Appendix 1. Example of simple marine social-ecological model that incorporates a sense of place.

This appendix provides a simplified example of the implementation of the concept of 'sense of place' using a hypothetical marine-based socio-ecological system (SES) with feedback in the system.

For simplicity, we describe the environment by three temporally-varying environmental variables describing land, water and fish resource quality. Together, these variables are used to define a sense of place *index* (SoPI) for two resource user groups. The model incorporates feedback between the environmental variables and the resource users via the SoPI, and is able to predict long-term (decadal) changes in i) the number of residents of a small coastal community, ii) tourist visitation numbers, iii) environmental quality, and iv) the SoPI for both resource user groups. We use our model to describe various changes to urbanization and the natural environment, and show how ignoring sense of place can change our long-term predictions regarding the state of the natural environment and the socio-demography of the resident human population. Thus, our model suggests that SoP should be accounted for when predicting the long-term impact of potential development scenarios.

Box 1: An example of a small coastal community in Tasmania, Australia that illustrates the model elements.

Orford is a scenically situated town of around 600 residents (Census 2011) located approximately 80 kilometres northeast of the urban centre of Hobart, Tasmania, Australia. Orford has extensive views towards Maria Island, as well as the Prosser River and Prosser Bay (Figure A1.B1). It has a number of picturesque east-facing beaches and is surrounded to the west and south by hilly and vegetated forests.

Orford has a permanent population of an older demographic (mainly retirees), but also caters for the younger working age groups (as evidenced by the presence of a local primary school). The predominantly residential settlement relies on neighbouring centres to provide higher order health and educational services. Aside from the permanent residents, there is a large influx of 'shack owners' in the summer months. Participation in recreational fishing is high on the east coast of Tasmania (27%). Recreational fishing is a very important pastime for both the 'shack owners' and the permanent residents of Orford. Orford is popular with holidaymakers and tourists in the holiday season, some of whom will participate in recreational charter fishing.

The coastal location and the recreational activity potential are an integral part of living in this region. The coastal aesthetics of the region are further enhanced by Maria Island, which lies off the coast of Orford and is a UNESCO World Heritage Site (Environmental Resources Management 2007) (Figure A1.B1). Maria Island has important natural and indigenous values and significance in terms of the European presence and use of the island (Tasmanian Parks and Wildlife Service 2013). A marine reserve (Maria Island Marine Reserve) was established in 1991 along a 7 km length of coastline that includes a no-take zone and fishing zone. There is currently no permanent population on Maria Island, but around 18,000 tourists visited the Island in 2014 using a tourist ferry leaving from the Orford area (Tasmanian Parks and Wildlife Service 2013). Maria Island receives mostly day or multiple day visitors who undertake recreational activities, including swimming and diving. Recreational vessel traffic to the south of Maria Island can access secluded bays with safe mooring sites for yachts during the summer months. Diving activities also take place around the island mostly by self-organised divers (dive club members) who are likely to visit using their own boat.

Figure A1.B1: Map of the study area and image from the passenger ferry and Maria Island.

Employment in Orford is mainly in retail, services and hospitality, but residents are also employed in construction and industry (aquaculture and fish processing). There are a few commercial fishers resident in the area (targeting rock lobster, abalone and several other species). Immigration to the area is influenced by employment availability. Employment opportunities are created by existing industries and businesses, and new local developments. Several developments have been planned, or have at some stage proposed, for the coastal community (Parliament of Tasmania 2015). Currently a Spring Bay Mill Project, a golf course, and a Marina development have been proposed. In addition, a new aquaculture development has just been established. Some of these developments will impact the marine environment via changes to the terrestrial environment (i.e. the nutrient input via the golf course). The golf course development will also likely have a positive impact on tourism. Other initiatives, such as the fish farm will likely impact water quality. The latter will affect marine resource users' sense of place illustrated by the fact that there has been much public protests in relation to establishment of the aquaculture farm (see for instance http://www.abc.net.au/news/2018-04-12/tassal-okehampton-bay-expansion-victory-over-opponents/9644784). This may lead some recreational fishers to leave the area if access becomes more difficult or fish abundance declines. The visual impact of the fish farms may also lead to those who don't extract marine resources to move away. Thus, if these two-way feedbacks between the natural and human systems are not accounted for, the consequences of alternative development scenarios will not be accurately predicted.

Conceptual framework

The state of the SES is defined by a set of environmental variables and groups of resource users. Our model predicts how the state of the SES changes deterministically over time, both in terms in how the users perceive and exploit the natural environment. Here, we consider two resident groups (X): observers (O) and users (U); however, the model can be readily extended to more groups. The number of resource users in both of these groups is driven by births and deaths (λ), immigration (I_x), and emigration (M_x) (see Figure A1.1 and Table A1.1 for definition of symbols and variables, and Table A1.2 for equations and model specification). The resource user's SoPI (node labelled sense of place index (S_x) Figure A1.1) responds reactively to changes in environmental variables (which in turn change as a consequence of investment in local developments – see also Box 1 for descriptive example).

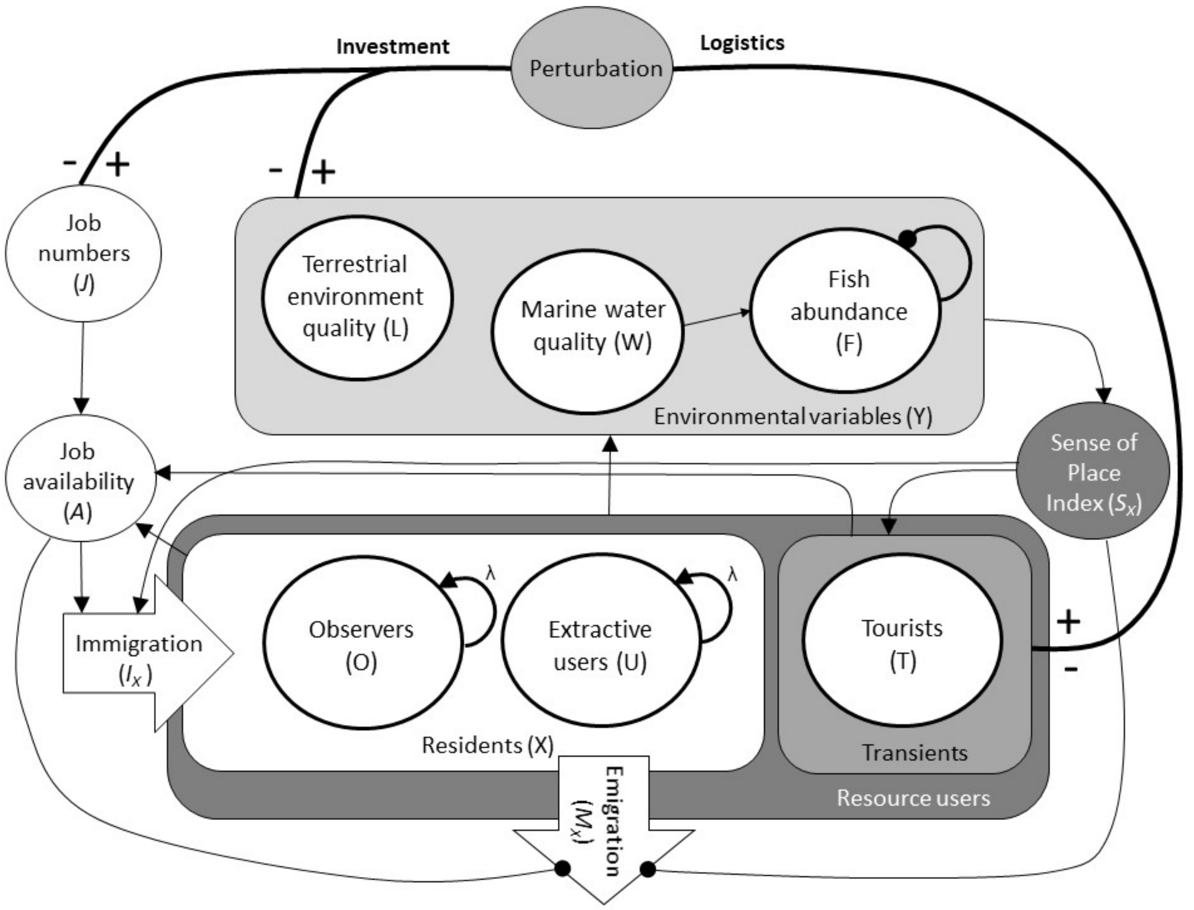

Figure A1.1: Conceptual model of a simplified socio-ecological system. Positive relationships are indicated by line ending with an arrow, and negative influences are indicated by line ending with a dot. The relationship between job numbers and job availability, which positively influence immigration and negatively influence emigration of residents is indicated with solid lines. The relationship between the quality of the environmental variables, the sense of place index (SoPI), is also indicated. A reactive response to more pristine or better quality environmental variables may lead to higher levels of the SoPI, which positively influences immigration of residents and transient numbers and negatively influences emigration. The interactions between the environmental variables are shown by the arrows in the environmental variables box. The relationship between job availability and residents are also indicated.

The environmental variables ($Y = L$, W, F) may be any aspect of the environment that influences affinity, including natural variables, but also resources that are managed and utilised. The environmental variables may be influenced by resource user numbers and these variables may also influence each other, as is typical of ecosystem models (i.e. W positively affects F). Fish abundance is self-limiting, indicated by the self-effect (see figure A1.1). Variation among individuals in how they respond to the environmental variables is captured by assuming that they can be divided into sub-groups (X = O or U), schematically represented by the different circles in Figure A1.1. Note all individuals within a particular *sub-group* can be assumed to respond to the environmental variables in the same way.

The dynamics of the environmental parameters and the resident population are influenced by feedback on each other via the SoPI (S_x), which is a summary of the environmental variables. Each resident group is associated with a SoPI. The feedback occurs because SoPI determines immigration (positive relationship – where a greater SoPI will lead to more immigration) and emigration rates (negative relationship) of each user group.

In this example, resource users are categorised as either residents or tourists (T). Residents and tourists differ with respect to the way they enter and leave the system. Resident movements are explicitly modelled via immigration and emigration rates, which are influenced by the SoPI. For instance, a healthy and clean local marine environment and the availability of facilities that enable access to the marine environment, will encourage immigration and reduce emigration from an area. The number of tourists in the system is determined directly from the SoPI. For example, clean and attractive locations attract more visitors. Thus, tourist numbers respond faster than resident numbers with respect to environmental change.

Resident numbers can increase through births and are also linked to local employment (J), which is reflected in their movement rates being dependent on local job availability (A). The presence of transients may also generate local jobs for residents, which positively influences resident numbers.

Table A1.1: Variables used to model a socio-ecological system of a small coastal community.

Variable	Definition
U	extractive users (who extract resources from the marine environment)
O	observers (who do not extract resources from the marine environment)
X	number in the resident-group ($X = O$ or U)
L	terrestrial environment quality
W	marine water quality
F	fish abundance
Y	environmental condition ($Y = L$, W or F)
d	number of dependents supported by each full-time worker
T	transient tourist group
β	parameter describing tourist responses to the environment
λ	population growth rate (births-deaths)
I	annual immigration
M	annual emigration
T_0	upper limit to the additional number of jobs created by tourism (and thus also indicating the upper limit to the number of tourists) if the environment were 'pristine'
J	jobs in the community (in the absence of tourists)
S	sense of place index score (SoPI)
w and l	positive constants
A	actual number of jobs available to residents
a	relative number of jobs available to residents

α_X	parameters that characterise resident group X
η and $\phi = 1-\eta_S(1-S_X)$ η_S relates immigration to the SoPI (note: $0 \leq \eta_S \leq 1$).	a non-negative constant representing the minimum number of group X that immigrate to the community each year when the SoPI for the group is at its maximum of one
γ and $\phi = 1-\gamma_S S_X$ γ_S relates emigration to the SoPI (note: $0 \leq \gamma_S \leq 1$);	a non-negative constant representing the maximum fraction of group X that emigrate from the community each year when the SoPI for the group is at its minimum value of zero. Emigration increases as the SoPI, S_X, decreases.

Table A1.2: Model specification for the socio-ecological system of a small coastal community.

Model equation	
$N_{U,t}$	Number of extractive users (U) at time t
$N_{O,t}$	Number of observers (O) at time t
$N_t = N_{U,t} + N_{O,t}$.	Total resident population size at year t
Y (= L, W, F)	Environmental variables
$E_{Y,t}$	Value of the environmental variable in year t
$L_t = \exp(-lN_t)$,	Land quality expressed as a negative relation with resident population size and tourist numbers
$W_t = \exp(-wN_t)$	Water quality expressed as a negative relation with resident population size and tourist numbers
$E_{F,t+1} = \left[1 + r\left(1 - \frac{E_{F,t}}{E_{W,t}}\right)\right] E_{F,t}\exp\left[-q\left(N_{U,t} + cN_{T,t}\right)\right]$	Environmental value equation where r is the net fish growth rate, q is fish catchability and c is the fishing pressure derived from tourists relative to resource-users (which we assume here is constant for reasons of simplicity). Note that water quality sets the carrying capacity of the fish stock
$N_{T,t} = T_0 \prod_{Y=L,W,F} f\left(Y_t, \beta_{Y,0}, \beta_{Y,1}\right)$,	Tourist number equation for year t as positively influenced by L, W, and F at the start of the modelled year
$f(X, \beta_0, \beta_1) = \frac{\exp(-\beta_1[X - \beta_0])}{1 + \exp(-\beta_1[X - \beta_0])}$.	Logistic relationship between additional tourism-related job creation and additional tourist visits
$A_t = J_t + N_{T,t} - N_t$ and $a_t = (J_t + N_{T,t} - N_t)/(J_t + N_{T,t})$,	Actual (A_t) and relative (a_t) number of jobs available to residents in year t respectively
$N_{X,t+1} = (1 + \lambda)\left[1 - M_X\left(S_{X,t}, a_t\right)\right]N_{X,t} + I_X\left(S_{X,t}, A_t\right)$	Equation describing changes in population numbers of resident-group X
$S_{X,t} = \prod_{X \in L,W,F} f\left(X_t, \alpha_{X,0}, \alpha_{X,1}\right)$,	Sense of place score (SoPI) for resident group X in year t. Resident movement rates depend on job availability and $S_{X,t}$, and it may depend on any of the environmental variables which are expected to have a positive effect on the SoPI for all resource-user groups.
$I_X(S_X, A) = \max\left\{\phi\eta_1, \phi\left(\eta_1[1 - \phi] + \frac{A}{2}\right)\right\}$,	Immigration of resident group X. If the SoPI is high, then movement into the community when jobs are available is likely to be faster, thus shifting the immigration curve upwards. In contrast, a high SoPI might lower emigration out of the community. Immigration decreases as the SoPI, S_X, decreases. The $A/2$ term indicates that both resident groups are equally represented in the wider community. For simplicity we have assumed that the η-parameters are the same for both resident groups, but this can be relaxed.
$M_X(S_X, a) = \max\{\phi\gamma_1, \phi(\gamma_1[1 - \phi] - a)\}$,	Emigration equation

Marine socio-ecological model specification

We illustrate the approach in the context of a small coastal fishing community with two types of residents and a transient tourist group. For convenience when describing immigration and emigration (see below) we set the units of population size for both residents and transients in terms of full-time resident jobs. Thus, $N_{U,t} = 100$ means the community contains 100 full-time extractive users in year *t*. Also, for convenience we set the baseline values of the environmental variables (e.g., unfished fish stocks, natural water conditions) to be unity. The extractive users (*U*) are fishers and extract fish from the marine environment. The baseline model parameter values are shown in Table A1.3. In the absence of empirical data to inform parameter choices, illustrative values (with justification) were selected, and considered to qualitatively at least capture realistic system dynamics.

Table A1.3: Model parameters, baseline values, and rationale for the assumptions.

Model parameters	Symbol	Baseline value	Rationale
intrinsic population growth rate	λ	-0.02	The growth rate in many small regional coastal communities in Australia is negative due to their demographic characteristics (with a disproportionate number of people in the older age groups)
effect of population size on terrestrial quality	l	0.0003	Higher population numbers will exert greater pressure on the quality of the terrestrial environment. For instance, through littering and vegetation clearance. This effect is assumed to be greater in the terrestrial context than for the marine environment.
effect of population size on water quality	w	0.0006	Greater population size will also exert greater pressure on water quality. For instance, through nutrient runoff, erosion, or pollution.
net annual fish growth rate	r	0.3	The intrinsic rate of population increase, based roughly on an average value for many fished marine species.
fish catchability per unit population size	q	0.0005	Catchability coefficient relates biomass abundance to the capture or fishing mortality. It will be a value between 0-1 (0 being no catch and 1 being the entire stock), and typically will be very small.
tourist effect on fishing rates relative to resident	cT	0.25	Tourists mostly go fishing using charter operators, whereas recreational fishers are locals who mostly will use their own boat (and do many day trips over a given year). Tourists are therefore expected to have lower fishing rates than local residents
Job number (J) conversion parameter	**Symbol**	**Baseline value**	**Rationale**
number of tourists associated with every tourist job	mult.T	25	It is estimated that 1 full time equivalent (FTE) (spread over many different services and businesses) will be added from an additional 25 tourists visiting the community per year. For example say a small town receives around 16,000 tourists per annum. If an additional 4,000 were to visit it would create 160 jobs (not all in tourism, but also e.g. in retail services and construction).

number of new residents associated with every new job	mult.X	3	On average a new job (FTE) will bring an employee and their family to the community. The average family size is 2.6 but a rounded average of 3 is assumed.
Simulation parameters	Symbol	Baseline value	Rationale
initial density of fish	$\underline{F}$.init	0.50	Sets fishery at 'reasonable level' of exploitation which is a commonly-used default corresponding to the level that yields the maximum sustainable yield
initial number of jobs supported by the community	J.init	800	The assumption is that there are 800 resident jobs plus 116 tourism jobs (at T0), adding up to 916 which is slightly higher than the number of residents (885) meaning the model will start off with active job-driven immigration
initial number of observers	$\underline{O}$.init	450	There are slightly more residents who are observers (and do not actively fish) than resource users
initial number of extractive users	U.init	435	There are slightly fewer residents who actively extract fish resources from the marine environment (through fishing thus affecting fish abundance) than residents who are observers
tourist carrying capacity	T_0	200	It is assumed that the number of tourists the community can support is around a quarter of the number of people who live in the community (in this case 23%)

Perturbations to the marine SES model

Without any development or perturbation, the system will eventually settle to an equilibrium state. However, the model can be used to explore how the community responds to perturbations. Two types of perturbations were implemented: an investment (e.g. building of tourist accommodation or fish processing facility that will lead to job growth) and logistics (e.g. a social media campaign that enhances tourist visitation) (Table A1.4).

Table A1.4: Details of the direct influences (response connections) for four scenarios, the base case and three perturbation types.

Scenario abbreviation	Description	Perturbation type	Long term Effect on land quality	Long term Effect on water quality	Change in tourist capacity	Change in jobs for residents
Base	Base case	Base case	-	-	-	-
Fish	Introduction of fish processing plant	Investment	-	negative	-	positive
Urban	Upgrading of urban infrastructure	Investment	positive	-	-	positive
Tourism	Tourism development	Investment	positive	-	positive	positive
Social	Social media & advertising campaign	Logistics	-	-	positive	-

The distinction between the perturbation types is made on the basis of the pathway and sequence by which they influence the SES: investment first influences job numbers, but can also affect the environmental variables; logistics first influences resource user numbers (it can attract both tourist visitation and residency). The two types of perturbations can be positive or negative as shown by the lines ending in + or – Figure A1.1). For example, an investment perturbation could lead to negative job numbers if a school were to be closed. Similarly, a negative social media campaign could lead to downward pressure on visitation numbers.

An investment perturbation is defined by the time frame over which it occurs and the number of permanent jobs (δJ) it creates. Such perturbations will result in attracting new residents to the area through immigration. Investment perturbations could also have a direct effect on land quality, water quality, or fish abundance.

Model results

We first present the hypothetical relationship between environmental variables, resource users, and the SoPI, because this relationship is key to the model and is a novel aspect. The curves in panels A, B, and C of Figure A1.2 show that tourists are more concerned about land quality compared to water quality and fish abundance *ceteris paribus*. These relationships can be established empirically, for instance, using different surveys and survey designs of resource user groups in a particular geographic location. A relatively strong positive response to improved land quality by tourists can be deduced from the steepness of the curve for tourists in panel A compared to panels B and C. Observers and extractive users are similar in their concern for water quality (the curves for these two resource users lie close together) but differ with respect to land quality and fish abundance *ceteris paribus*. Panel C in Figure A1.2 shows that a low level of fish abundance has the greatest effect on the SoPI for extractive users (the short-dashed curve lies below other curves at low levels of fish abundance). In contrast, panel A shows that low levels of land quality do not have such a great effect on extractive users compared to the other two resource user groups *ceteris paribus*.

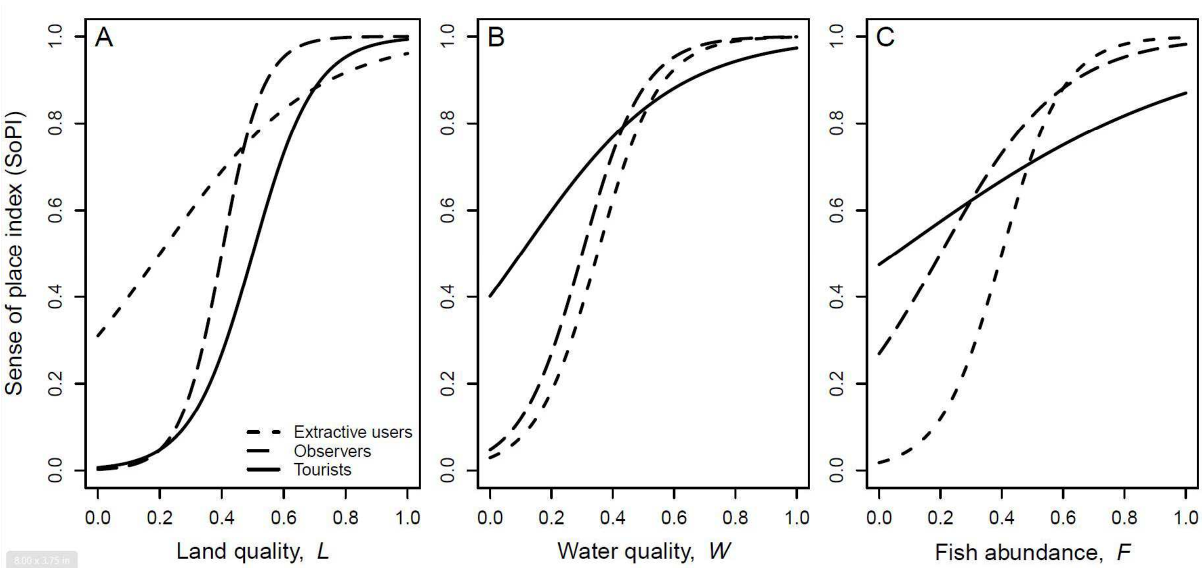

Figure A1.2: Relation between (A) land quality, (B) water quality, and (C) fish abundance and the sense of place index. Curves are plotted for residents who are either extractive users (short-dashed line) or observers (long-dashed line), and tourists (solid line). Unless indicated, the remaining parameters are set to L = W = F = 1 and T = 0.

Assuming the SoPI relations shown in Figure A1.2, we considered four different perturbation scenarios (Table A1.4). In each case we perturbed the system in year 10 and tracked changes in SoPI for each group over the following 20 years. In order to assess the effect of a SoPI on consumer-resource feedbacks we performed simulations when SoPI was fixed throughout the simulation and also when it changed in response to changing environmental conditions.

In the case of the Fish scenario, when the SoPI was dynamic the three resource user groups all experienced rapid declines in their SoPI due to the introduction of the fish processing plant in year 10 (Figure A1.3, black lines). SoPI values slowly improved as environmental conditions improved but levels never returned to pre-perturbation levels. SoPI improved because relative fish abundance gradually improved (Fig. A1.4), which was due to lower catches after many resource users had left the system due to the perturbation. Importantly, when SoPI was ignored catch numbers did not decline much after the perturbation, as resource user numbers were more stable, which led to further reductions in relative fish abundance (Figure A1.4).

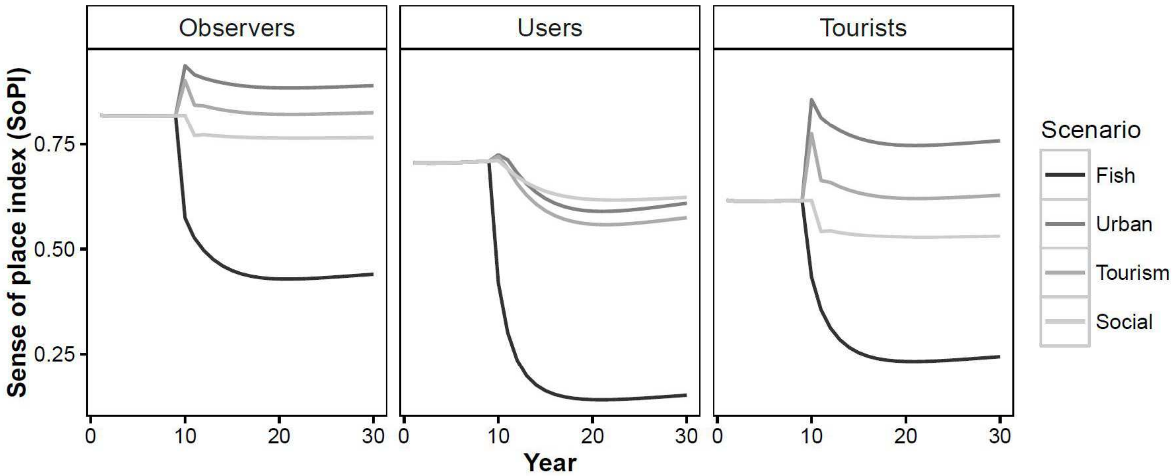

Figure A1.3: Modelled sense of place index for observers, users and tourists of a hypothetical marine socio-ecological system with feedback between land quality (L), marine quality (W), and fish abundance (F), for four perturbation scenarios.

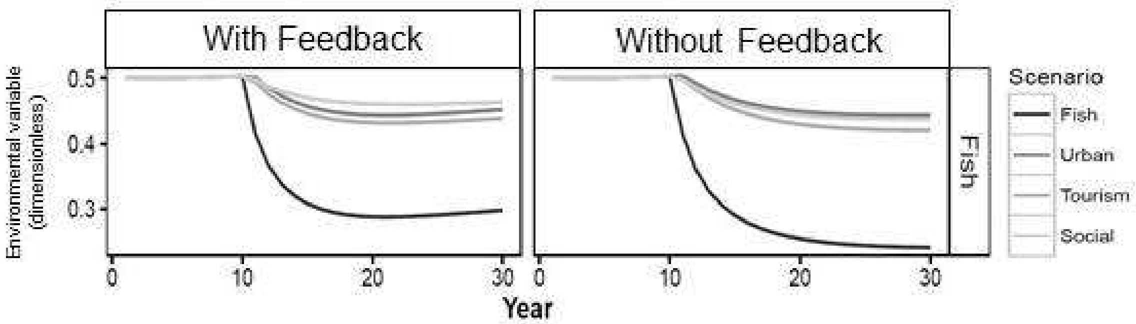

Figure A1.4: Predicted changes in relative fish abundance (F) for a hypothetical marine socio-ecological system with and without feedback between SoPI and the environmental variables land quality (L), marine quality (W), and fish abundance (F), for four perturbation scenarios.

SoPI dynamics for the three other perturbation scenarios are presented in Figure A1.3. In each of these examples the change in the SoPI associated with each group differently substantially (Figure A1.3), which affected both the absolute and relative numbers of individuals present in the community in each of the three groups (O, U, and T) over time. A common outcome was that relative fish numbers declined as a result of each perturbation (Figure A1.4), and fish numbers failed to recover in the long-term when the SoPI was static (Figure A1.4, right panel) Again, lack of recovery in the absence of a dynamic SoPI was caused by continued high levels of fish exploitation. These simulations demonstrate the importance of considering a dynamic sense of place variable when predicting long-term community outcomes.

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