Adaptation options for marine-industries and coastal communities using community structure and dynamics

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Abstract

Identifying effective adaptation strategies for coastal communities dependent on marine resources and impacted by climate change can be difficult due to the dynamic nature of marine ecosystems. The task is more difficult if current and predicted shifts in social and economic trends are considered. Information about social and economic change is often limited to qualitative data. A combination of qualitative and quantitative models provide the flexibility to allow the assessment of current and future ecological and socio-economic risks and can provide information on alternative adaptations. Here we demonstrate how stakeholder input, qualitative models and Bayesian Belief Networks (BBN) can provide semi-quantitative predictions, including uncertainty levels, for the assessment of climate and non-climate driven change in a case study community. Issues are identified including the need to increase the capacity of the community to cope with change. Adaptation strategies are identified that alter positive feedback cycles contributing to a continued decline in population, local employment and retail spending. For instance, diversification of employment opportunities and the attraction of new residents of different ages would be beneficial in preventing further population decline. Some impacts of climate change can be combated through recreational bag- or size-limits and monitoring of popular range-shifted species that are currently unmanaged, to reduce potential for excessive removal. Our results also demonstrate that combining BBNs and qualitative models can assist with effective communication of information between stakeholders and researchers. Furthermore, the combination of techniques provides a dynamic, learning-based, semi-quantitative approach for the assessment of climate and socio-economic impacts and the identification of potential adaptation strategies.

Keywords: Climate change, qualitative modelling, Bayesian Belief Network, fisheries, socio-economic, stakeholder input.

1. Introduction

The prosperity of coastal communities in Australia and around the world is often highly dependent on marine resources (McGoodwin 1990; FAO 2000; Allison 2001). The health and abundance of these marine resources are impacted by a range of factors including climatic change and exploitation rates (Fletcher et al. 2003; Tuler et al. 2008). Coastal communities may therefore be economically impacted by changes such as warming ocean temperatures which cause range shifts in commercially valuable species

(Hughes 2000; 2003) and can alter reproductive capacity (Donelson et al. 2010). In addition to adapting to a changing marine environment, coastal communities need to cope with non-climate drivers such as ongoing demographic (Turner et al. 1996) and cultural transformation (Adger et al. 2009). For example, the sea change phenomenon has already had significant impacts in Australia (e.g., Young et al. 2006, Huang et al. 2012). For coastal communities to remain economically viable, retain population and adapt to biophysical changes, economic opportunities will need to be maximised and possible threats minimised. In Australia and worldwide fishing towns are undergoing a restructuring process (Ommer 2007), for example, from fishing towns to tourism or mining towns. Studies assessing adaptation strategies in these communities are necessary to assist their progress into the future and must consider complex dynamics incorporating climate and non-climate driven change to ensure that adaptations benefiting one sector are not maladaptive to others.

Modelling these complex systems is essential to allow assessment of vulnerability (Lahsen et al. 2010) and identify effective adaptation strategies (Meinke et al. 2009). However, the dynamic nature of ecosystems and limited data availability often make undertaking such assessments difficult. With limited data, investigation into the magnitude of change and interactions between economic, ecological, and social domains can be hampered. Furthermore, a lack of economic, ecological, and social data integration can lead to reduced precision and greater uncertainty (Latour et al. 2003; Plaganyi and Butterworth 2004). Processes that easily incorporate stakeholder knowledge are particularly valuable in these situations (Reed 2008).

The complexity and uncertainty associated with simultaneous ecological, social and economic change can be accounted for (Berkhout and Hertin 2000) using multiple scenarios in combined qualitative models (e.g. Levins 1974, Dambacher et al. 2002) and Bayesian Belief Networks (BBNs) (e.g., Marcot et al. 2001, McCann et al. 2006). In this study a combination of qualitative models and BBNs makes use of data gathered through semi-structured interviews to produce alternative scenarios and semi-quantitative predictions of environmental, social and economic change. Hosack et al. (2008) outline the theory that underpins the integration of qualitative models and BBNs. The combination of the two modelling approaches is particularly useful in situations where there is no 'best' adaptation strategy with respect to costs and resources to address an applied management problem. In these cases, the level of uncertainty applicable to different scenarios provides an alternative decision making criterion. As far as the authors were able to determine, this is the first study in which the combined methods are applied to a complex management problem incorporating climate and non-climate drivers in the marine environment.

Extensive local knowledge is central to the production of relevant and useful models for applied problems (Reed 2008) and, as such, stakeholder knowledge is used in this study. To ensure the process of assessment is not further complicated and to encourage stakeholder involvement, it is particularly important to use modelling approaches that are comprehensible and transparent (Matthews and Selman 2006; Metcalf 2010). Benefits of stakeholder-researcher interaction include the promotion of both researcher and stakeholder learning which can increase model representativeness (Kalaugher et al. 2012). Pre- and post-modelling results can be more easily communicated when stakeholder involvement is facilitated in applied management problems (van der Sluijs et al. 2003) and research uptake improves as a consequence (Phillipson et al. 2012). Importantly, the use of stakeholder knowledge allows the definition of the appropriate level of complexity required to assess current local issues and future needs (Berkhout et al. 2001).

Qualitative models and BBNs are assessed to predict the effects of change and identify potential adaptation strategies in a coastal community in south-east Australia. A model representing the ‘current’ (as of February 2012) structure and dynamics of the coastal community with respect to the impacts of change on marine-dependent industries and associated links into the broader community is outlined. A second model outlining different fisheries management approaches (referred to as Fisheries Management model) is also presented. Adaptation strategies are identified and used to distinguish results that are most consistent with recorded observations (Hosack et al. 2008) and management alternatives that may be beneficial for the community.

2. Material and methods

2.1 Case study community

St Helens in south-east Australia, Tasmania (41°20’S, 148°15’E) was used as a case study due to rapidly increasing local sea surface temperature (up to 4 times the global average, Cai et al. 2005) attributed to climate change (Poloczanska et al. 2007). As a consequence, changing species abundance and range shifting distributions have already been observed in this region (e.g., Last et al. 2010). St Helens thus provides a rich source of information for modelling of biophysical, social and economic change. Information gained with respect to these pressing climate change issues and identified potential adaptation strategies for this region may serve as an example for other Australian and global regions experiencing a slower rate of change.

St Helens is a relatively small community with a population of approximately 2,000 residents (Australian Bureau of Statistics 2011). Compared to the national average, the St Helens population has a higher proportion of older people (≥ 65 years) (Census 2011). Fishing and forestry were traditionally important industries. However, the community has changed in recent years with a shift away from these primary industries. In particular, the size of the local fishing fleet has decreased significantly. In the past, fisheries for rock lobster (*Jasus edwardsii*), scallops (*Pectin fumatus*) and abalone (*Haliotis* spp.) provided a large proportion of employment in the fishing industry. However, ‘retail trade’ and ‘health care and social assistance’ make up over 10% of total employment and only around 2% of the labour force in St Helens is currently employed in ‘fishing and aquaculture’ (Census 2011). The size of the commercial fishing sector operating out of St. Helens has declined over the past 30 years for various reasons including changes in fisheres management systems (Hamon, et al., 2009) and environmental change (Ling, et al., 2009). The local commercial fishing fleet has declined from approximately 35 vessels 20 years ago to around 10 vessels in 2012 (anecdotal information from survey participants). Countering this decline, there has been a marked growth in the aquaculture sector and the establishment of a processing factory for the roe of the invasive urchin *Centrostephanus rodgersii*. In addition, recreational and charter fishing are important to the local economy and draw visitors to St Helens, which is known as the ‘Game fishing capital of Tasmania’. The size and demographic characteristics, and economic activities, in this coastal community are representative of many coastal communities in Tasmania and Australia therefore making the findings in this study widely applicable.

2.2 Data collection

The spatial scale of the study was defined prior to data collection and included the area within the 'St Helens' postcode (7216). Data collection was undertaken using a semi-structured interview approach (n = 35) and consisted of key sectors, industries, species and impacts as perceived by interviewees as well as the relationships between these key aspects of the community. This information was used directly as input into the qualitative models. Semi-structured interviews were undertaken as they are an effective instrument to consider the scope of issues (Kalaugher et al. 2012) and ensure a maximum level of information detail is obtained. Interview respondents (i.e., stakeholders) were from a variety of different sectors including:

- Commercial and recreational fishing
- Aquaculture
- Charter boats (i.e., fishing) and marine tourism
- Accommodation, retail and restaurants
- Education and local council
- Boat maintenance, port master and marine safety

Interview duration was approximately 60 minutes with a focus on the nature of their employment and/or business, and how their business and community is impacted by changes in the marine environment, and by other socio-economic changes. Participants were then asked to identify future opportunities to deal with change and potential adaptations that could improve individual and community outcomes. Recorded perceptions were only incorporated into the models if they were mentioned by multiple participants and not refuted, or were able to be cross-validated with published information or expert knowledge (i.e. fisheries managers, scientists, members of government).

Regional extension staff with contacts in marine industries were used to facilitate discussions with key community participants. Experts were selected in this way as it was not feasible to survey large samples of the population (Ruhanen and Shakeela, 2012). A small number of individuals were also attracted through snowball sampling (Goodman, 1961) and interest was garnered through a media release, radio interview and an information sheet that were publically available approximately one week prior to the survey. As climate change has become a politically-charged issue (Nursey-Bray et al. 2012), the semi-structured format was used to reduced potential bias. This format assists in the avoidance of anchoring to the issue of climate change, adverse reactions to participation in a study focussing on climate change and 'tactical' survey responses. For example, fishers may be reluctant to focus on environmental issues if they believe the information may be used by the government to alter management regulations and negatively impact their livelihoods.

2.3 Qualitative modelling technique

Qualitative models can include non-quantifiable aspects of complex and integrated systems. These models are designed to gain a better understanding of system dynamics and allow key factors that impact on system stability to be identified (Bodini et al. 2000). This technique uses signed digraphs displaying direct effects between variables.

For example, a fishery has a direct negative effect on a target fish species (●—) and the fish species has a direct positive effect on the fishery (◄—) (Fig. 1). Birds are shown to prey on the target species and also feed on bycatch thrown overboard by fishermen. Negative self-effects (◯) are used to represent intra-specific density dependence or a reliance on factors that are external to the modelled system, such as the impact of markets on the fishery.

All direct interactions between variables (+, –, 0) can also be represented in a community matrix (**A**, Eq. 1). Following established mathematical protocol, this matrix can be used to calculate predicted direction of response to perturbation (disturbance) using the adjoint of the negative community matrix (Eq.2, for additional detail on adjoint matrices see Levins 1968; Puccia and Levins 1985; Dambacher et al. 2003). Perturbed variables read down matrix columns while the response of variables to perturbation is read across matrix rows. The numbers at the top of each column correspond to the variable name at the start of each row.

$$\mathbf{A} = \begin{matrix} 1.\,Fishery \\ 2.\,Fish \\ 3.\,Birds \end{matrix} \overset{\begin{matrix} \mathit{1.} & \mathit{2.} & \mathit{3.} \end{matrix}}{\begin{bmatrix} - & + & 0 \\ - & - & - \\ + & + & - \end{bmatrix}} \qquad (1)$$

$$\text{adj. } (\text{-}\mathbf{A}) = \begin{matrix} 1.\,Fishery \\ 2.\,Fish \\ 3.\,Birds \end{matrix} \overset{\begin{matrix} \mathit{1.} & \mathit{2.} & \mathit{3.} \end{matrix}}{\begin{bmatrix} + & + & - \\ - & + & - \\ +,- & + & + \end{bmatrix}} \qquad (2)$$

Prediction signs are calculated as the net feedback cycles between a perturbed variable and the variable of interest using Maple 15 (Dambacher et al., 2003). For example, in figure 1 there is only one feedback cycle involved in the response of the fishery to an increase (perturbation) in the abundance of fish. The fishery is predicted to increase its production in response to an increase in fish abundance. In contrast, there are two feedback cycles involved in the response of birds to an increase in the fishery. The fishery may have a direct positive impact on birds or an indirect negative impact on birds by reducing the abundance of fish. As these feedback cycles are countervailing, the prediction response is ambiguous. Ambiguity of predictions is important because when the strength of the interactions is taken into account, one strong feedback cycle may outweigh multiple weak cycles in the opposing sign. In this way, particularly as systems become more complex, ambiguity may result in an unexpected response to change. 'Probability of sign determinacy' (Hosack et al., 2008) was used as an indication of reliability of response. Using the methods of Hosack et al. (2008) we use a Monte Carlo procedure to determine the probability that the sign is stable and is unlikely to result in an unexpected response due to a strong cycle in one direction.

Semi-structured interview data was incorporated into the qualitative models (and BBNs) as key variables and their relationships (links). For example, multiple interviewees reported that heavy rainfall events caused the closure of oyster farms and that extended closures, as had recently occurred, caused some employees to be given leave without pay or forced to find alternative employment. In the St Helens community model, oyster aquaculture and employment are shown as key variables while rainfall is a perturbation to the system (Table 1, Fig. 2a). These relationships between these variables are shown by a negative link from rainfall (perturbation) to the oyster aquaculture variable due to the decline in production. In addition, a decline in the oyster aquaculture variable is shown to have a positive link to local employment. It is important to note here that a positive link means that change in the initial variable will be followed by change in the same direction in the end variable and is not a value judgement. This means that a decline in the oyster aquaculture variable will cause a further decline in local employment by reducing the availability of jobs in the area. All links included in the models are derived from interview participants.

When using this qualitative modelling technique, it is important to note that negative feedback is stabilising, as it opposes change and allows a return to the former state. In contrast, positive feedback enhances the effect of the original change (Levins, 1998) and contributes to instability. Model stability is assessed using the degree to which the overall feedback of the system is dominated by stabilising negative feedback cycles. Model stability is measured using weighted feedback (*wFn*) where values of *wFn* close to -1 are perfectly stable (Dambacher et al. 2003). Stable systems tend to return to equilibrium following a perturbation. Values for *wFn* that are close to +1 are totally unstable and they may switch to an alternative equilibrium. This means the system can no longer be adequately represented by the current model (Dambacher et al. 2003). A weighted feedback of 0 represents a system that is equally likely to be stable or unstable. Particularly influential interactions and feedback cycles can be identified and modified to increase stability, predictability and management outcomes. These modifications in addition to the mediation of external negative impacts essentially form the identified adaptation strategies.

Adaptation strategies that increase model stability are favoured as they offer greater predictability which is useful for assessing the potential outcomes of different strategies. Adaptation strategies that benefit (i.e., are predicted to improve/increase) important model variables such as target species or economic sectors, are also favoured. For example, strategies that increase the capacity of the community to cope with change or increase the abundance of fish for recreational fishing are identified.

2.4 Integration of qualitative models into Bayesian Belief Networks

BBNs are used to determine (i) predicted changes following implementation of adaptation strategies, (ii) the probability of different strategies to reduce negative impacts and iii) the model most likely to represent particular situations. BBNs are a semi-quantitative approach that allows the calculation of conditional probabilities for change in any variable, given change in another (e.g., Marcot et al. 2001). Similar to qualitative modelling, BBNs use a graphical notation to illustrate linkages between different system components. The difference between the qualitative models and BBNs is that all links in the BBNs are probabilistic while links in qualitative models are purely directional. BBNs use relationships between variables to form the basis for conditional probabilities. For example: What is the probability of a decline in the rock lobster fishery at location X, given an increase in pests in the area?

The reliance on relationships between variables determines that conditional probabilities central to the BBNs can be calculated on the basis of community matrix information developed during qualitative modelling (sensu Hosack et al. 2008). BBN structure is equivalent to the associated signed digraph. For example, each variable in the signed digraph becomes a node with its own conditional probability table (CPT) in the BBN. Similarly, perturbations impacting the signed digraph are shown as input variables in the BBN. BBNs were developed and analysed using Netica 4.16 following input from qualitative models using Maple 15.

Probabilities of sign determinacy, calculated as part of the qualitative modelling analysis, are translated into probabilities for use in the CPTs for the BBN (Hosack et al. 2008). For example, each variable/node in a qualitative model and associated BBN has the potential to increase, decrease or undergo no changes in response to a disturbance to the system. Therefore, if there is no knowledge of the direction of change there will be an equal likelihood of an increase, decrease or no change (i.e., $Pr = 0.\dot{3}$) in the BBN. In contrast, a probability of 0.8 that a variable will increase will have corresponding probabilities for a decline and no change of 0.1. The cyclical nature of signed digraphs is embedded in the BBN through these CPTs and the relationships between nodes and their input variables.

A simple measure of uncertainty has been used for the results of the BBNs whereby probabilities of 0.8 and higher are regarded as likely based on model structure and have high likelihood (Dambacher et al 2003; Hosack et al. 2008). Predictions with probabilities between 0.6 and 0.8 are regarded as having moderate likelihood and those with probabilities less than 0.6 have low likelihood of occurring.

Using qualitative models to assist in the determination of conditional probabilities significantly reduces the time and effort required by experts and community members using a more traditional approach, which is to estimate probabilities. In the method applied here, community and expert input was required only to develop the graphical structure of the signed digraph. The use of this technique therefore allowed the construction of more complex BBNs than would be possible if experts were required to provide conditional probabilities for all links in a model (Ticehurst et al. 2007).

We develop two qualitative models and associated BBNs to represent aspects of the overall community structure and recreational fisheries management considered important by stakeholders. These ‘systems’ (refers to qualitative models and associated BBNs) are impacted by external and internal changes (called Press Perturbations) reported to affect the coastal community. Both systems also have associated alternative structures incorporating identified potential adaptation strategies to allow the assessment of adaptation strategy effectiveness.

3. Results

3.1 System 1: Coastal community model

Model structure

The coastal community model (Fig. 2a) represents the perceived interactions between different marine sectors, non-marine economic sectors (i.e. retail), population size, and local employment (Table 1). Aside from economic sectors, the coastal community model also incorporates marine species interactions. For instance, the variable called *‘new’ fished species* represents non-endemic species that were observed in the region due to climate driven changes such as altered current systems and increasing sea surface temperatures. *C. rodgersii* is another species that is present in St Helens due to the increased southerly extension of the warm East Australian Current (EAC) (Ling 2008). This species has created urchin barrens and negatively impacted the local rock lobster fishery but also supports a growing urchin roe industry (called *Urchin factory*). Species targeted by the commercial, recreational, and charter sectors are included in the model by means of the *ecosystem* variable. Change in each marine and non-marine economic sector is represented as a change in employment (i.e. numbers employed) and the level of productive activity (i.e., production quantities as opposed to profit). For example, the arrow (positive link) from *oyster aquaculture* to *local employment* indicates that growth in this sector will increase *local employment* (Fig. 2a). Similarly, an increase in *charter and recreational fishing* will cause a decline in the abundance of ‘New’ fished species (as indicated by the negative link, Fig. 2a). Climate- and non-climate impacts observed by community respondents are represented in the coastal community model by means of so called press perturbations, which are sustained disturbances from one or multiple variables (Fig. 2b, Table 1).

Analyses

The coastal community model is moderately stable (*wFn* = -0.24) and the key dynamic influencing how the system responds to disturbance are the short positive feedback cycles including the variables *retail*, *local employment*, and *St Helens population*. This structure emerged because many interviewees indicated that visitors travel to St Helens to fish recreationally, which in turn, supports local retail and employment. Higher local employment is perceived to help retain a workforce and encourage people to move into the area, thereby expanding the population of the town. This increases retail spending and further increases the population.

The positive feedback cycle within the coastal community model can not only lead to a continual increase in employment, population and retail spending but also to a continual downturn, reducing each variable involved. For example, a reduction in local employment forces people to move out of the area in search of work, which reduces retail spending and thus further reduces local employment opportunities. Such an effect is predicted in the associated BBN where an unequivocal decline in local employment (Pr = 1.0) resulted a decline in the St Helens population (Pr = 0.7) and retail (Pr = 0.7) as well as a decline in charter and recreational fishing (Pr = 0.6), all with moderate likelihoods.

An urchin processing facility (*urchin factory*) was recently opened in St Helens and provides local employment. It was expected that the climate change induced increase in urchin abundance would add to general employment opportunities by stimulating the local economy and reducing the negative impacts on the ecosystem, which could in turn be beneficial for commercial rock lobster and abalone fisheries. However, when other simultaneous perturbations occur, such as extreme rainfall events and declining employment in commercial fisheries due to more appealing employment in other sectors external to St Helens, this is not the case. The model predicts that a continued increase in urchins will reduce local employment (Pr = 0.5) and the St Helens population (Pr = 0.5) despite the increase in urchin factory production (Pr = 0.6). While the certainty of these predictions is low, they are indicative that a positive result for employment and town population is not highly likely.

3.1.2 Alternative coastal community model

Model structure & analyses

Adaptation options that increase the capacity of the community to cope predicted changes were identified. They include a strong self-effect on local employment or population to regulate externally-driven declines in these variables. In reality this may be achieved through diversification of employment opportunities and encouraging younger working people, including families, to move into the area. The alternative coastal community model investigates the impact of altering the positive feedback cycle which could occur in reality through adaptations to increase employment opportunities in the area such as encouraging and funding new businesses and the development of the aquaculture and tourism industries. This could, in turn, increase the population by bringing new people into St Helens for work and further diversify employment through the need for services to support a larger population such as education, healthcare and trades.

The positive feedback cycle in the coastal community model is removed by deleting the link between *retail* and *local employment* (Fig. 2c). It should be noted that removing this link does not mean that the retail sector no longer provides local employment; rather it represents a situation where the 'relative' contribution of retail to local employment is reduced as substantial alternative employment opportunities exist. This alternative coastal community model has markedly higher stability (*wFn* = -0.78, Class I) than the original coastal community model discussed in Section 3.1.1. This result suggests the alternative scenario is less likely to shift into another state and is therefore more likely to generate reliable predictions.

The alternative community model structure reduced the vulnerability of St Helens to a decline in population size when subject to the perturbations listed in Table 1. Rather than the decline observed with moderate likelihood in the original model (Pr = 0.7), a low likelihood increase in population (Pr = 0.4) was predicted. The alternative model also predicts an increase in *charter and recreational fishing* (Pr = 0.7) where a decline was previously observed. However, removing the influence of *retail* on *local employment* does not remove the risk of decline in the marine sectors, *oyster aquaculture* (Pr = 1.0) and *commercial fishing* (Pr = 0.9) due to indirect impacts from rainfall and oyster production, urchin grazing and increased recreational fishing. The business models of these marine sectors must be able to cope with the variability associated with these changes in order to remain viable.

3.2 System 2: Recreational fisheries management model

Model structure

Recreational fishing is important as it attracts numerous visitors to St Helens each year and helps to support the community through associated retail, accommodation and tourism spending. The fisheries management model (Fig. 3a) represents the general view of current recreational fisheries management in Tasmania.

The recreational fishery has recently been impacted by an influx of warmer water species due to the extension of the EAC. These species, such as King George whiting (KGW) (*Sillaginodes punctata)*, yellowtail kingfish (*Seriola lalandi)*, and striped marlin (*Tetrapturus audax*), are currently unmanaged because existing regulations do not cater for these previously non-local species. These species are popular with recreational fishers and the lack of management may eventually become an issue for fisheries authorities if overfishing occurs. This scenario is relevant in many locations as the regulation of fishing for range-shifted and unmanaged species is likely to become an important issue in other climate change affected coastal communties.

The fisheries management model shows recreational fishers primarily targeting managed species as well as some unmanaged species. The model therefore includes the variable called *recreational fishing (unmanaged species)*, representing fishers targeting ‘new’ species that are largely unregulated. In reality recreational fishers are unlikely to either target only managed or unmanaged species but they are separated into two variables to allow a ‘relative’ impact assessment. The variable called *public perception* is included to represent the lobbying potential of the public who exert influence on fisheries management to adjust (increase) regulations when stocks decline (sensu Aslin and Byron 2003). This is a two-way interaction, meaning that an increase in regulations will increase the public perception of *fisheries management*.

The negative link from *fisheries management* to *recreational fishing (managed species)* indicates that a reduction in management and policing would increase fishing for managed species, and vice versa. The negative link from *managed species* to *fisheries management* indicates that increased monitoring and research of fish populations to ensure bag and size limits are appropriate will reduce the need for management.

Analyses

The fisheries management model is perfectly stable (*wFn* = -1.00). The qualitative model and BBN predict there will be a fall in the number of both managed and unmanaged species due to a sustained increase in recreational fishing (Table 2). These results have moderate and high likelihood respectively. In turn, declines in the abundance of unmanaged species and public perception are predicted to increase fisheries management activites (Pr = 0.6). However, an increase in management actions fuelled by a decline in public perception does not bring about a greater abundance of unmanaged species. This is due to the lack of feedback between unmanaged species and fisheries management (Table 2). An increase in management will only increase the abundance of managed species while having an ambiguous affect on the abundance of other species.

3.2.1 Alternative recreational fisheries management models

Model structure & analyses

The two adaptation options were investigated. As adaptation is not always positive, the first option shown is not beneficial and is included to provide an example of possible changes if fisheries management is not strict and non-compliance is allowed (Fig. 3b). The second adaptation option shows the impact of including the regulation of previously unregulated fish species and provides benefits to the fish species and recreational fishing by increasing fish abundance (Fig. 3c).

In the first adaptation scenario, the allowance of illegal take and high accidental mortality results in the capture and removal of over- and under-sized fish. As a result, both managed and unmanaged species are ambiguously impacted by management and will not necessarily increase in abundance due to management activities (Table 2). The issue of a lack of monitoring and remedial action, seen in the original model, is therefore exacerbated and affects both species variables. These results suggest,if non-compliance is an issue, that the regulations and policing that exist in this scenario are not sufficient to adequately manage stock sustainability. Based on the stability (*wFn* = -1.00) of the qualitative model, these results are reliable.

In the second fisheries management adaptation scenario, management of previously unregulated fishing is shown by negative feedback between *recreational fishing (unmanaged species)* and *fisheries management* (Fig. 3c). A link between *fisheries management* and *unmanaged species* (to represent monitoring) has not been included because to monitor all unmanaged species would be impractical and unlikely to occur. This adaptation scenario is perfectly stable (*wFn* = -1.00) and therefore reliable based on model structure. A positive input to fisheries management is predicted to increase the abundance of both managed and unmanaged species with moderate likelihood (Table 2). Both types of recreational fishing (managed and unmanaged species) are predicted to decline with moderate likelihood due to the feedback between fishing and fisheries management. As feedback is cyclical, this decline in recreational fishing will reduce fisheries management and eventually cause recreational fishing activity to increase again. The feedbacks within this scenario are sufficient to ensure an increase in recreational fishing and the subsequent decline in the abundance of both species will eventually return the system to equilibrium by increasing fisheries management activities.

Using the associated BBN, analyses were undertaken to determine which of the three models (the fisheries management model and the two adaptation scenarios) best represents the desired increase in fish abundance while allowing recreational fishing to continue. The second adaptation scenario has the model structure (Pr = 0.6, moderate likelihood) most likely to represent increases in the abundance of both managed and unmanaged species, public perception and fisheries management following increases to recreational fishing.

4. Discussion

The development of qualitative models and BBNs that incorporate perceived climate and non-climate changes and potential adaptation scenarios has many benefits. For example, the process enables better communication of ideas and complex system relationships while making effective use of available data. In addition, the modelling approaches used in this study semi-quantitatively capture the dynamics of the socio-ecological system, from biophysical impacts to a high-level social and economic understanding of the consequences of change. Such an approach has broad applications for planning (Kruse et al. 2004, Sturtevant et al. 2007), as the direct and indirect effects of climate change become more apparent and as communities transition into the future (Young et al. 2006).

Integrating the use of qualitative models and BBNs facilitates the use of qualitative stakeholder knowledge in a data-limited situation while also permitting an assessment of the conditional probabilities associated with change. Such assessments can be beneficial both generally and specifically, in guiding further investigations and providing a preliminary indication of the likelihood of policy and management success (Levontin et al. 2011). The modelling approach used here assists with the identification of adaptations to increase long-term resilience in coastal communities through three mechanisms. Firstly, the models are able to identify flexible and diverse systems that can be resilient to perturbations (FAO 2008) as well as identify coping mechanisms to deal with change rather than focusing solely on the consequences of change (Kalaugher et al. 2012). Increasing the diversity of employment in coastal communities is one such coping mechanism that was identified in the coastal community model, as it increases stability and population size despite declines in some sectors.

Secondly, the models are able to identify adaptations that encourage dampening (negative) rather than amplifying (positive) feedbacks. The dampening of a feedback system is observed in the fishery management models developed in the current research, where incorporating an additional negative feedback cycle provides the necessary means to increase recreational species abundance as well as public perception of ‘fisheries management’. The need to dampen feedback has been recognised as necessary for policy makers and managers in the assessment of adaptations (Cinner et al. 2011) and was shown to maintain model stability and produce beneficial outcomes for key variables in this study.

Lastly, the capacity for the system to cope with change is strengthened through the assessment and identification of adaptations (i.e., changes) designed to improve system stability (Duit and Galaz 2008). This is achieved by identifying of the role and dominance of any destabilising positive (amplifying) feedbacks as well as identifying coping mechanisms. For instance, the stability of the coastal community model was dominated by a key positive feedback (between retail, local employment, and the general population), which when removed, permitted increased stability as well as improved employment opportunities. An adaptation scenario to improve the diversity of employment and diversification of the age range was suggested as a logical and realistic change that can also lessen the reliance on retail for local employment (and cuts the positive feedback cycle). It is by no means assumed that this is the only adaptation that would lessen the reliance of local employment on retail and the future identification of alternative strategies that achieve the same result (i.e. increased stability) should also be considered in community planning processes.

Improving community capacity to identify issues can be particularly important for vulnerable small- to medium-sized communities as it can allow them to moderate their own vulnerability through adaptation (Spittlehouse and Stewart 2003). For example, visualisation of the models using community perceptions allows the discussion and assessment of whether fisheries management is sufficient to maintain stocks of previously unmanaged species. The different fisheries management scenarios highlight the need to ensure there is feedback between management and recreational fishing. While this may seem an intuitive result, these models have widespread applicability for two reasons. Firstly, range-shifts are becoming commonplace globally and associated management issues and adaptations must therefore be considered as soon as possible (Madin et al. 2012). Techniques such as qualitative modelling and BBNs can be used to assist this process. Secondly, commercial fisheries will increasingly target valuable range-shifted species (Perry et al. 2005, Cheung et al. 2010) and will require similar adaptations as illustrated in this study for recreational fisheries. Effective adaptation strategies should reduce sensitivity, alter exposure and increase the capacity of the system to cope with change (Adger et al. 2005). The techniques used in this study can essentially convert community perceptions into an assessment of these characteristics for different strategies and therefore assist with further planning and risk assessment.

The types of models used in this study are, by no means, the only methods that can be used to assist the identification of potential adaptation strategies. For example, simple flow diagrams or mind maps can be beneficial in ensuring information from various sources can be incorporated into assessments and provide stakeholders with an holistic view of the system (Zuber-Skerritt 2002). Any technique that allows visualisation and discussion, and easily incorporates differences of opinion and knowledge can be particularly useful for encouraging knowledge sharing and learning. Furthermore, such processes can increase the uptake of management decisions (Kalaugher et al. 2012). Data-intensive, dynamic quantitative models may also be beneficial when adequate data is available; however, these will likely have greater use in closing the gap between holistic thinking, as in this study, and the specific details involved in change (Bassi 2009). Highly quantitative models can be used to identify specific magnitudes of change and the magnitude of adaptation success once the full picture of impacts and responses have been considered.

Regardless of the techniques used to identify potential adaptation strategies, the effectiveness of the strategy will always depend on the ability and willingness of governance structures to deal with the issue at hand (Urwin and Jordan 2008, Pahl-Wostl 2009). In many cases, the routines enabling decision-making depend largely on inherited routines and practices that have been used previously (David 1994), even if they are ineffective. Coastal communities experience dynamic, integrative and complex problems that may require modifications to governance structures to improve the uptake of adaptation strategies and avoid ‘lock-in’ or path dependence (Storper 1997). To diversify employment opportunities and the age range of residents in St Helens, the regional and economic development bodies must first recognise the need for change and have the capacity to identify and implement the specific actions required.

Successful adaptation ultimately depends on the actions of individuals and the flexibility that exists in their social or institutional structures to support them (Kalaugher et al. 2012). However, one of the most critical factors for planning will be an awareness of direct and indirect impacts and how the broader community may need to adapt to changes previously perceived as unrelated. In other words, understanding the dynamic nature of the system in the context of ever-changing environments is essential for the development of effective adaptation strategies (Kalaugher et al. 2012). An acceptance of and dedication to adaptation strategies will not occur without an holistic understanding of the reasons for implementation and the benefits and disadvantages they may engender. Methods such as those undertaken in this study can facilitate this awareness and act as a springboard to the uptake of flexible and dynamic adaptation strategies. Taking such a proactive step could prove valuable in comparison to waiting for top-down solutions that may never arrive or may come only in response to extreme events. Communities and policy-makers can benefit from these and similar methods that may aid the assessment of their own adaptation needs without a full-blown quantitative investigation and can be used to stimulate further discussion and ideas.

Acknowledgments

This research was funded by the Fisheries Research and Development Corporation (FRDC) and the Department of Climate Change and Energy Efficiency. Special thanks to all community participants for their valuable contributions. We would also like to thank Jeff Dambacher and the anonymous referees for their useful comments and suggestions.

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Figure legends

Figure 1: Signed digraph showing birds and a fishery removing fish from the system (negative effect on fish, •—), fish providing food for birds and product for the fishery (positive effect on birds and fishery, ◂—) and the fishery providing birds with additional food through releasing bycatch (positive effect). Negative self-effects represent density-dependence or a reliance on factors external to the system (e.g., market demand, profit, habitat).

Figure 2: Coastal community model representing the dynamics of marine-dependent sectors and the marine environment in St Helens, Tasmania.

a) Current St Helens Community system.

b) Changes and impacts (perturbations) on the current St Helens Community system (shown as negative •— and positive ◂— press perturbations) as perceived by local survey participants (Table 1).

c) Alternative coastal community model with link removed (blue arrow) from retail sector to local employment.

Figure 3. Fisheries management scenario for recreational fishing in St Helens. Links in blue have been changed from model a.

a) Current fishieries management;

b) Alternative model 1, showing capture and removal of under- and/or over-sized fish;

c) Alternative model 2, showing management and policing of fishing regulations for managed and unmanaged species.

Figure 1.

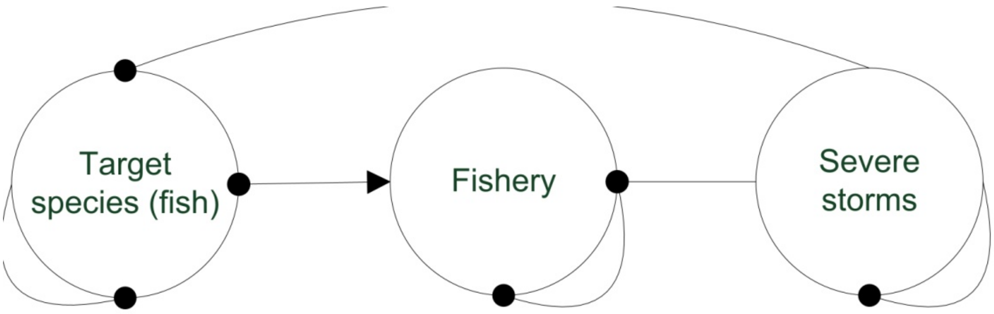
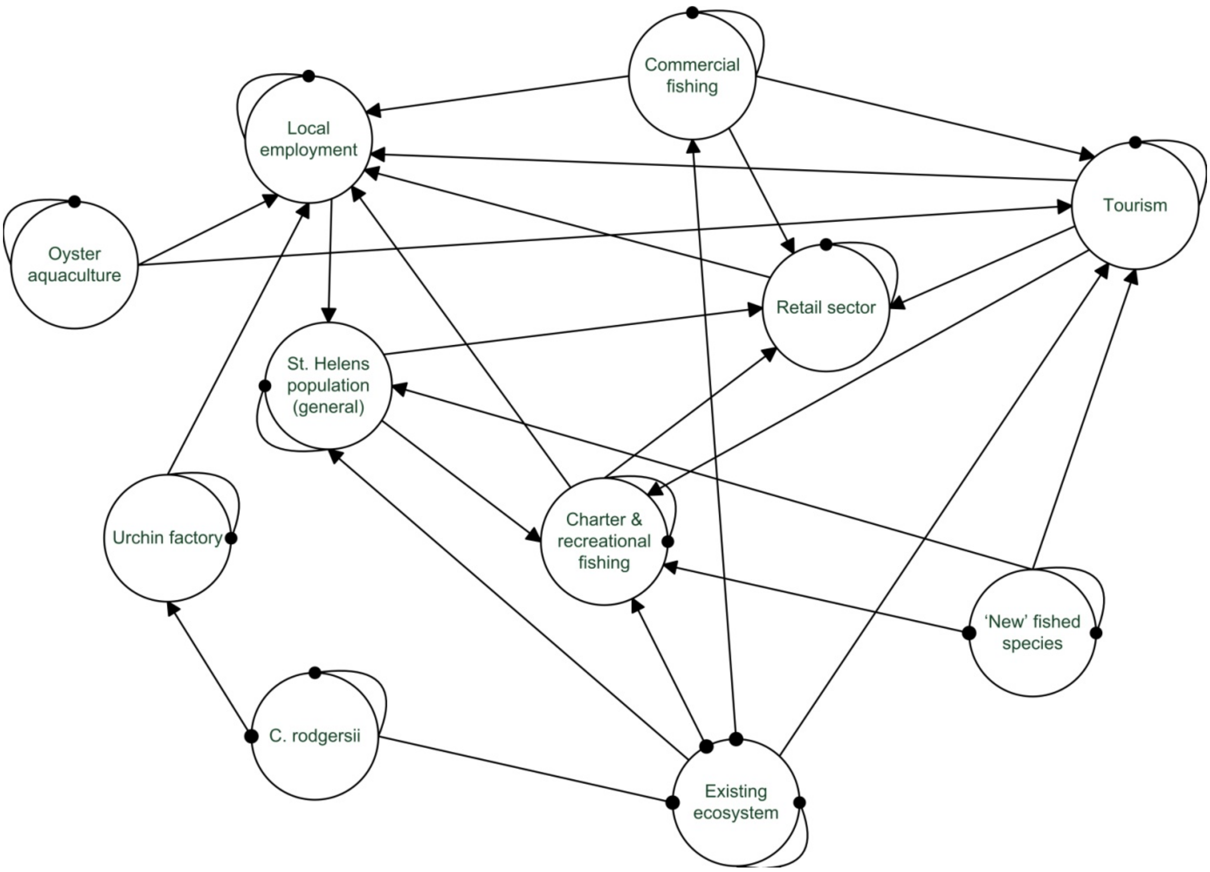
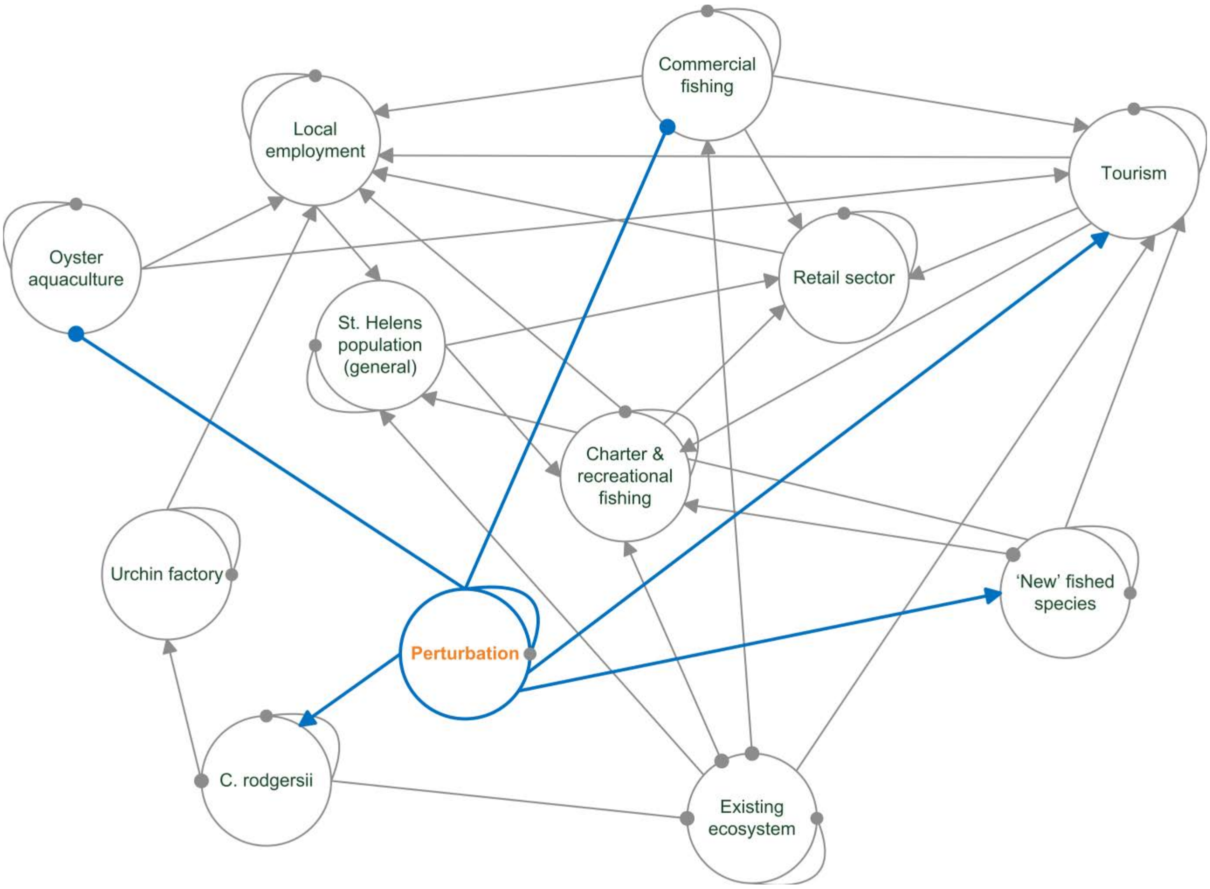


Figure 2. a)



b)


Commercial fishing
Local employment
Tourism
Oyster aquaculture
Retail sector
St. Helens population (general)
Charter & recreational fishing
Urchin factory
'New' fished species
Perturbation
C. rodgersii
Existing ecosystem

c)

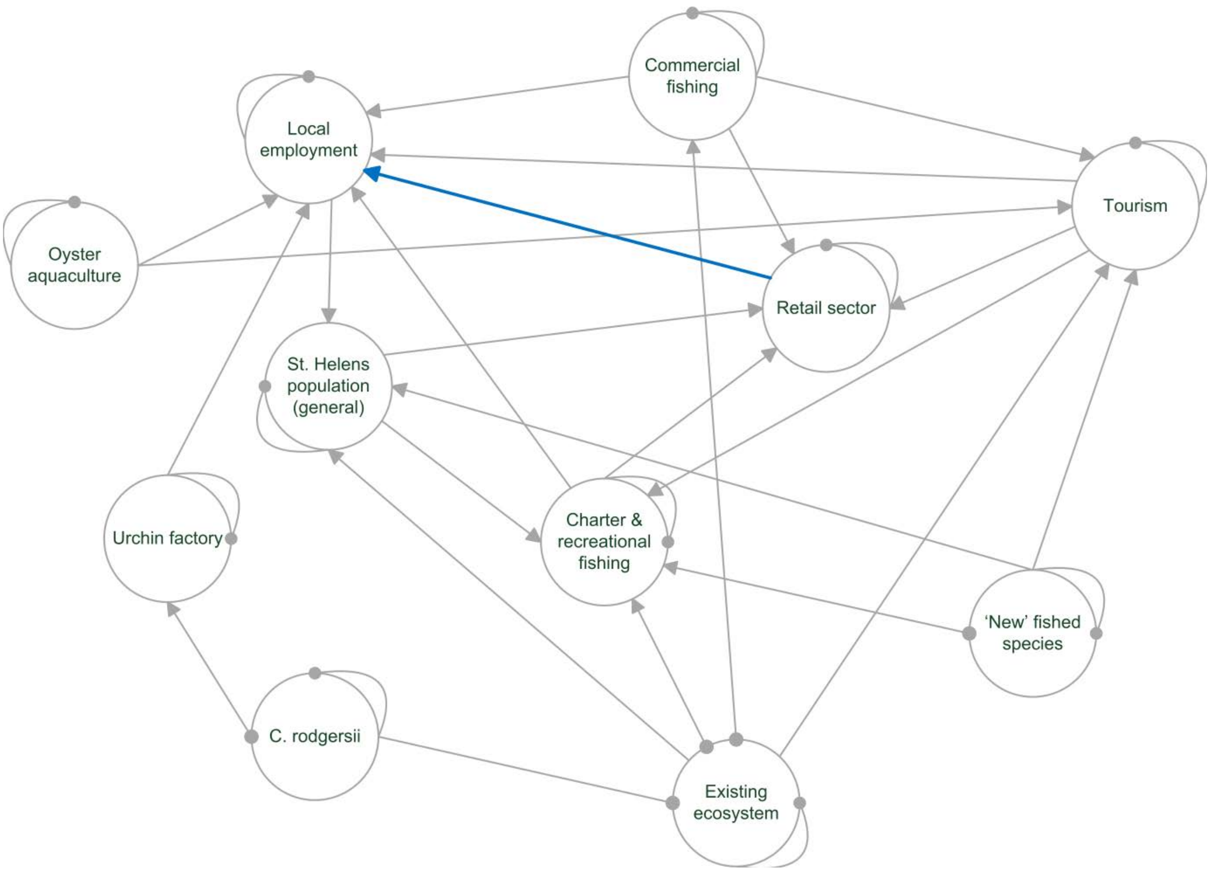
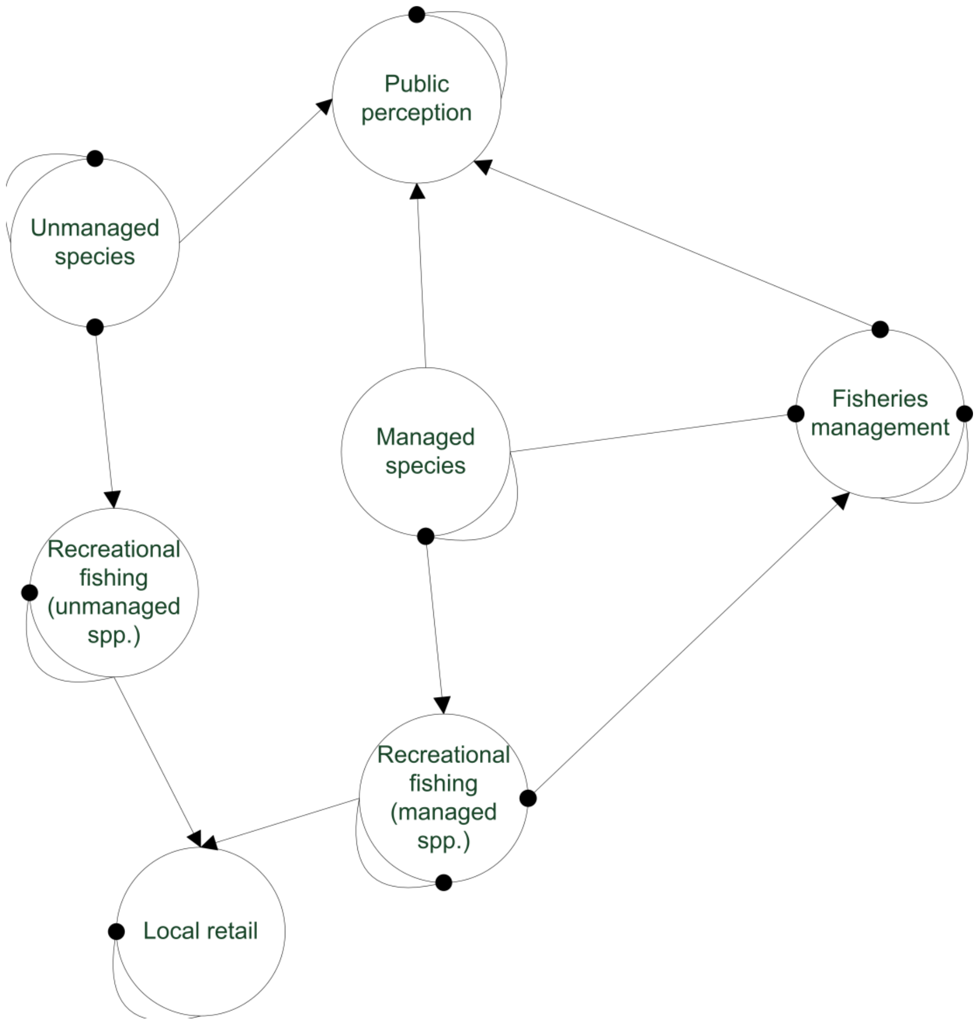
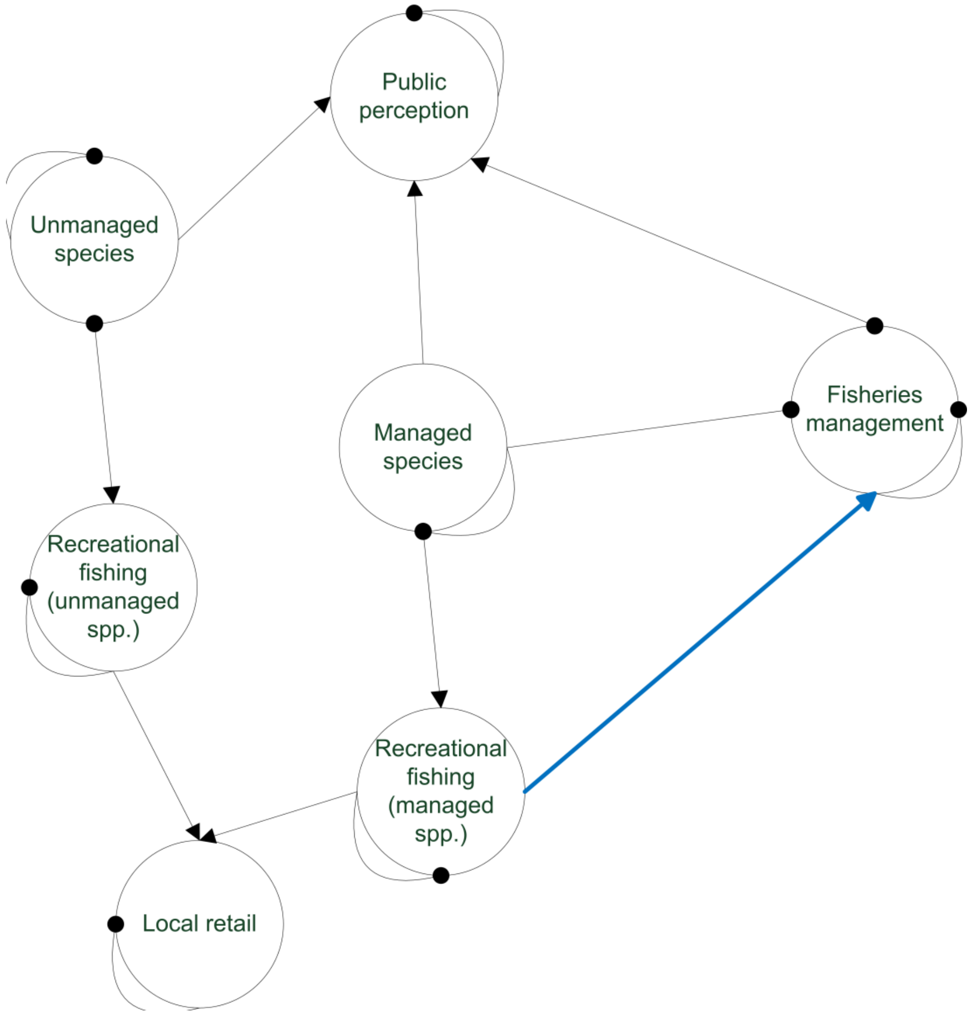

Commercial fishing
Local employment
Tourism
Oyster aquaculture
Retail sector
St. Helens population (general)
Charter & recreational fishing
Urchin factory
'New' fished species
C. rodgersii
Existing ecosystem

Figure 3.

a)


Public perception
Unmanaged species
Fisheries management
Managed species
Recreational fishing (unmanaged spp.)
Recreational fishing (managed spp.)
Local retail

b)


Public perception
Unmanaged species
Managed species
Fisheries management
Recreational fishing (unmanaged spp.)
Recreational fishing (managed spp.)
Local retail

c)

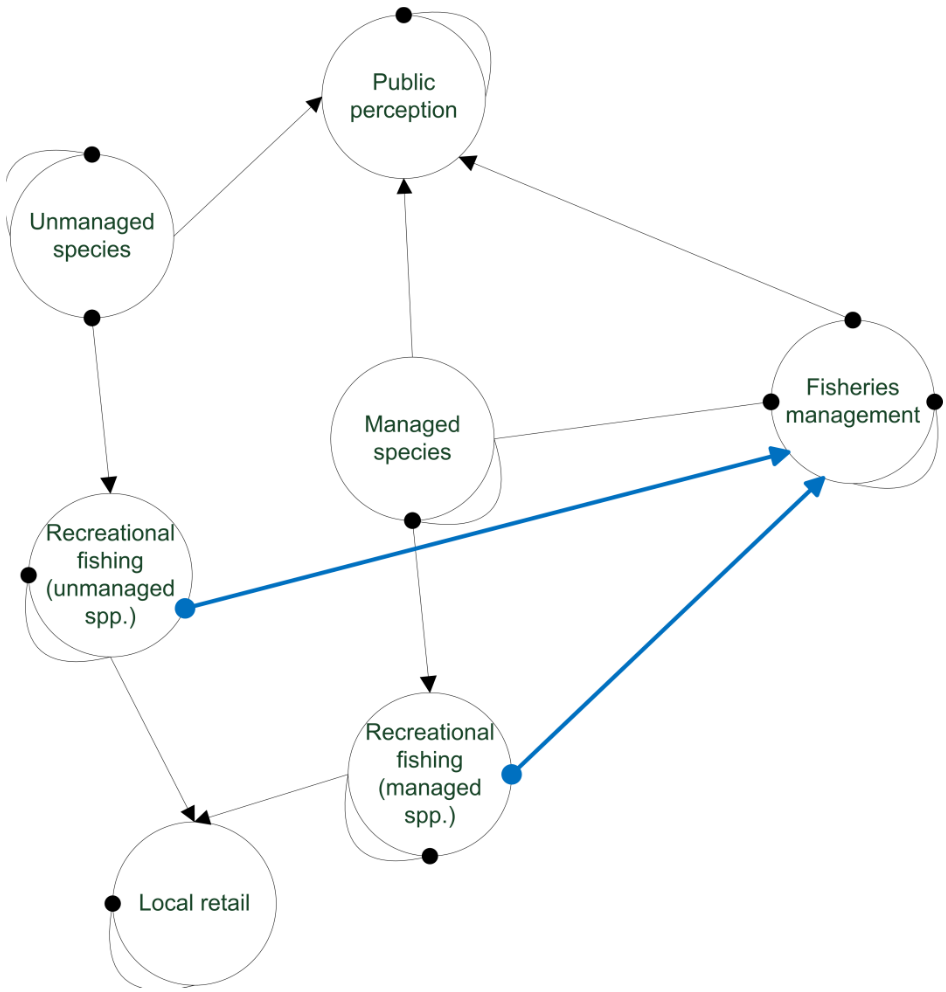

Public perception
Unmanaged species
Managed species
Fisheries management
Recreational fishing (unmanaged spp.)
Recreational fishing (managed spp.)
Local retail

Table 1: Modelled system names, interactions and press perturbations represented. CC = climate change-driven impacts.

System 1	Represents	Press perturbations (i.e., impacts)
• Coastal community model (Fig. 1a-b)	• Interactions between current marine sectors (e.g., aquaculture, commercial, recreational and charter fishing) and climate and non-climate (e.g., retail, population size) interactions in the case study community as perceived by stakeholders.	• Reduced oyster aquaculture production through extreme rainfall and flooding events (CC) • Increased employment in tourism • Reduced employment in commercial fishing • Increased abundance of 'new' fished species through warming currents and extension of the East Australian Current (CC) • Increased abundance of long-spined sea urchin (CC)
• Alternative coastal community model (Fig. 1c)	• Coastal community model with adaptation strategies in place.	• All above
System 2	**Represents**	**Press perturbations (i.e., impacts)**
• Recreational fisheries management model (Fig. 2a)	• Interactions between current recreational fisheries management, managed and unmanaged species, and community perceptions identified by stakeholders.	• Increased participation in recreational fishing for both managed and unmanaged species • Increased action by fisheries management
• First and Second alternative recreational fisheries management models (Fig. 2b-c)	• Recreational fisheries management model with different adaptation strategies in place.	• All above (for Recreational fisheries management model)

Table 2: Results for perturbations to fisheries management models and adaptation scenarios using a Bayesian Belief Network (BBN). The probability of an increase (↑), decrease (↓) or no change (-) was assessed for each response with the most likely response reported. Uncertainty levels are: high likelihood (Pr ≥ 0.8) green, moderate likelihood (0.6 ≤ Pr >0.8) yellow, low likelihood (Pr < 0.6) red.

Scenario	Perturbation/input	Responses	Probability ↓	–	↑	Likelihood
Fisheries management model	↑ Recreational fishing (for managed and unmanaged species)	Unmanaged species	0.8	0.1	0.1	green
		Managed species	0.6	0.1	0.3	yellow
		Public perception	0.5	0.2	0.3	red
		Fisheries Management	0.1	0.1	0.8	green
	↑ Fisheries management and ↓ Public perception	Recreational fishing (managed species)	0.6	0.1	0.3	yellow
		Recreational fishing (unmanaged species)	0.4	0.2	0.4	red
		Unmanaged species	0.4	0.2	0.4	red
		Managed species	0.3	0.1	0.6	yellow
First adaptation scenario	↑ Recreational fishing (for Managed and Unmanaged species)	Unmanaged species	0.8	0.1	0.1	green
		Managed species	0.8	0.1	0.1	green
		Public perception	0.4	0.2	0.4	red
		Fisheries Management	0.1	0.1	0.8	green
	↑ Fisheries Management and ↓ Public perception	Recreational fishing (managed species)	0.4	0.2	0.4	red
		Recreational fishing (unmanaged species)	0.4	0.2	0.4	red
		Unmanaged species	0.4	0.2	0.4	red
		Managed species	0.4	0.2	0.4	red
Second adaptation scenario	↑ Recreational fishing (for managed and unmanaged species)	Unmanaged species	0.6	0.1	0.3	yellow
		Managed species	0.6	0.1	0.3	yellow
		Public perception	0.5	0.1	0.4	red
		Fisheries Management	0.1	0.1	0.8	green
	↑ Fisheries Management and ↓ Public perception	Recreational fishing (managed species)	0.6	0.1	0.3	yellow
		Recreational fishing (unmanaged species)	0.6	0.1	0.3	yellow
		Unmanaged species	0.3	0.1	0.6	yellow
		Managed species	0.3	0.1	0.6	yellow