Modelling The Impacts Of Coastal Condition On Social And Health Aspects Of Human Wellbeing: Implications For Coastal Management

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EXTENDED ABSTRACT

Coastal areas across the world are experiencing rapid population growth. One of the main drivers of this growth is the aesthetic value of coastal regions, which is based at least partly on good environmental quality. However, in the absence of good management, this population growth has the potential to degrade environmental quality.

Changes in coastal condition are not only important in terms of environmental impacts, but are also likely to affect the quality of life of people living in the coastal zone. Information on potential social implications of resource management actions is increasingly required before management decisions are made. However, there are few tools available to assess the impacts of changes in environmental resource condition on people. The aim of this paper is to demonstrate a system dynamics model that can be used to assess the potential impacts of changes in the condition of coastal waterways on human quality of life.

The model is based on the Pumicestone catchment in south-east Queensland. It consists of three sub-models; environmental condition, human health, and social wellbeing. The environmental sub-model is very simple, and includes population growth and management actions driving decreases and increases in waterway condition respectively. Waterway condition is made up of water quality, vegetation and biota. The health model is driven by changes in the environmental sub-model. Enterococci concentrations (a water quality indicator) are positively related to the risk of coming down with gastrointestinal illness; bacterial and heavy metal contamination of oysters (biota indicator) leads to increased health risk and the potential closure of oyster aquaculture farms; and increased iron concentrations in the water promote summer blooms of the toxic cyanobacterium *Lyngbya majuscula* (vegetation indicator), which can cause dermatitis in swimmers. Perceived waterway condition is driven by overall waterway condition (comprising water quality, vegetation and biota) and affects the frequency and duration of recreational visits made to coastal waterways. Recreational visits result in greater amounts of exercise, and also contribute to overall mental and physical health. In terms of social impacts, recreational visits are related to attachment to place and social interaction, which in turn lead to wider social networks and the sense of belonging to the place, significant determinants of quality of life. Place attachment is also related to willingness to contribute to an area and rates of volunteerism, both of which have positive contributions to waterway management. A simple version of the model is given in Figure 1.

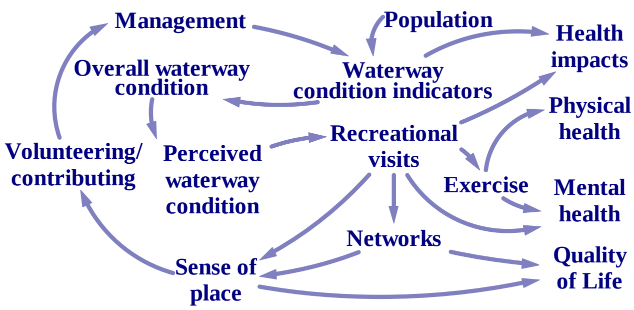

Figure 1. Structure of the integrated model.

Results from three scenarios show that social and health aspects of wellbeing deteriorate as a result of population growth in the absence of management, but improve if management efforts are sufficient to offset the negative impacts from population growth. However, the positive effects are diminished, and in some cases do not occur within the model timescale, when management efforts are delayed relative to population growth.

Dynamic models offer a potentially very useful tool for integrated impact assessment. The integrated quality of life assessment framework described here can be easily generalised to other places and situations, including other types of natural resource management, and offers a potentially valuable tool for natural resource managers.

1. INTRODUCTION

Australians have a strong affinity for the coast. Approximately 87% of Queenslanders live within 50 km of the coast (Australian Bureau of Statistics 2002), and coastal populations are experiencing rapid rates of growth (Department of Local Government and Planning 2002). This rapid increase in population places pressure on the quality of the local environment, including coastal waterways, thus threatening some of the features that attract people to the coast.

The rising population and potential for environmental degradation presents a challenge for coastal managers. But it also presents a potential threat to the wellbeing and quality of life of the people living in the coastal zone. Changes in the quality of the coastal environment have the potential to affect the health and quality of life of residents (Cox *et al.* 2003).

Despite this, the potential impacts of changes in the condition of the coast on human wellbeing are not usually considered by coastal managers, for the simple reason that they are difficult to measure. In contrast, the costs of environmental management strategies are easy to measure, and are often used to argue against expensive management or rehabilitation options. Decisions are therefore often based on incomplete information; the costs to humans and the benefits to the environment arising from management are clear, but the benefits to humans are not. The ability to identify pathways of impact and demonstrate the value of a management decision on human wellbeing would therefore greatly aid natural resource managers.

A number of studies have demonstrated the interaction between waterway condition and human health. For example, the effects of bacterial contamination on bather illness and the impact of toxic contamination of shellfish on consumers have been studied (Kay *et al.* 1994; US Environmental Protection Agency 2005). Limited information is also available on some social impacts relating to the presence and condition of natural systems (Cox *et al.* submitted; Cox *et al.* 2003; Maller *et al.* 2002). However, the more complex linkages, including feedbacks between the human and natural systems, have not been measured. In addition, the available information is usually used piecemeal, and not in an integrated assessment, thereby limiting the ability of managers to estimate or incorporate multiple effects into planning.

Dynamic models offer a relatively easy way to integrate the assessment of impacts on different aspects of wellbeing such as social and health aspects, and to examine impacts of different scenarios. Most of the previous attempts at modelling interactions between natural and human systems have focussed on economic impacts (Beukering and Cesar 2004; Grasso 1998; Moffatt and Hanley 2001). The few models that have included social aspects of the human system have done so from the point of view of the impacts of social structures on the natural ecosystem, rather than the other way around (Meadows and Robinson 2002). Social and health impact assessments using modelling are extremely rare, although social impact assessment of natural resource management is becoming more common and is required in projects such as the National Action Plan for Salinity and Water Quality.

The aim of this paper is to report on a systems dynamic model developed to assess the potential impacts on quality of life of changes in the condition of coastal waterways. Social and health aspects of quality of life are incorporated in this version and economic impacts will be added in the next stage.

2. MODEL DESCRIPTION

The model was developed based on the Pumicestone catchment in south-east Queensland. A simplified version of the model structure is given in Figure 2 (time lags, coefficients and some auxiliary parameters have been removed for clarity). Following system dynamics conventions, stocks are shown in boxes, auxiliary variables are shown without a box and arrows between variables represent conserved flows of information or material. The model runs for 20 years with a monthly time step. The model consists of three sub-models; environmental condition, human health, and social wellbeing. The three components are described first below, then the links and feedbacks between the sections are described.

The environmental condition component is very simple and represents population growth (driving deterioration in environmental condition), and management (driving improvement). The environmental component is deliberately simplistic, as the aim of this model is to examine the impacts of environmental change on wellbeing, and not the detail or the processes of the environmental change. Ideally, more detailed site-specific environmental models would be used to determine the likely change in environmental indicators of interest under different management scenarios. That information could then form an input to this model to determine the implications for wellbeing. The environmental condition component therefore consists of overall waterway condition, which is made up of vegetation, water quality and biota, measured on a score from 1 (worst) to 5 (best). Each of these has one or more specific indicators, which are related to particular health impacts (*Lyngbya majuscula* blooms, enterococci concentrations and zinc and arsenic concentrations in shellfish), and a general indicator representing other aspects of waterway condition. Changes in the specific indicators are driven by a proxy variable 'diffuse runoff quality', which represents the effects of nutrients, sediments and bacteria entering coastal waterways through urban and rural stormwater. The general indicators are driven by more direct population effects. Social impacts are driven by the overall waterway condition score and health impacts (with the exception of exercise and self-assessed physical and mental health) by the specific indicators. The purpose of the environmental sector is to represent overall changes in environmental condition that may impact wellbeing parameters.

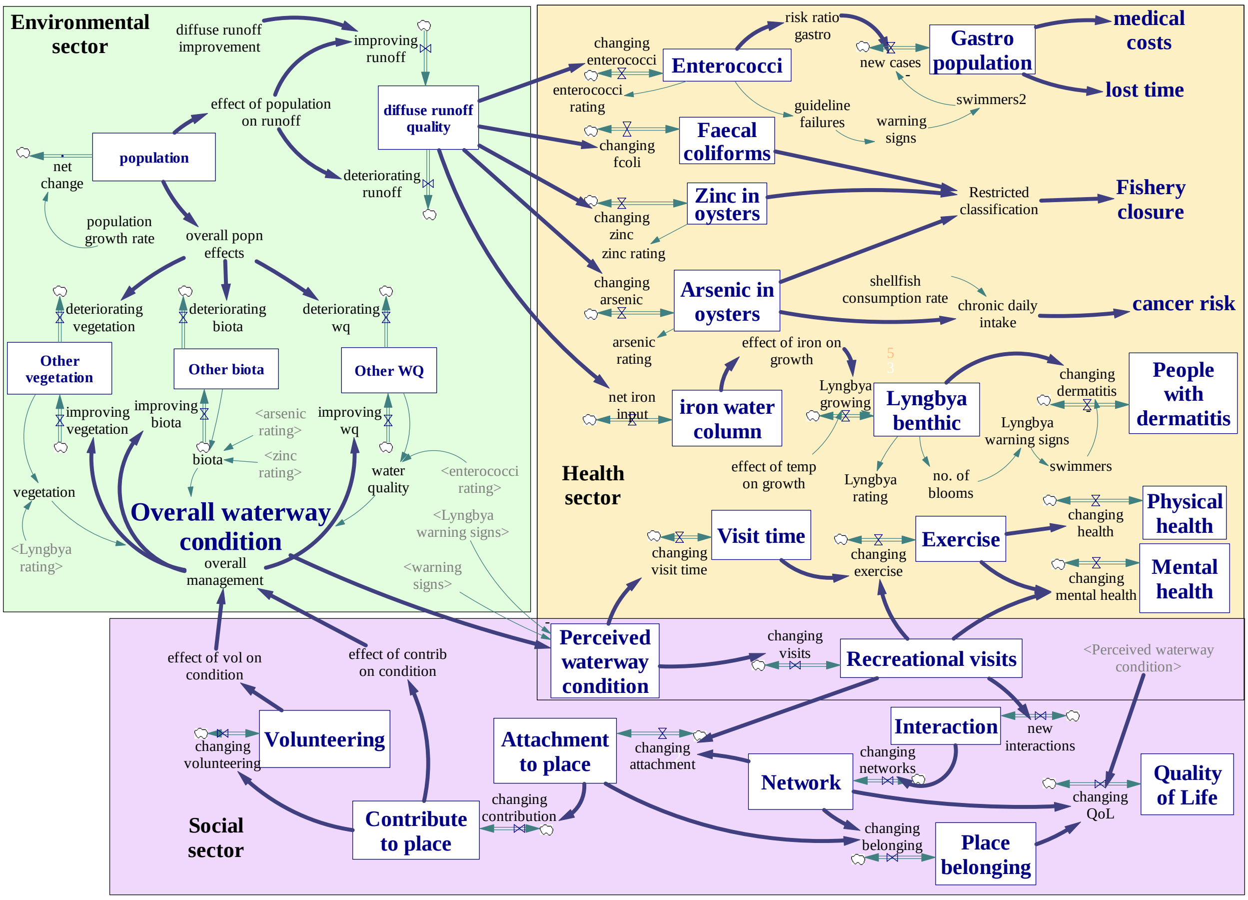

Figure 2. Simplified stock-flow diagram of the integrated model.

The human health sub-model has four sections, representing three different health risks and one health benefit arising from interaction with coastal waterways. The first section represents the risk of bathers contracting gastrointestinal illness as a result of bacterial contamination of recreational waters. This section uses bacterial information sourced from the government monitoring program (Webb 2001) and risk ratios described in Kay *et al.* (1994). The average enterococci concentration is affected by the quality of diffuse runoff (which is determined by management and population growth). When enterococci concentrations in water exceed guidelines a certain number of times, signs warning against swimming are put up. The second section examines risks to consumers of contaminated shellfish. Data on contaminant concentrations in cultured oysters in Pumicestone Passage were derived from State Government monitoring programs (Beattie and Dexter 2002). When concentrations of either faecal coliforms in water or metals in shellfish exceed guidelines, oyster aquaculture is shut down. Health risks arising from the consumption of contaminated oysters were calculated based on information in the US EPA Integrated Risk Information System database (US Environmental Protection Agency 2005) and shellfish consumption rates given in the National Nutrition Survey (McLennan and Podger 1999). Arsenic and zinc concentrations were used in the model as these contaminants were present at concentrations closest to the guidelines (Cox *et al.*

in prep). The third health section describes the potential for skin and respiratory irritation arising from contact with toxic *Lyngbya majuscula*, a cyanobacterium that blooms during summer in Deception Bay. The *Lyngbya* bloom model is an extremely simplified version of the model given in Arquitt and Johnstone (2004). *Lyngbya* blooms are controlled in this model by iron pulses, which enter the system with rainfall events, and by water temperature (not included in the Arquitt model). The relationship between blooms and dermatitis frequency was derived from survey data in Osborne (2004). After two bloom events, signs warning of the dangers of swimming during blooms are erected. The fourth section describes the health benefits in terms of exercise and self-assessed physical and mental health arising from recreation in coastal environments. Frequency and duration of recreational visits are affected by the perceived quality of the coast, and recreational visits positively relate to exercise, physical and mental health. Data for these relationships were sourced from Cox *et al.* (submitted). The health sector of the model therefore represents specific aspects of human health that may be impacted by coastal waterway condition.

The third component of the model describes the impacts of changes in environmental condition on social aspects of wellbeing. Perceived waterway condition is related to overall condition. The number of recreational visits to waterways increases with the perceived quality of the waterways. Recreational visits in turn increase the frequency of social interaction with other locals, and the degree of attachment to place. Social interaction leads to wider social networks (friends and family), which are a significant determinant of quality of life. Wider social networks also increase place attachment, which is related to stronger commitment to place as well as a stronger sense of place belonging. Place belonging is also related to quality of life. Increased commitment to place leads to more volunteer work. Perceived waterway condition is the third determinant of quality of life. Data for the social section were derived from a regional survey (Cox *et al.* submitted). Changes in social variables are driven by the difference between current and initial level of cause variables, multiplied by a coefficient derived from regression analysis of the survey data. Most of the social variables are measured on a scale from 1 to 5, although networks is measured as number of friends and recreation visits as visits per month.

There are several links and feedbacks between the model subsections. Both the social and health impacts are driven by changes in environmental condition; gastroenteritis frequency, shellfish toxins and *Lyngbya* blooms by specific indicators of condition, and recreational frequency and social impacts by perceived waterway condition. The erection of signs warning against swimming as a result of bacterial contamination or algal blooms decreases perceived condition and the percentage of recreational visitors swimming (and therefore vulnerable to health impacts). Perceived waterway condition is also 'sticky', in that it takes longer to revise a perception upwards than it does to revise it downwards following a change in actual condition. Perceptions also change more quickly as the number of visits increases. Place commitment and volunteerism both have an effect on waterway management; this can be thought of as residents placing pressure on managers and politicians to improve environmental condition, and undertaking direct improvements as part of local community groups. Recreational visits, which are affected by perceived condition, affect the number of people undertaking coastal recreation, and therefore the likelihood of contracting gastrointestinal illness or irritations from *Lyngbya* blooms.

Three scenarios were developed and tested, in addition to the reference mode. The reference mode (no change in population or management) was set up to generate no change in wellbeing variables as a baseline. The first scenario (deterioration) represents a gradual deterioration in coastal condition as a result of constant population growth at 2.6% per year (the current rate), with no management. The second scenario (improvement) represents constant management that results in improvements in coastal condition over time (that is, management more than compensates for population growth). The third scenario (delay) represents delayed management action, such that coastal condition first deteriorates, then the deterioration provokes management action. Each of these scenarios is likely; population growth in the region is real, and will impact on waterway condition, but managers are constantly implementing programs aimed at improving waterway condition. The extent to which these programs are successful remains to be seen. Overall waterway condition under each of the three scenarios is shown in Figure 3.

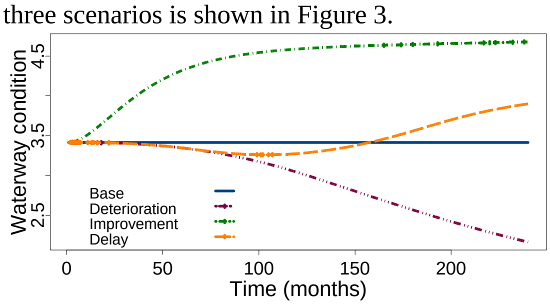

Figure 3. Waterway condition under the base run and three scenarios.

3. MODEL RESULTS

The final values of key parameters and the percentage change from the base run are given in Table 1 for each of the model runs. Under the base run, visit time and networks changed slightly as a result of a decrease in perceived waterway condition, due to the erection of signs warning of dangers of swimming due to bacterial contamination and *Lyngbya* blooms (at months 74 and 27 respectively). All other parameters remained constant. Under the deterioration run (constant population growth with no management), all key variables became worse, although the changes were small for variables with small coefficients and long time delays. The largest changes were for the number of people contracting gastroenteritis (47%), the length of time spent on each recreational visit (-48%) and the number of people experiencing dermatitis symptoms (29%). The changes in people experiencing gastroenteritis (Figure 4) and dermatitis were particularly large due to the combined effects of an increased population leading to an increased number of swimmers, and the environmental degradation leading to higher enterococci concentrations.

Under the improvement scenario, all key variables except people with dermatitis improved. The largest changes were for the length of time spent on recreational visits (136%) and the number of recreational visits (66%). The reason for the increase in people suffering from dermatitis was related to the effect of management actions on *Lyngbya* blooms. Under the assumptions made in this model, only small concentrations of iron are required in the water column to initiate *Lyngbya* growth. The management actions included in the scenario did not reduce iron sufficiently to prevent blooms from occurring. The number of blooms therefore did not change in the improvement compared with the base run scenario. However, the increased population and improvements in other aspects of waterway condition led to an increased number of people visiting the waterways and swimming, resulting in a higher number of dermatitis cases. The relative importance of temperature and iron in controlling *Lyngbya* blooms is not well understood; however, it is likely that only a very large reduction in iron inputs would lead to a decrease in the number of blooms.

Table 1. Values and percent change for key model parameters under base run and three scenarios.

Variables (units)	Initial	Final value (240 months)				Percent change from base run		
		Base	Deter.	Improved	Delayed	Deter.	Improved	Delayed
Population (people)	126942	126942	213054	213054	213054	67.8	67.8	67.8
Overall waterway condition	3.41	3.41	2.16	4.68	3.90	-36.7	37.0	14.2
Perceived waterway condition	3.41	3.39	2.16	4.66	3.86	-36.3	37.1	13.6
Vegetation	3.00	3.00	1.69	4.20	3.52	-43.7	39.9	17.3
Biota	3.59	3.59	2.26	4.90	4.11	-37.0	36.6	14.8
Water quality	3.66	3.66	2.33	4.95	4.19	-36.4	35.4	14.5
Enterococci (CFU/100mL)	330	330	354	163	315	7.2	-50.5	-4.6
Gastro population (people)	0	561	825	489	880	47.1	-12.7	56.9
Arsenic in oysters (mg/kg)	0.264	0.264	0.288	0.097	0.249	9.0	-63.1	-5.7
Fishery closure	no	no	yes	no	no			
Cancer risk (excess lifetime risk)	2.34×10^{-4}	2.34×10^{-4}	2.55×10^{-4}	8.6×10^{-5}	2.21×10^{-4}	9.0	-63.1	-5.7
Lyngbya blooms (no.)	0	20	20	20	20	0	0	0
People with dermatitis (people)	0	52	67	128	84	28.5	145.7	61.8
Recreational visits (visits/month)	2.50	2.47	1.89	4.10	2.53	-23.5	66.0	2.3
Visit time (hours/visit)	4.00	3.90	2.02	9.19	4.08	-48.2	135.7	4.7
Exercise (hours/month)	29.00	29.01	28.82	30.10	29.04	-0.6	3.8	0.1
Physical health (scale)	4.30	4.30	4.29	4.34	4.30	-0.1	0.9	0.0
Mental health (scale)	3.60	3.59	3.27	4.50	3.54	-8.9	25.5	-1.1
Place belonging (scale)	4.00	4.00	3.95	4.19	3.97	-1.1	4.8	-0.6
Networks (friends)	10.40	10.31	9.01	12.73	9.81	-12.6	23.5	-4.8
Place contribution (scale)	4.00	4.00	3.96	4.22	3.97	-1.0	5.5	-0.6
Quality of Life (scale)	4.50	4.49	4.42	4.71	4.47	-1.7	4.7	-0.6

A variety of responses was observed under the delayed management scenario. Cancer risk, exercise, recreational visits and length of visits improved; gastroenteritis cases, dermatitis cases, mental health, quality of life, place belonging and networks deteriorated, and no change was seen in physical health. The number of people with gastroenteritis and dermatitis increased for the reasons explained above. The deterioration in quality of life, mental health, place belonging and networks was due to the delay in perceiving improvements in waterway condition, combined with the small coefficients of change for these variables.

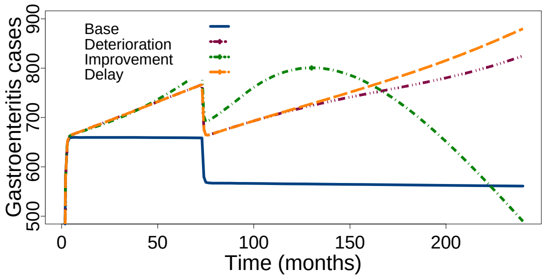

Figure 4. Estimated number of people contracting gastroenteritis as a result of swimming. The initial drop in cases is due to the reduction in swimmer numbers as a result of warning signs being erected.

4. MODEL USE AND MANAGEMENT IMPLICATIONS

Dynamic models such as the one presented here are potentially very useful tools for natural resource managers. Currently, there is no way for managers to assess the potential benefits to humans that would arise as a result of ecosystem management actions. Assessment of the costs of such actions, however, is straightforward, and high costs are often used as an argument against proceeding with management actions. Measurement of benefits is currently restricted to economic impacts on natural resource-associated industries, and does not include social, health, or general wellbeing impacts. For example, Rolfe *et al.* (2005) assessed economic and social impacts of protecting environmental values for waterways, but only the economic impacts were quantified, although social and health benefits were mentioned as being potentially important. The main advantage of this type of method is the inclusion of qualitative variables such as perceptions, and explicit modelling of feedback loops and time lags, which can lead to surprising and interesting results that may not be captured in simple spreadsheet type assessments. The integration of environmental and wellbeing variables in a single model provides important information for managers that can be used to inform and improve management decisions.

The model as described here does have some limitations. Although the relationships are based on the best available data, there are many parameters for which the values are uncertain. In particular, the relative importance of temperature and iron in controlling *Lyngbya* blooms is not yet understood; the relationships between waterway condition and social aspects of wellbeing need to be validated in more locations and there is practically no information available on the rate of change of social wellbeing variables. In addition, while data are available for most of the model parameters, time series data is more difficult to obtain. This means that calibration of the model against real long-term data is not possible at this stage. The increasing focus on social aspects of environmental management will hopefully lead to the collection of data that could be used for calibration of future models of this type. The next stage of model assessment will include sensitivity analysis of all uncertain variables, to ensure that conclusions drawn from the model are robust. One of the important outcomes from this model will be the identification of parameters that are important in analysing human-environment interactions, but for which there is currently little available information.

The modelling framework used here could easily be generalised to other areas or ecosystem types. Although some specific aspects (for example, *Lyngbya* blooms or oyster aquaculture) may not be applicable in all areas, the general concept of using already established relationships between ecosystem and health and social wellbeing in this type of integrated assessment is easily transferable. The information used in the model is relatively simple to obtain. Much of the data used in the health sub-model is readily available and can be accessed and assessed as part of a desktop study. Some of the social data is not currently readily available, but could be collected relatively easily by administering a survey. The Australian Bureau of Statistics is also starting to collect data on social capital and wellbeing, which could be used in this type of assessment. Information on other social variables such as the number of visits to natural areas may be available in some areas.

5. CONCLUSIONS

The results of model scenarios show that management actions designed to improve the condition of coastal waterways will also have beneficial effects on social and health aspects of human wellbeing. Natural resource managers are in urgent need of methods to assess impacts of changes in natural area condition as a result of management actions on people. Dynamic models such as this one offer a useful tool for integrating a variety of information, and can be easily used to examine the impacts of different scenarios or of changing model assumptions. Further research on the links between ecosystem condition and human wellbeing would add greatly to integrated impact assessments. Application of this type of integrated modelling has the potential to dramatically improve understanding of linked human-ecological systems and therefore contribute to continued improvement of management decisions.

6. ACKNOWLEDGMENTS

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