and spiritual purposes (Bohnet and Kinjun 2009). Similar conflicts emerged when comparing the visions for the future provided by individual school students. For example, some students' artwork focused solely on agricultural expansion and urban development whereas other students' work focused solely on biodiversity conservation (Bohnet et al. in review). In contrast, one school jointly prepared their vision for the future in a three-dimensional landscape model that aimed at balancing agricultural development, biodiversity conservation, water quality improvement, cultural diversity and quality of life for the people in the area (Fig. 5).

In addition, the interview and workshop results as well as the school projects provided a wealth of contextual local information relevant to the Tully WQIP. For example, the issue of native vegetation clearing on the upper reaches of rivers for agricultural production and associated consequences were mentioned: "*The flooding is exacerbated by the fact that the water is coming down faster from the ridges which increases the height of the flood…. We in the lower regions are suffering the consequences of the development in the upper regions*". The results also highlighted differences in community perceptions of current water quality depending on age, background and uses considered. While most primary producers related current water quality to their farming enterprises, agreeing that "*the quality is plenty good enough*", non-farming residents, who answered the question in the context of drinking water quality and Traditional Owners, who answered the question in the context of their current uses did not agree. As one Traditional Owners stated: "*We eat a lot of fish, but you don't know what's in the fish, what's in the water*."

Whilst collecting social data for knowledge integration was the primary aim during Stage I and II, the research also focused on testing tools (methods) and processes (participatory and collaborative approaches) with the potential to integrate social and ecological information, to raise public awareness and to foster communication and collaboration among stakeholders throughout the development of the Tully WQIP (Fig. 4). This was seen as a prerequisite for developing community acceptance of the costs associated with improved water quality. For example, the use of a

Fig. 5 Three-dimensional landscape model depicting the school student's preferred vision for the future of the Tully–Murray basin. They are aiming at balancing agricultural development, biodiversity conservation, water quality improvement, cultural diversity and quality of life for the people in the area (*Source*: Bohnet et al. in review)

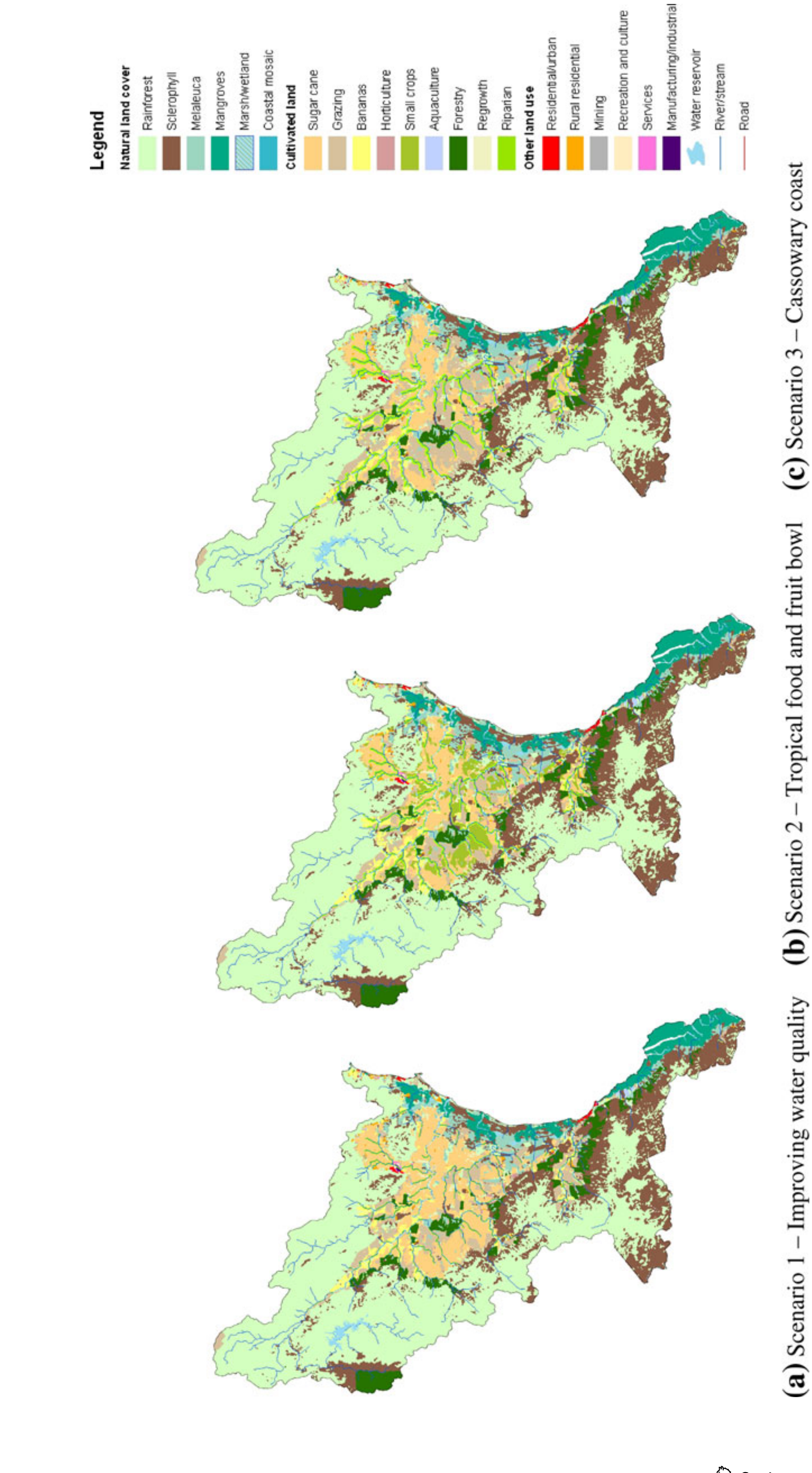

Fig. 6 Community defined scenarios for the future of the Tully–Murray basin: **a** Scenario 1—Improving water quality in the sugarcane landscape; **b** Scenario 2—Tropical food and fruit bowl; **c** Scenario 3—Cassowary coast. Note the increase in riparian buffer widths from Scenario 1 to Scenario 2 and 3; the increased amount of land under small crops at the expense of land used for sugarcane production in Scenario 2; and the increase of grazing land in Scenario 3

series of basin maps in the community workshops (Stage II) allowed the mapping of water uses and values in a spatially-explicit context, which facilitated knowledge integration and fostered communication and sharing of local knowledge among workshop participants. The suggested land use and management changes to improve water quality, such as introduction of riparian buffer zones and conversion of land unsuitable for agricultural production, stimulated workshop discussion while providing further information for data integration (Stage III).

Three distinct and spatially-explicit land use and management change scenarios based on the community's vision for and assumptions of the future were the combined outcome from the interviews, community workshops, school projects and meetings with the socio-cultural action team and the TMFP (Fig. 6). These future designs summarise the social data collected and link them with biophysical information from the basin (Fig. 4). The scenarios reflect local perspectives about the future. Hydrological, agronomic, biodiversity and economic research also carried out in the basin to underpin development of the Tully WQIP allowed modelling of some of the impacts of the community based landscape scenarios (Fig. 4). Landscape scenarios and modelling results presented to the TMFP and socio-cultural action team were used as a tool to stimulate discussion amongst members to build their adaptive capacity to deal with change and ultimately to develop community acceptance in relation to the costs associated with intentional landscape change to improve water quality. Discussions focused on the potential impacts of and trade-offs between the different futures presented and costs associated with inaction. Furthermore, discussions focused on how to ensure that changes impacting adversely on water quality in the basin can be avoided and how current management practices can be adapted to improve water quality (Stage III).

Presentations and discussions at three local schools, that organised a follow-up meeting, focused on students' preferred futures, the potential consequences of their preferred futures, and how potential negative consequences could be minimised. The schools project thereby contributed to connect students with their local environment and community, to develop their social responsibilities, and to strengthen their 'action competence' (Bohnet et al. in review).

Evaluation of the effectiveness of the social-ecological framework to water quality improvement planning

Examination of the tools and processes applied during the three stages of research using Sheppard's (2005) process criteria for participatory decision-support methods indicate that broad representation of and open access by stakeholders has been achieved through use of a wide range of tools and processes. Tools included: face-to-face interviews, community-based scenarios, project flyers and articles in local newspaper; processes included: community workshops and TMFP and socio-cultural action team meetings. Broad stakeholder representation has been identified by Sheppard (2005) as a requirement to demonstrate equity and credibility, and to reduce risk of overlooked issues later in the process (Table 4). The role of the TMFP at the start of the project and the three stage structured research contributed to transparency and a process that allowed for different kinds of engagement and knowledge integration. Dialogue between different interest groups during community workshops, TMFP and socio-cultural action team meetings addressed local issues and conflict regarding past, present and potential future threats to water quality in the basin and how these could be addressed and mitigated. Community-based scenarios and school projects, which served as boundary objects, were powerful tools for integration of knowledge and stakeholder values in sustainability assessments. They also provided forums for learning and capacity building (Table 4). The evaluation demonstrates that the social-ecological framework, adapted to a water quality improvement planning context, meets the standards arising from the literature on processes for participatory planning and management of natural resources such as water.

The qualitative evaluation using Mandarano's (2008) performance criteria identified important outputs and outcomes while highlighting major challenges related to multi-stakeholder collaborations (Table 5). Applying the social-ecological framework brought about conflict between stakeholder groups which could only be resolved through shared problem framing and agreement upon data being used to develop the Tully WQIP. Related to this challenge is the voluntary nature of WQIPs and the lack of a clear

Table 4 Examination of the tools and processes used in the development of the Tully Water Quality Improvement Plan (WQIP) using Sheppard's (2005) principles and process criteria for participatory decision-support methods

Principle	Process criteria	Principle and process criteria applied during development of the Tully WQIP
Broad representation of stakeholders	Process provides for representation of all interests concerned by the issue driving the participatory process, including administrators, actual and potential users, and people whose livelihoods or other interests are affected by the decisions	Achieved; broad representation of stakeholders (TMFP; action-teams; interviews, community workshops, schools) who can drive participatory process
Open access to stakeholders	Open access to the process is provided throughout, encouraging equitable inclusion of a broad range of stakeholder groups (both organised and unorganised), with limitations on the dominance of the process by any groups. A neutral or unintimidating forum is provided	Achieved; ongoing communication (project flyers, local newspaper and radio) and invitations to encourage citizen participation in development of the WQIP
Clearly structured decision-making process	The process is transparent to stakeholders, lay people and managers from the outset, with clear and timely documentation of purpose, process, results, and the degree of public influence on recommendations and decisions'	Achieved; roles and responsibilities discussed and agreed by TMFP, as well as communicated at the outset of engagement processes
Engaging process	The process is attractive, interesting, and worthwhile for participants, encouraging significant numbers of people to show up and participate actively throughout the process	Achieved; significant numbers of people were involved in the development of the Tully WQIP
Understandable and accurate information	Reliable scientific information is presented with clear graphic formats for use in stakeholder deliberations, without being overly technical	Achieved; social and ecological information was presented in TMFP meetings for stakeholder deliberations
Appropriate scale and detail for participants and managers	Dialogues between the public and managers address local settings on scales that are meaningful to community members	Achieved; community workshops, community-based scenarios and TMFP meetings provided opportunities for dialogue about issues of local concern
Focussed on assessing sustainability over time	Multiattribute analysis methods are structured around sustainability criteria and indicators.	Achieved; community-based scenarios provided focus for sustainability assessment
Credibility of the process	Methods are straightforward enough to be both understood by managers and explicable to the public with appropriate presentation. Participants are included in the design of the process, agree to ground rules for the process, and remain involved throughout	Achieved; at the level of TMFP and action-teams
Mutual learning and capacity building	The process is structured to permit all participants to learn from it, with capacity building or educational aids provided where necessary.	Achieved; TMFP provided main forum for members to learn, question scientific and local knowledge and to bring in additional expertise
Feasibility	Overall process is meaningful to stakeholders, with specialised support where necessary	Achieved; mainly at the TMFP level

policy and delivery framework for WQIPs that clarifies (i) who the key stakeholders are that are 'required' to participate in the process (for vertical and horizontal institutional integration) and (ii) the roles and responsibilities of these stakeholders (Lane and Robinson 2009). In the case of the Tully WQIP multiple-stakeholders have worked together over 3 years to develop a WQIP without statutory power while legislation to achieve target reductions in pesticides and nutrients was passed shortly after the finalisation of the Tully WQIP (Table 5). This decision does not appear to take account of the time and resources that have been invested to build effective voluntary partnerships in the Tully–Murray basin to address water quality issues (Robinson et al. 2009).

Table 5 Assessment of the performance of the adapted social-ecological framework to water quality improvement planning in the Tully–Murray basin using Mandarano's (2008) evaluation criteria

Performance evaluation criteria	Definition	Performance of the social-ecological framework to water quality improvement planning
Outputs		
High-quality documents	Documents produced through a collaborative process that justify action or identify a clear approach for implementation and are approved by a consensus-based approach	Achieved; TMFP role was central to the process, involving circulation of documents and feedback from stakeholders
Collaborative science	Scientifically sound information produced through a consensus-based approach that stakeholders understand and accept	Achieved; scientifically sound science produced by multiple science teams, outputs understood and agreed by TMFP
Outcomes		
Social		
Social capital	New and improved working relationships, formation of trust, norms of reciprocity	Achieved; growth of engagement by some TMFP stakeholders (e.g. industry groups) and disengagement by some (e.g. government)
Intellectual capital	Mutual understanding, shared problem frames, agreed upon data or shared information	Research process and TMFP meetings brought out conflicts between water uses/values and stakeholder groups as well as disagreement about what the key pollutants are. However, mutual understanding, shared problem framing and agreement upon data has been reached over time through discussion and negotiation
Political capital	Ability to work together for agreed ends, end to a stalemate	Achieved; TMFP worked together to develop Tully WQIP
Innovation	Strategies, actions and ideas that are new to the context, break a stalemate or change policy	Because the voluntary approach by primary producers to the adoption of 'reef friendly' management practices is too slow to reverse the decline in reef health, the Queensland government has introduced legislation to achieve target reductions in pesticides and nutrients flowing to the reef
Institutional change	Changes in or new attitudes, behaviours, actions, decision-making processes, and institutions that incorporate learning from experience in the collaborative process, spin-off partnerships	Achieved; TMFP was incorporated under the Catchment Management Association and became synonymous with it; primary schools incorporate learning from their involvement; scientists in school partnerships are a spin-off
Environmental		
Restoration projects completed	Restoration projects completed by the collaboration or indirectly through actions by others	Achieved; several riparian revegetation and weed removal projects are underway
Land protected from development	Lands acquired or otherwise protected by collaboration or indirectly through the actions by others	No voluntary agreements have been achieved to improve water quality
Changes in environmental parameters	Changes in environmental quality appropriate to goals	Negligible; to achieve reductions in end-of-basin loads takes a long time and major reductions in fertilizer inputs
Perceptions of improved environmental quality	Participants' perception of success in improving environmental parameters	Participants perception is that improvements have not been achieved due to a lack of funding for implementation of measures identified in the Tully WQIP

Discussion

Has the application of the social-ecological framework to water quality improvement planning supported integration of social and ecological knowledge?

The research suggests that whilst the application of the social-ecological framework has successfully facilitated knowledge integration to develop the Tully WQIP, knowledge integration for water quality improvement planning presents a significant challenge. The task involves engagement with multiple-stakeholders and groups and considerable technical and social complexity. The TMFP played a significant role as it brought together relevant stakeholders and facilitated plan development through regularly held meetings (Fig. 4). These meetings provided a forum for biophysical and social scientists to present their research approaches, methods and results, to discuss potential conflicts and how data integration could best be achieved (Coburn 2003). To integrate the social and ecological data for the Tully WQIP, it was essential to link the social data, i.e. the community's uses and values of water, to the different water types in the basin and to distinguish between the different reaches of rivers. Therefore, in Stage II of the research, a series of basin maps were used in the community workshops to facilitate mapping of community uses and values of basin waters in a spatially-explicit context.

The tools (methods) and processes (participatory and collaborative approaches) used during Stage I and II supported the collection of in-depth social and contextual data that was used in a number of ways. For example, data on proposed changes in land use and management to improve water quality, such as the introduction of riparian buffer zones, was incorporated by the catchment modelling team (see Armour et al. 2009 for more detail), data related to the community's uses and values of water that were not directly linked to water quality improvement was included in the Tully WQIP under the heading 'Additional issues of concern' (Kroon 2008) and data related to possible future land use and management changes in the basin was used to develop community-based scenarios for the future of the basin (Bohnet 2008b). Mapping of the community-based scenarios also required integrating social information with biophysical information such as topography, soils, water and land use. The subsequent modelling work also relied on social information being integrated with biophysical information. For example, social information on proposed changes in land management was an essential input for modelling of sediment and nutrients loads of the different scenarios and provided the basis for discussion about future landscape developments, trade-offs between different options and measures to improve water quality during Stage III.

Has the application of the social-ecological framework fostered collaboration amongst stakeholders to achieve the desired outcomes for the Tully Water Quality Improvement Plan (WQIP)?

The wide range of tools and processes that have been employed throughout the three stages of research seem to have fostered collaboration amongst stakeholders and contributed to the credibility of the science that underpinned the Tully WQIP (Cash et al. 2003). For example, the qualitative face-to-face interviews with local community members, instead of representatives, were intended to be inclusive by capturing not only the water uses and values of local elites but a wide range of community members, many of whom are marginalised (Berkes 2009). These one-on-one interactions helped building relationships and trust between the researcher and individual members of the local community early in the development of the Tully WQIP. Kruse et al. (1998) previously fund that the key factor that led to social capital, a prerequisite for collective action and social learning, was the frequent presence of researchers in the community. My experience with development of social capital for water quality improvement planning in the Tully–Murray basin reinforces the significance of researcher presence in the community and ongoing interactions.

The establishment of the TMFP and the three action teams were critical to foster vertical and horizontal institutional collaboration, knowledge co-production, trust building and conflict resolution (see also Berkes 2009). Regular communication between the researcher, socio-cultural action team and TMFP was essential for everyone involved to learn about the various sciences (and other) components that informed development of the Tully WQIP (Pahl-Wostl 2006; Tàbara and Pahl-Wostl 2007). However, it became evident that some government agencies disengaged from the collaborative process, which delayed delivery of the Tully WQIP for almost a year (see Kroon et al. 2009 for more detail). Not having a formal commitment about the roles and responsibilities of key stakeholders that are 'required' to be involved in a decentralised planning process has jeopardised collaboration between the stakeholders who closely worked together for over 3 years to develop the Tully WQIP. In addition, lack of funding for the WQIP implementation further contributed to disengagement from the collaborative process.

Conclusions

Adaptation of the social-ecological framework to water quality improvement planning in the Tully–Murray basin enabled integration of social and ecological knowledge which is a key requirement to the development and management of sustainable land- and sea-scapes. The application of a wide range of tools and processes (including design) tailored to the local context and requirement of the NWQMS provides an Australian case study of transdisciplinary research which contributes towards achieving a more holistic and forward-looking approach to landscape ecology. However, whilst the social-ecological framework fostered collaboration amongst stakeholders, it could not prevent disengagement of some of the key stakeholders from the collaborative process. Further research into the roles and responsibilities of multiple-stakeholders for knowledge integration and collective action in developing and managing sustainable land- and sea-scapes is recommended to enhance the contribution of landscape ecology to sustainability.

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