Title	Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping
Author(s)	Gray, Stefan
Publication date	2019-07
Original citation	Gray, S. 2019. Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping. PhD Thesis, University College Cork.
Type of publication	Doctoral thesis
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Item downloaded from	http://hdl.handle.net/10468/10560

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

MAKING SENSE OF CHANGING COASTAL SYSTEMS: OVERCOMING BARRIERS TO CLIMATE CHANGE ADAPTATION USING FUZZY COGNITIVE MAPPING

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Dissertation submitted to the
University College Cork for the degree of
Doctor of Philosophy

NATIONAL UNIVERSITY OF IRELAND, CORK

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July, 2019

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Cite this thesis as follows:

Gray, S. 2020. *Making sense of changing coastal systems: Overcoming barriers to climate change adaptation using Fuzzy Cognitive Mapping*. Ph.D. thesis, University College Cork, Cork, Ireland, 206 pages

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Dedication

To Jess, Jackson and Joel.

While it's quite true that if someone asks, 'is anyone here a Doctor?' in mid-flight I won't be much use, the mere fact that you're still speaking to me to gleefully point that out I take as a triumph.

Acknowledgements

This thesis was made possible by the generous support of the Irish Environmental Protection Agency Climate Change Research Programme (CCRP) 2008-CCRP 3.6, under the unfailingly insightful guidance of Dr Margaret Desmond, who expanded the spatial and thematic boundaries of the research to align it with emerging thinking from Europe. I am grateful for Dr Desmond's mentorship and thought leadership in bringing this work to a wider stage.

The research and field work underpinning the thesis was conducted at the Coastal and Marine Research Centre (CMRC) in Cork, Ireland (now MaREI). The guidance and support of staff there, in particular the Centre's Director Jeremy Gault, and Senior Scientists Cathal O'Mahony and Dr Barry O'Dwyer, made its completion possible, as did the technical and procedural advice of Dr Kieran Hickey, Professor Robert Devoy and Professor Fiona Cawkwell of University College Cork.

Thank you all for your patient help and unwavering support over the years, I'm forever indebted to you.

Publications

Peer Reviewed Journal Articles and Book Chapters:

[1] **Gray, S.**, O'Mahony, C. Hills, J. O'Dwyer, B. Devoy, R. and Gault J. 2016, "Strengthening coastal adaptation planning through scenario analysis: A beneficial but incomplete solution", Marine Policy, doi.org/10.1016/j.marpol.2016.04.031

[2] S. A. Gray, E. Zanre and **S. R. J. Gray** (2013) *Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs*. In: Papageorgiou E. (Eds) *Fuzzy Cognitive Maps for Applied Sciences and Engineering*. Intelligent Systems Reference Library, Vol 54. Springer, Berlin, Heidelberg

[3] **Gray, S.**, O'Mahony, C., O'Dwyer, B., Gray, S. A., Le Tissier, M., and Gault J. (submitted) "Caught by the fuzz: Using FCM to prevent coastal adaptation stakeholders from fleeing the scene", Marine Policy

[4] **Gray, S.,** Gagnon, A., Gray, S. A., O'Dwyer, B., O'Mahony, C., Muir, D., Devoy, R. J. N., Falaleeva, M. and Gault, J. (2014) *"Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping"*, Ocean and Coastal Management, doi.org/10.1016/j.ocecoaman.2013.11.008

[5] Gray, S. A., **Gray, S.** De Kok, J. L. Helfgott, A. E. R. O'Dwyer, B. Jordan, R. and Nyaki. A. (2015). *"Using fuzzy cognitive mapping as a participatory approach to analyse change, preferred states, and perceived resilience of social-ecological systems"*. Ecology and Society 20(2):11. http://dx.doi.org/10.5751/ES-07396-200211

Abstract

This thesis describes the role and value of Fuzzy Cognitive Mapping (FCM) in undertaking coastal climate change adaptation at the local scale, comparing FCM against existing, scenario-based adaptation methods in overcoming known barriers to adaptation. It describes the attributes and limitations of FCM as a modelling tool, exploring what must be accounted for in considering the use of FCM in mixed stakeholder settings where individual and group knowledge must be integrated to form a view of the system under study, discussing in some detail the facilitation strengths and weaknesses inherent to the method. These issues are then described via reference to case-studies in Ireland and Scotland, drawing inferences regarding the ease with which an FCM-based approach to adaptation might be substituted for orthodox, scenario-based adaptation. This is found to not only be feasible, but preferable, provided there is sufficient facilitation capacity on hand to manage the added complexity that FCM carries over simple narrative scenario development. Adding to the value that FCM offers in adaptation contexts, the thesis also explores its value as both a diagnostic tool for establishing what additional capacity building or data may be required by adaptation decision makers, and also as a tool for gauging the extent to which resilience gains (or losses) might be measured. Although FCM cannot be claimed to provide a robust objective measure of resilience gains or losses, it can nevertheless usefully illustrate to decision makers the strengths and limitations of their own understanding of the systems which they must manage. This is perhaps where the future of FCM-based systems analysis in support of adaptation may ultimately lie.

Contents

List of figures

List of tables

Acronyms

CCRP	Climate Change Research Programme
CIAV	Climate Impacts, Adaptation and Vulnerability
CLAD	Coastal Climate Adaptation and Development (Irish EPA funded project)
EC	European Commission
EPA	Environmental Protection Agency
EU	European Union
FCM	Fuzzy Cognitive Mapping
GHG	Greenhouse Gases
IMCORE	Integrated Management of Coastal Resources (EC FP7 funded project)
IPCC	Intergovernmental Panel on Climate Change
LECZ	Low Elevation Coastal Zone
MaREI	Marine and Renewable Energy Ireland
NCCAF	National Climate Change Adaptation Framework
SES	Social-ecological system
UNFCCC	United Nations Framework Convention on Climate Change

National and European projects supporting this research

This research was conducted under the auspices of the Irish EPA Climate Change Research Programme (CCRP), specifically as part of the Coastal Climate Adaptation and Development (CLAD) project.

CLAD

The CLAD project investigated the extent to which emerging insights in the adaptive co-management and resilience literatures might prove useful in enhancing the adaptive capacity of Irish coastal management in the face of climate change.

The research described in this thesis was developed under CLAD's broad umbrella of objectives, which were delineated by the CCRP research questions it sought to investigate:

- How can coastal climate adaptation best be supported given existing conditions and governance structures in Irish coastal management?
- What role can the insights offered by the Adaptive and Collaborative management literatures play in securing greater coastal resilience in Ireland?
- How might climate impact and adaptation data best be scaled for use by Irish coastal planners?

Taking these objectives as a starting point, the research was developed to explore decision support approaches that were:

1 Readily applied with the existing resources and capacities of Irish coastal management practitioners

2 Informed by emerging insights from social-ecological systems analysis, including theories of Panarchy, collaborative knowledge generation and experimental 'learning by doing' approaches to natural resources management

3 Capable of integrating data and knowledge between national and local scales

The work also benefitted by collaborative engagement with two other (European funded) projects, IMCORE and CoastAdapt. The role each played in helping to progress this research is described in sections 1.3.1 and 1.3.2.

Innovative Management for Europe's Changing Coastal Resource (IMCORE)

IMCORE was an Interreg IVB funded project which ran from 2009 to 2012. With a budget of €6m, IMCORE was a relatively large multinational undertaking, spanning nine countries around the coast of north west Europe. The project was led by the Coastal and Marine Research Centre in Cork.

The project's aim was to develop climate change adaptation strategies at each of the case study sites. Each site employed a novel Expert Couplet Node (ECN) approach to knowledge generation and diffusion. Each ECN was comprised of an academic research team and a paired planning/practitioner team involved in the practical design and implementation of adaptation locally.

The project team developed a scenario-based adaptation process methodology (see paper 1) which formed the backbone of the adaptation strategy developed at each case study site.

In Cork Harbour, the application of the IMCORE scenario-based method informed a baseline assessment of the strengths and limitations of scenario analysis as a foundation for coastal adaptation. Access to similar work undertaken at other IMCORE case study locations also helped to differentiate what might constitute generalisable truths of its use from site-specific quirks of the process in Cork.

CoastAdapt

CoastAdapt was a project focussed on supporting coastal communities of the North Atlantic periphery in adapting to the impacts of climate change. The project took in five case study sites in four countries (Iceland, Norway, Ireland and Scotland), adopting a strongly community-led approach to the development and trial of innovative approaches to adaptation strategy development.

The project focussed on understanding how people, businesses and local authorities cope with and plan for climate change, taking the position that these factors were crucial in determining how peripheral coastal communities can maintain confidence in their future security and prosperity.

The project supported the development of visualisation and innovative participatory techniques to bring home the impacts of climate change to local scale decision makers, and to illustrate the range of adaptation options available, making explicit the trade-offs between them.

In the context of this research, the support and resources of the CoastAdapt project were key drivers in exploring innovative participatory modelling methods in the Tralee Bay case study site. This provided a useful counterpoint to the scenario-based adaptation process followed in Cork Harbour.

Part I: PROJECT BACKGROUND AND LITERATURE REVIEW

1. Introduction

"Global warming isn't a prediction. It is happening."

— James Hansen[1]

1.1. A climate of certainty

In the all too recent past, climate change was envisaged as a nebulous, long-term risk that future generations may have to contend with. This view is no longer tenable. Since 1900, the temperature of the atmosphere has risen globally by close to 1°C at the surface of the Earth (Lindsay & Dahlman 2018). This has not been a linear rise, with the rate of warming accelerating since the 1980s; a new temperature record has been set on average every three years and the 10 warmest years since the instrument record began have all occurred since 1998 (Lindsay & Dahlman 2018).

[1] Hansen, J. (2012) 'Game over for the climate', *New York Times*, May 9, Available at: https://www.nytimes.com/2012/05/10/opinion/game-over-for-the-climate.html. Accessed 7 July 2019

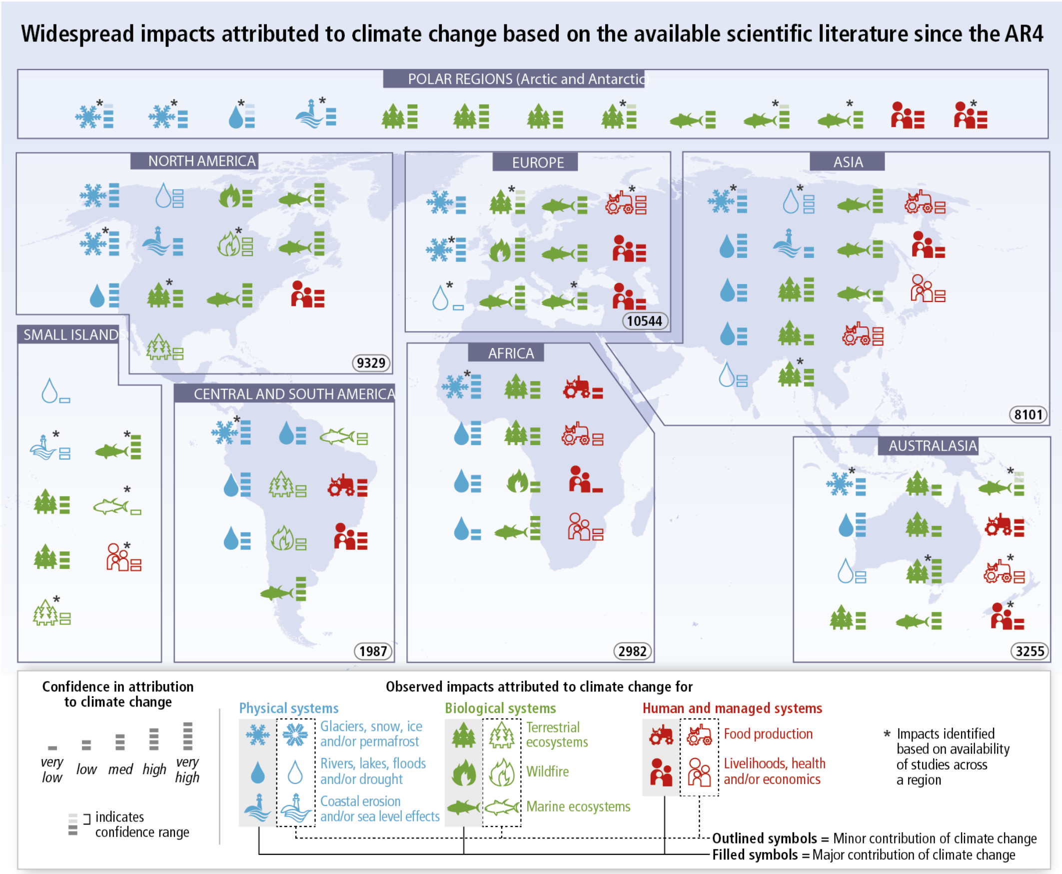


Figure 1: The widespread impacts of climate change across the globe, derived from studies conducted between 2007's IPCC AR4 and 2014's IPCC AR5 (Pachauri & Meyer 2014, p.7)

The impacts of rising temperatures have already touched nearly every physical, biological and human system globally (Figure 1). The 1°C of warming already witnessed has increased the moisture content of the atmosphere by 7%, creating greater climatic instability and exacerbating extreme downpours (Rhein et al. 2013). Impacts attributable to climate-related extremes also appear to be increasing in number (IPCC 2014b), and in respect to their costs, rising in a non-linear manner similar to increasing global average temperature (NOAA 2018).

On the coast, the impacts of climate change pose a significant hazard. The volumetric expansion of the ocean in response to surface warming has seen sea levels rise globally on average 1.5 – 1.9mm yr^{-1} between 1901 and 2010, accelerating to 3.2 – 3.6mm yr^{-1} in the period 1993 to 2010 (Church 2013). This rising trend is highly likely to continue throughout the 21st century, particularly as melting of the cryosphere begins to make a more substantial contribution to sea level change (Wong et al. 2014).

Broadly speaking, erosion-prone coastal systems will see increasing rates of retreat as sea levels rise, with an as yet relatively poorly understood change in the frequency and intensity of storms potentially amplifying rates of coastal inundation and retreat (Wong et al. 2014). These risks, in combination with rising sea surface temperatures, falling pH, and the biogeographical migration of marine species (Rhein et al. 2013), leave coastal dwellers and marine-dependent communities facing a number of significant impacts of climatic change to account for (Nicholls & Cazenave 2010; Kron 2013).

Yet, despite its many inherent risks, the global coast remains uniquely attractive, with the percentage of the global population living in the Low Elevation Coastal Zone (LECZ)[2] remaining disproportionately high. The LECZ accounts for just 2% of the world's land area but is home to more than 10% of the global population, a proportion which is even greater among the Least Developed Countries at 14% (McGranahan et al. 2007). Due to patterns of increasing urbanisation and the coastal location of most of the world's mega-cities, the percentage of the global population inhabiting the LECZ is likely to continue to grow over the course of the 21st century, particularly in Africa and Asia (Neumann et al. 2015).

This growth in the world's coastal population places a growing number of people squarely in harm's way. Although difficult to quantify with certainty, recent economic assessments have begun to explore the potential costs of sea level rise and climatic change over the 21st century (Figure 2) (Jevrejeva et al. 2018; Steffen et al. 2014; Anthoff et al. 2010). In the event that warming cannot be constrained below 2°C by 2100, global annual flood costs absent adaptation may fall between US$14.3 – 27.0 trillion yr^{-1} (Jevrejeva et al. 2018).

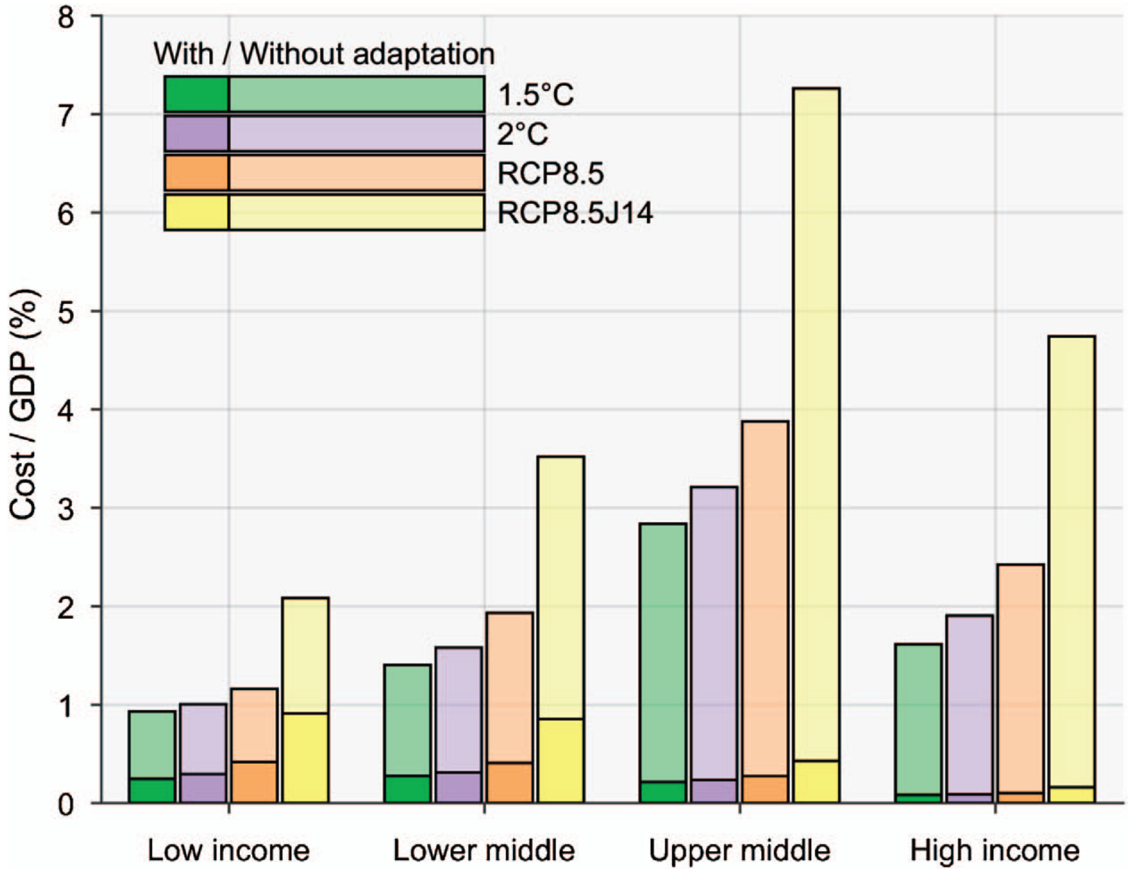
1.2. Policy responses to climate change

Climate change has to date given rise to two distinct (though often interdependent) policy responses. The first, mitigation, dates back to the earliest discussions of climatic change and its root causes (Bodansky 1993). The second, adaptation, is a later addition to the policy mix, the rationale behind its secondary status being that the greater the

[2] "The LECZ is commonly defined as the contiguous and hydrologically connected zone of land along the coast and below 10m of elevation" (Neumann et al. 2015, p.2)

success in achieving mitigation aims, the lesser the need for adaptation action there would likely be (Gupta 2010).

Any hope that mitigation success might delay or significantly offset the need for meaningful adaptation policy development appears unlikely to be realised, and, in a



coastal context, could be argued as indefensible.

Figure 2: Jevrejeva et al. (2018, p.8) illustrate the potentially stark difference in costs resulting from flood damage with adaptation (dark bar) and without adaptation (light bar) on an annual basis as a percentage of GDP (World Bank income groups with four climate scenarios). The climate scenario "RCP8.5" corresponds to the median of "RCP8.5_J14" (0.86 m SLR); RCP8.5J14 corresponds to the 95th percentile of RCP8.5_J14 (1.8 m SLR) (Jevrejeva et al. 2018; Jevrejeva et al. 2014).

1.2.1. Mitigating the causes of climate change

Nevertheless, the primary policy response to the threat posed by climate change has been to attempt to find global agreement on a route to the abatement of greenhouse gas (GHG) emissions (UNFCCC 1997). The value of attempting to do so is inarguable, despite the at times seemingly insurmountable difficulties involved in forging meaningful progress on the global stage (Vidal et al. 2009). Mitigation policy seeks to cut the problem off at source by reducing the concentration of GHGs in the atmosphere, both via curtailing future emissions and developing effective carbon sinks (IPCC 2014a).

Regardless of the success or failure of global efforts to mitigate climate change at its GHG root, and thus optimally limit warming to 1.5°C above a pre-industrial global average temperature (UNFCCC 2015), latencies in the global ocean-atmosphere system mean the impacts of the changes wrought to date will continue to play out over the coming decades and even centuries. Warming underway in the oceans will lock in continued sea level rise well beyond 2100, and the greater energy content of the atmosphere trapped by feedbacks between atmospheric carbon, methane, nitrous-oxide, CFC's, water vapour and alterations in earth's albedo, will likely result in the amplification of extreme events for many decades to come.

1.2.2. Adapting to the impacts of climate change

These stark realities have forced an increasing emphasis on the second strand of policy response; that of acknowledging, assessing and attempting to reduce societal vulnerability to the least acceptable risks that climate change inevitably carries with it. Although historically a justifiably junior partner in global climate policy, adaptation has risen in prominence considerably over the past decade as the limitations of global mitigation efforts have become clear. Yet despite it its rise in prominence, exactly what climate change adaptation involves in practice remains somewhat poorly understood (Biesbroek et al. 2013; Mimura et al., 2014).

The IPCC define adaptation in relatively simple terms as "the process of adjustment to actual or expected climate and its effects…seek[ing] to moderate or avoid harm or exploit beneficial opportunities." (IPCC 2014b p.5). This straightforward statement to some extent disguises a number of complex challenges involved in adapting to uncertain change, as the rapid evolution in structure and content between IPCC AR4 and AR5 Working Group II reports arguably attests. In 2007's AR4, reporting on adaptation was primarily focussed on a single, 26-page chapter (Adger et al. 2007). By 2014's AR5, adaptation reporting had expanded to encompass four chapters across 146 pages (Noble et al. 2014; Mimura et al. 2014; Klein et al. 2014; Chambwera et al., 2014).[3]

The growth in adaptation literature speaks to the complexities involved in seeking to adjust sophisticated, highly connected and dynamic social-ecological systems to as yet uncertain change over long periods of time. Current thinking sees climate adaptation as a process comprised of the iterative analysis and management of a number of key concepts, seeking the moderation or avoidance of harm, or exploitation of beneficial opportunities. These key concepts are defined in Table 1 below (IPCC 2014b, p.5):

Impacts	"…effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts."
Risk	"The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard."

[3] This expansion of reporting effort is likely to be have been triggered by the view that adaptation progress to 2007 had been concerning. Work at that time toward understanding how societies and the ecosystems they rely on were adapting to global environmental change found that measures planned and undertaken in response to the hazards posed by climate change were insufficient, leading the authors to acknowledge that adaptation efforts had faced an array of poorly understood "barriers, limits and costs" (Parry et al. 2007, p.19).

Vulnerability	"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."
Resilience	"The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation."
Transformation	"A change in the fundamental attributes of natural and human systems. Within this summary, transformation could reflect strengthened, altered, or aligned paradigms, goals, or values towards promoting adaptation for sustainable development, including poverty reduction."

Table 1: Key adaptation concepts (IPCC 2014b, p.5)

Analysis and management of these concepts is typically envisaged as occurring iteratively throughout an ongoing adaptive risk management process (IPCC 2014b). Figure 3 illustrates three generic phases of this adaptation process as 'scoping', 'analysis' and 'implementation',[4] within which various sub-processes and assessments occur.

The emergence of a global pandemic in early 2020 offers a useful perspective on the role of disruption to the analysis of adaptation. Although much of what adaptation practitioners seek to achieve is pre-emptive, there is a case to be made that post-disruption recovery must also figure in future thinking on how and where adaptation science must focus its attention, given the considerable scope of climate-related disruption on a scale which may dwarf that imposed by the emergence of COVID-19.

[4] This phased approach has been described similarly elsewhere, though using slightly different terminology (c.f. Moser & Ekstrom, 2010, who use the terms 'understanding', 'planning' and 'managing' to label their phases).

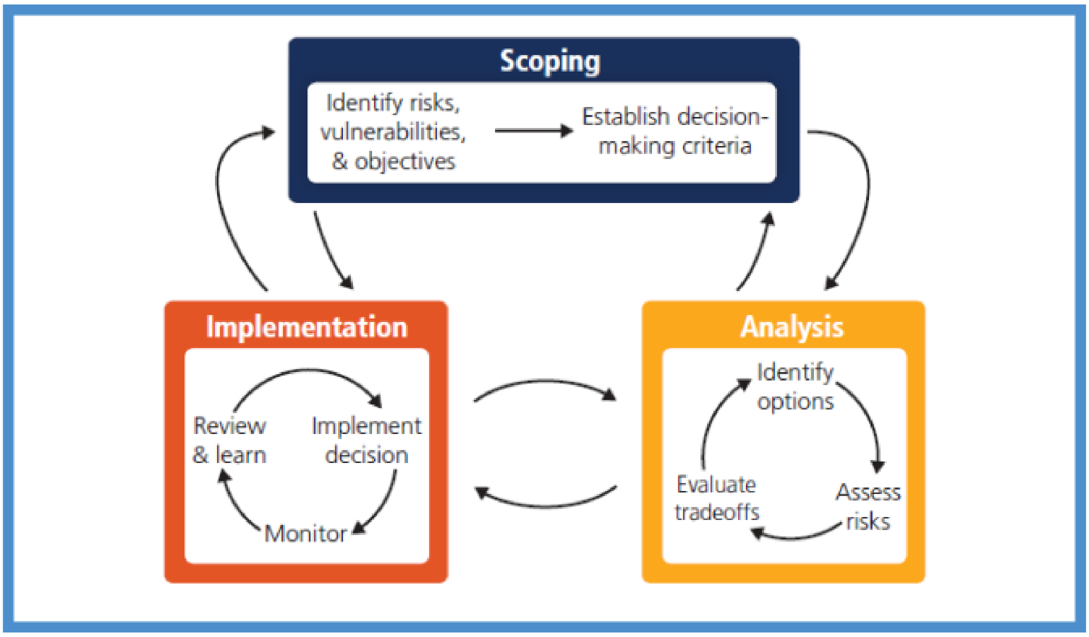


Figure 3: Climate change adaptation conceptualised as an iterative risk management process containing multiple feedbacks (IPCC 2014b, p. 9)

1.3. EU adaptation policy

In Europe, the framework under which climate change adaptation action is fostered is the EU Strategy on Adaptation to Climate Change (COM (2013) 216). The overall aim of the Strategy "is to contribute to a more climate-resilient Europe [by] enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination." (COM (2013) 216, p. 5).

This aim is to be progressed via eight specific Actions:

1. Encourage all Member States to adopt comprehensive adaptation strategies
2. Provide LIFE funding to support capacity building and step up adaptation action in Europe (2013–2020)
3. Introduce adaptation in the Covenant of Mayors framework (2013/2014)
4. Bridge the knowledge gap
5. Further develop Climate-ADAPT as the "one-stop shop" for adaptation information in Europe
6. Facilitate the climate-proofing of the CAP, the Cohesion Policy and the CFP
7. Ensure more resilient infrastructures

8. Promote insurance and other financial products for resilient investment and business decisions

Though characteristically open-ended and in many ways lacking in specificity, these actions were designed to foster synergies across scales, building a nested structure which facilitates coherence in adaptation efforts from the supra-national to local level. As with much communication and policy making at the highest level in Europe, a degree of blandly inoffensive phrasing must be resorted to in order to placate any dissention among the disparate perspectives the EC represents. That said, these actions are nevertheless intended to support adaptation strategies in sectoral, local authority and municipal adaptation processes, in conjunction with key supporting actions in regard to adaptation financing, knowledge sharing, mainstreaming, and of particular relevance to this work, in adaptation support research (Action 4).

1.3.1. Knowledge gaps highlighted under Action 4 of the EU Adaptation Strategy

The Commission drew particular attention to a number of knowledge gaps at the time of the Strategy's publication which the research community were urged to address, including:

i. "information on damage and adaptation costs and benefits;
ii. regional and local-level analyses and risk assessments;
iii. frameworks, models and tools to support decision-making and to assess how effective the various adaptation measures are;
iv. means of monitoring and evaluating past adaptation efforts"

(COM (2013) 216, p. 7)

The research described in this thesis was designed and undertaken to specifically address the second and third of the points raised in Action 4 above.

Point two refers primarily to the challenges of uncertainty which cascade at the local scale, making risk and adaptation analyses at these scales particularly problematic.

Point three refers specifically to the paucity of understanding of how decisions can best be supported under conditions of uncertainty and data scarcity, particularly where mixed stakeholder groups must reach some degree of unanimity in order to progress.

Subsequent sections will go into greater detail regarding these specific challenges in the context of coastal adaptation in Ireland.

1.4. Adaptation policy in Ireland

Research into the range of potential impacts of climate change that Ireland might face began in earnest in the early 2000s, and has been refined and updated regularly (Sweeney et al. 2002; Sweeney et al. 2003; McGrath et al. 2005; McGrath et al. 2008; Sweeney et al. 2008; Desmond et al. 2009; Desmond et al. 2017; Fealy et al. 2018). The costly and potentially life-threatening risks highlighted by Ireland's climate change impact projection studies have triggered a number of adaptation research and policy development initiatives, primarily under the auspices of the Environmental Protection Agency's research programmes (c.f. STRIVE 2007-2013, EPA Research Strategy 2014-2020).

Ireland published its first National Climate Change Strategy in 2000, which was superseded by a second strategy in 2007. Both were focussed primarily on mitigation planning, but the latter strategy did nevertheless include a two-page section on adaptation promising further work to come (DEHLG 2007, p. 46).

1.4.1. The National Climate Change Adaptation Framework (2012)

This further work duly arrived in 2012. The framework provided by the European Union in its 2013 Adaptation Strategy was a key reference point for the approach adopted in regard to adaptation in Ireland. Publication of Ireland's National Climate Change Adaptation Framework (NCCAF) (DECLG 2012) in fact marginally preceded that of the EU Strategy, but had been strongly informed by the Commission's earlier White Paper (COM(2009)147).

The non-statutory NCCAF advocated a phased approach to adaptation in line with the White Paper. The NCCAF's first phase specified the identification of vulnerability at a national scale and prioritisation of adaptation options and actions. A second phase mandated the development and implementation of sectoral and local scale adaptation action plans (DECLG 2012).

As with much adaptation in Europe (and beyond) during this time, the NCCAF reads as the somewhat hastily prepared and incomplete policy outline, particularly given the scale of the challenge climate adaptation poses in an exposed and relatively ill-equipped island state such as Ireland. However, the NCCAF met the essential need of bridging the gap until a more nuanced, fully developed policy framework could be employed.

1.4.2. A core knowledge gap highlighted by the NCCAF

At the time of the publication of the NCCAF, relatively little was known regarding the development of local scale adaptation plans. This shortfall in knowledge was explicitly stated in the document, with the need for further research in supporting local scale actors to engage with and plan for long term climatic impacts acknowledged (DECLG 2012, pp. 7, 9, 41).

In line with the research required in response to Action 4 of the 2013 EU Adaptation Strategy, the knowledge gap in local scale adaptation referred to in the NCCAF is a key focus of the work described in this thesis.

1.4.3. National Adaptation Framework (2018)

The January 2018 publication of the National Adaptation Framework (NAF) (DCCAE 2018a) provided Ireland's first statutory adaptation instrument, building on and filling many of the gaps left by earlier policy developed under the NCCAF. The NAF thus adopted a similar approach to that of the NCCAF, directing adaptation to be undertaken at both national and local scales, and providing guidance to the respective agents tasked with planning adaptation actions. This took the form of Sectoral Planning Guidelines for Climate Change Adaptation (DCCAE, 2018b) and a Local Authority Adaptation Strategy Development Guideline (Gray 2015).

The work described here underpins much of the development of the Local Authority Adaptation Strategy Development Guideline.

1.5. Key challenges to overcome in Irish coastal adaptation planning

Recent work in Ireland has explored the challenges facing coastal decision makers and communities in coming to terms with the impacts of climate change (Falaleeva et al. 2011; Kopke & O'Mahony, 2011; O'Mahony, et al. 2015). This work, and the broader reflections of the adaptation research literature, identifies three distinct yet closely interlinked adaptation challenges which are of particular relevance to coastal adaptation planning in Ireland.

1.5.1 The absence of a shared view of the coastal system

Due to the often poorly defined roles and responsibilities attending the coastal zone (McKenna et al. 2008), decision making in coastal management is often beset by contest (O'Connor et al. 2010), with differing perceptions of coastal management objectives frequently resulting in the delay or outright rejection of proposed management measures (Köpsel & Walsh 2018), and the absence of a systemic appreciation of coastal dynamics in the formulation and/or implementation of regulation serving to undermine the efficacy of those measures that have been enacted (Neal et al. 2018).

To say the least, these are less than optimal conditions under which to engage with an uncertain, costly and complex challenge such as coastal climate change adaptation.

If adaptation is simply conceived of as a special case of social-ecological system transition toward an alternate basin of attraction (Walker et al. 2004), then building a shared conception of the system becomes a key first step in effecting a desired change. The adaptive co-management literature further describes transition towards adaptive governance as requiring the emergence of a shared view of the system's key structures and functions (Olsson et al. 2006). This is necessary to facilitate the types of constructive conversation and compromise necessary to enable decisions to be made which are effectively experimental in nature.

This is not to imply that achieving unanimity of opinion among stakeholders with different desires and objectives is necessary. These sources instead indicate that a useful means of overcoming the deadlock often faced in Irish coastal adaptation might be found in the development of some form of shared systemic conception of the coast – a common, relatively neutral language for the consideration of coastal decision making, where benefits, trade-offs, and cause-effect relationships can be made explicit, and knowledge can build and evolve over time as the successes and failures of adaptive interventions are learnt from.

This shared conception, or even a shared description, of how the coast is structured and functions is currently absent (Falaleeva et al. 2011; Falaleeva et al. 2013). A key attribute of decision support approaches employed in facilitating coastal adaptation should therefore be the development of a shared conception of the coast as a social-ecological system.

1.5.2 Ambiguities in adaptation decision making at the local scale

A second challenges arises through perceptions regarding adaptation being very different at different scales of governance (Klein et al. 2014). Questions such as what must be adapted to, how adaptation should be prioritised, and what specifically supports/constrains adaptation processes are viewed differently by local authorities than regional or central government actors.

This scalar disjuncture of perception in adaptation decision making is particularly challenging in coastal contexts where definitive data are sparse and costly to acquire (Paterson et al. 2017). The spatially differentiated impacts of climate change, and the equally differentiated adaptive capacities of the communities affected by them, result in climate adaptation requiring markedly different approaches and solutions in different locations (Adger & Kelly 1999; Cutter et al. 2000; Turner et al. 2003; Nordgren et al. 2016). So, it is with local scale actors that much of the responsibility for adaptation action falls.

Yet in a technical, decision making sense, adaptation at the local scale presents real difficulties (Crabbe & Robin 2006; Termeer et al. 2013). The most sophisticated of global climate models (GCMs) currently available offer projections of change at relatively coarse cell resolutions amenable to larger (global or regional) spatial scales of analysis (Zheng et al. 2018), and the expertise to interpret their outputs is often concentrated within national meteorological organisations or science bodies. Dynamical, empirical and statistical downscaling of GCM or regional climate model (RCM) output is possible and is regularly undertaken but carries increasing levels of uncertainty the finer the spatial scale of analysis becomes (Chen et al. 2011).

Figure 4: The cascade of uncertainty that local scale adaptation must overcome (Wilby & Dessai 2010, p.181)

These technical challenges contribute significantly to a 'cascade of uncertainty' in local scale adaptation (Wilby & Dessai 2010) (Figure 4). Projections of future societies, emissions trajectories, and climate model fidelity are all highly uncertain. Extrapolating from these projections to determine downscaled regional and local impacts adds further scope for error. At the stage where adaptation responses must be appraised, selected and implemented, the 'envelope of uncertainty' involved is at its maximum extent.

Those that are prepared to risk taking action despite this uncertainty face a range of challenges stemming from adaptive capacity deficits (Gupta et al. 2010). The expertise (Crabbe & Robin 2006; Bierbaum et al. 2014), financial resources (Burton 2011; Zimmerman & Faris 2011; Nalau et al. 2015) and legislative tools (Urwin & Jordan 2008; Amundsen et al. 2010) required to tackle complex, long term problems such as sea level rise are in short supply at the local scale.

However, central governments are typically ill-equipped to engage with and resolve the locally specific issues of coastal communities faced with the impacts of climate change (Corfee-Morlot et al. 2009; EEA 2013). Disparities in local exposure, vulnerability, and adaptive capacity make the adaptation requirements of different communities often markedly different, and the legitimacy of voice required to make judgments regarding the degree of risk and resilience considered acceptable in local terms may be absent at a national scale (Falaleeva et al. 2011; EEA 2013).

Developing tools and approaches to bridge this scalar divide has to date proven challenging, particularly in a coastal context (Nalau et al. 2015). Decision support tools that assist decision makers at the local scale to account for uncertainty using a locally legitimate, place-based vernacular are therefore desperately needed (Noble et al. 2014). Such tools must also provide a practicable means to close the 'psychological distance' between esoteric and often conceptually abstract climate information and decision makers on the ground, recognising and accounting for perceptual differences which originate in personal values, and supporting the understanding of cause and effect relationships via the analysis of mental models (Jones et al. 2014).

1.5.3 Lack of transformative vision in planning adaptation

A third adaptation challenge is the inherent conservatism and incrementalism evident in early attempts to discuss and conceptualise coastal adaptation in Ireland. In many respects, this is a factor which is made more intractable by feedbacks stemming from the lack of a shared system view and the ambiguities imposed by scale described above.

Where agreement as to the cause and effect of coastal change between farmers, residents, tourism operators and local authorities is absent, the space for taking courageous steps to address coastal climate risk shrinks drastically. Similarly, the ambiguity of roles and responsibilities, and a limited capacity to interpret and act on uncertain information at the local scale, raises the stakes for those wading into the adaptation issue. Under such circumstances, an adaptation plan which accounts for transformative systemic change is unlikely to garner stakeholder support.

Yet the deep uncertainties accompanying climate change impact projections at the scale of coastal management decision making arguably leads to a need to approach adaptation as a potentially transformative issue (Noble et al. 2014). The cumulative effects of changes in sea level, wave height, storm activity, precipitation and patterns of coastal development may well result in non-linear systemic responses, capable of overwhelming incrementalist adaptation measures and making existing modes of living and working in the coastal zone untenable.

For this reason it is of critical importance to factor in the potential for transformative change in adaptation planning, shifting the coastal system from its current equilibrium state toward what is described in the resilience literature as a new stability landscape where resilience to change is optimised in desirable ways (Ollivier et al. 2018).

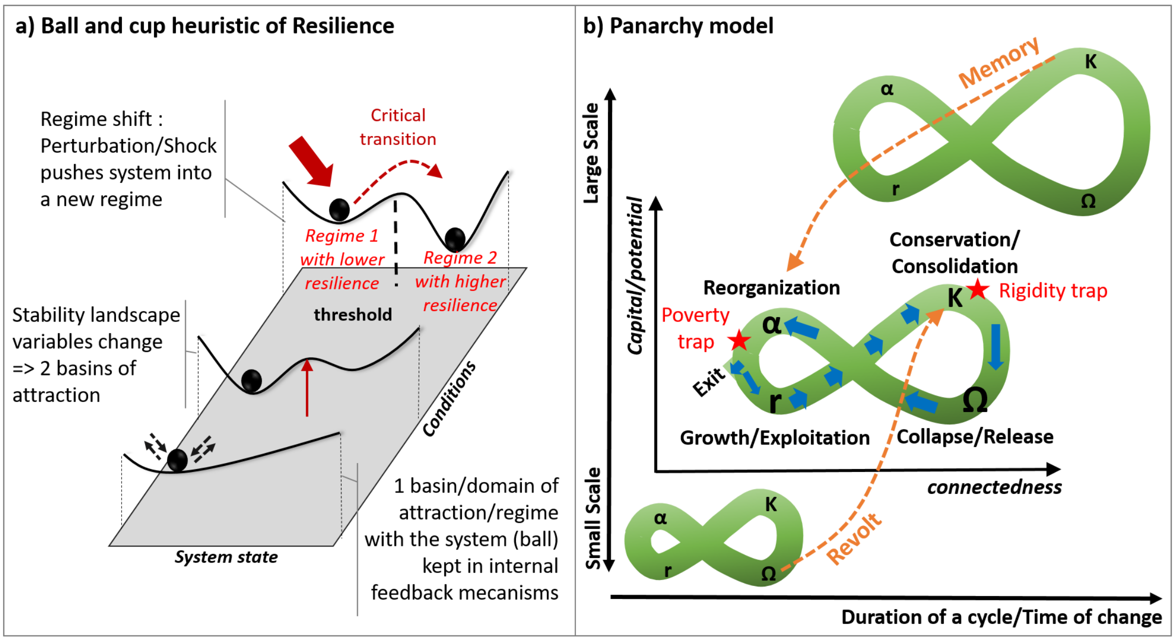


Figure 5: The ball and cup heuristic of resilience and transition, contextualised via reference to the panarchic cycle (Ollivier et al. 2018, p.2)

This view of social-ecological system dynamics sees change as an inevitable (and often radical) property of complex systems. Pre-empting and thus directing change toward a desired future stability landscape (via adaptive intervention) is thus seen as a wise precaution rather than rather than an unnecessary extravagance.

Addressing the three challenges described here will greatly enhance the adaptive capacity of Irish coastal communities. Decision support tools can, to varying degrees, assist in realising improved adaptation outcomes. Those employed in Irish coastal adaptation contexts should aim to address the challenges described in this section to the greatest extent possible.

1.6. Decision support tools to facilitate coastal adaptation

In recent years coastal climate change adaptation legislation, policy, reference materials and guidelines have begun to proliferate (USAID 2009; Scott et al. 2013; Lemmen et al. 2016; JICA 2016; Bell et al. 2017; RSA 2017; Gibbs & Hill, 2011).

As illustrated in 1.3 and 1.4, the publication of adaptation policies at supra-national and national levels has been accompanied by specific calls to develop methods, tools and guidance to support adaptation processes (DECLG 2012; COM (2013) 216; DCCAE 2018a). This reflects a broad acknowledgement that the introduction of adaptation policy and provision of climatic change information are rarely sufficient in themselves to achieve adaptation objectives (Tribbia & Moser 2008; Biesbroek et al. 2013). The development of decision support approaches which are robust in a context of deep uncertainty, contested mental models and conflicting values is thus a key adaptation need.[5]

1.6.1 The potential benefits of scenario analysis in facilitating adaptation

Wright and Goodwin (2009, p.10) define scenarios as "purposeful stories about how the contextual environment could unfold over time", consisting of a description of an end state, an interpretation of how current conditions will evolve, and an internally consistent account of how the envisioned future might logically unfold. Planning exercises built around this conception of scenarios emerged as a tool for the development and analysis of military strategy in the early stages of the cold war (Lindgren & Bandhold 2003, p. 193). Scenario planning methodologies have now been in use for some 60 years across a range of sectors and fields (Börjeson et al. 2006), most notably in the field of corporate strategy formulation via the RAND Corporation and Royal Dutch Shell (Schwartz 1997, p. 272).

The futures research literature describes scenarios as falling into three broad categories, delineated by their method of generation, intended purpose and the central question they seek to resolve within a given decision context (Notten et al. 2003; Bradfield et al. 2005; Börjeson et al. 2006).

Predictive scenarios are typically quantitative, and computer generated, offering data on the plausible evolution of a modelled system of interest given the occurrence of a theorised series of events, and the accuracy with which cause-effect relationships are

[5] These are characteristics of 'complex risk' as defined by Jones et al. (2014, p. 202). Complex risk contexts are those where sociocultural and cognitive-behavioural factors are central to decision making, requiring the systematic framing and modelling of multiple drivers, and the participatory creation of shared understandings in order to overcome initially contested mental models and differing values.

parameterised (Börjeson et al. 2006). These scenarios seek to determine what will happen in the future. Examples of predictive scenarios include climate model runs or traffic flow forecasts.

Explorative scenarios are typically qualitative in nature and look to explore a range of potentially plausible outcomes resulting from the interplay of significant but uncertain drivers of change (Börjeson et al. 2006). Scenarios of this type are more explicitly subjective and intuitive than predictive scenarios (though both are ultimately reliant upon the subjective input of scenario-builders). Explorative scenarios attempt to understand what could happen in the future, with notable examples of this type of scenario being those employed by Royal Dutch Shell in strategy development prior to the oil shocks of the 1970s.

Normative scenarios fulfil a different role, in that rather than working toward a pre-determined future date, these scenarios are 'backcast' from an idealised future toward the present (Dreborg 1996). The circumstances described within a normative scenario thus represent an optimal, highly desirable future that those participating in the scenario planning process would wish to see realised (Quist & Vergragt 2006). Working back from this desired end point, participants describe the incremental actions and events upon which its realisation is contingent. This approach to scenario planning is used to help clarify to decision makers what should happen in a given circumstance.

In practice, these alternate scenario types are often hybridised or used sequentially within a broader scenario planning process (Carlsson-Kanyama et al. 2008). Alcamo and Heinrichs (2008) describe scenario-planning processes that involve not only the development (or building) of scenarios, but also the subsequent evaluation of their consequences in support of decision-making regarding the future, as 'scenario analysis'. For the remainder of this thesis, the term scenario analysis will be used in this sense.

Scenario analysis could provide a range of tools for adaptation planning, ranging from a technical perspective of a possible future to contributing to dissemination and engagement. Wright et al. (2009) identify a number of claimed benefits of scenario analysis in the futures research literature (Table 2).

Claimed benefit:	Achieved through:
Enhances perception	• Aiding in identification and understanding of key trends • Increasing managers sensitivity to change • Allowing managers assumptions about the system and the future to be made explicit • Diminishing 'anchoring' bias (viewing the perpetuation of present conditions into the future as the most likely outcome)
Deals with uncertainty	• Offering a structured approach to complexity, acknowledging the unknown • Allowing insight into what is of long-term significance and what is transient (and thus of less relevance in future planning) • Highlighting the plausibility of alternate futures diminishes bias toward underestimation of uncertainty
Integrates planning	• Providing a platform for the integration of formal and informal data, information and knowledge • Allowing the integration of disparate management functions and plan elements due to the flexibility of inputs within the scenario building process
Enhances communication	• Offering a logically argued and neutral framework for discussion of the future, both within and between organisations • Integrating a range of future issues and options into a coherent, communicable whole, spurring organisational action • Providing enduring channels of communication (opened among participants during the scenario development process) beyond its project lifecycle

Table 2: Claimed benefits of scenario analysis (adapted from Wright, Cairns, & Goodwin, 2009).

Evaluating the extent to which narrative scenario analysis can realise these claimed benefits in support of adaptation aims is the focus of Paper 1.

1.6.2 Selecting an alternative approach to improve on scenario analysis

A number of alternative methods and tools beyond narrative scenario analysis are available to support adaptation decision making at the local scale. Each offers different strengths and carries different overhead in terms of their ease of facilitation. These will be briefly reviewed below (for further detail and a complete review of participatory modelling theory, methods and applications see Gray, Paolisso, Jordan and Gray, 2017).

Qualitative concept mapping is a systems modelling approach which is relatively easy to facilitate with stakeholders (Bisung and Dickin, 2019; Trochim and McLinden, 2017). Modellers set out the concepts, structures and key functions of the system under analysis, often using a simple software platform or structured notational system. The relationships between nodes in the concept map are simple and easy to record and illustrate. However, they lack a dynamic capacity and are thus a static snapshot which cannot provide the basis for adaptation assessment via scenario forcing.

Bayesian belief networks are a graphical and quantitative modelling method, derived from concept mapping, which describes correlative and causative relations between nodes in a network (Robinson and Fuller, 2017). Arriving at a shared conception of the components to include in the network, and who to describe the probabilistic relations between them can be difficult and time consuming, but where this is achieved Bayesian networks offer useful probabilistic insights into the likely outcomes of changes in the system. However, Bayesian nets are not only complex to facilitate, they can often be difficult for stakeholders to intuitively grasp, and they do not allow for dynamic feedbacks within the network as they illustrate a unidirectional causal trajectory.

Agent based models function through the determination of rules of behaviours for simulated agents, with initial state conditions ultimately determining what the model will produce. Agent based models provide useful facsimiles of aggregate-level system behaviour. They allow for feedbacks, handling non-linearity in system behaviour well, and can also simulate conceptual units reflecting real-world values. However, agent types cannot easily be altered, and they are particularly inflexible in participatory setting due to the constrain that models must typically be constructed before stakeholder workshops, allowing little scope for the incorporation of stakeholder views and perceptions 'on the fly'.

Multi-criteria analysis (or MCA) techniques encompass a number of approaches to decision support which offer decision makers various routes to the weighting of the alternatives available to them. This typically occurs via the identification of a range of measurable criteria of success (or value) in outcome and establishing a weighting regime to determine their relative importance. Simple linear additive models (where scores against criteria are summed to give an overall performance score), or more complex Analytical Hierarchy Processes (where pairwise comparisons of the value of one option against another are made in series) can be used to give an overall assessment of a given option in a given decision context. These are often criticised for their overt subjectivity, but perhaps more damningly, MCA approaches have been found to lack the creativity and potential to provoke broader systemic insights than other, more flexible and holistic decision support approaches.

Fuzzy cognitive mapping (or FCM) is a participatory modelling method (Gray et al. 2017) which builds a map of cognition representing an individual's thought processes in relation to a given problem space (Axelrod 1976; Kosko 1986). FCMs provide a visual and dynamic external representation of an individual's internal perceptions of the structure and function of a given system or problem domain (Özesmi & Özesmi 2004; Gray et al. 2014). Using simple mathematical relationships, internal qualitative beliefs are semi-quantitatively encoded to create fuzzy dynamic models comprised of model concepts and weighted edge relationships that describe the causal linkages between them (Wei et al. 2008). Graph theory then allows inferences to be drawn regarding the role each element plays in the networked system, and what the influence of changes in its expression may indicate relative to other concepts through a series of model iterations (Kosko 1986; Kok 2009). The drawbacks of FCM lie in its inability to adequately model temporal dynamics or non-linear relationships between nodes in the map. However, these limitations can be relatively easily worked around in facilitating participatory decision making in 'live' stakeholder contexts.

Of the alternatives readily available for experimentation in Irish coastal adaptation decision support, FCM offers the greatest degree of flexibility and potential for impact with stakeholders. For these reasons it has been selected for further comparative analysis against scenario analysis in supporting climate adaptation.

1.6.3 The potential benefits of fuzzy cognitive mapping in facilitating adaptation

FCM is increasingly coming to be employed in environmental decision contexts (Özesmi & Özesmi 2004; Jetter & Kok 2014). This is perhaps the case because FCM is a method which has been claimed to be particularly well suited to decision-making under uncertainty. A capacity to semi-quantitatively integrate disparate, loosely defined qualitative and quantitative inputs based on a modellers understanding of the system has been cited as marking out FCM as a particularly versatile tool in this regard (Helfgott et al., 2015). Further, FCM's capacity to generate and explore the consequences of scenarios involving different system states has been described to ably facilitate structured thought experiments, which, although relatively simple to parameterise, account for sophisticated systemic interactions to produce meaningful 'what-if' outputs (Kok 2009; Jetter & Kok 2014). This latter feature is considered to be one of the most compelling points in FCM's favour where complexity and a lack of data cloud decision contexts (Gray, et al., 2015). Crucially, FCM-based future planning is also claimed to serve as a structured platform which might successfully bridge the divide between highly technical, quantitative analyses of a given situation or problem and the more subjective, qualitative assessments of decision makers faced with uncertainty (Kok 2009; van Vliet et al. 2010).

The key decision support attributes of FCM as cited in the literature (after Gray et al. 2016) are tabulated below (Table 3).

Claimed attribute:	**Achieved via:**
Copes with complexity (Kosko 1986; Helfgott et al. 2015; Mourhir et al. 2017; Solana-Gutiérrez et al. 2017)	• Incorporating qualitative and quantitative inputs • Facilitating the inclusion of loosely defined concepts and relationships within the modelling process • Providing a simple, semi-quantitative description of the system under analysis via the identification of its key concepts and their relationships • Allowing sophisticated system models to emerge via a simple, iterative series of cause-effect relationships parameterised using descriptive terms
Integrates knowledge across domains and scales (van Vliet et al. 2010; Helfgott et al. 2015; Gray et al. 2015)	• Making modelling process accessible to participants from any background or level of domain expertise • Flexibility of modelling framework allowing analysis of system domains ranging from micro to macro scales • Providing a modelling platform across which differing forms of (lay and expert, local and general) information and knowledge can be

	combined to provide semi-quantitative outputs
Identifies and makes explicit contrasting views of the system (Kontogianni et al. 2012; Helfgott et al. 2015)	• Providing a simple, visual illustration of where a given stakeholder's internal mental model of the system differs from another's • Facilitating a semi-quantitative analysis of the relative impact of contrasting perceptions on the system as a whole
Facilitates social learning (van Vliet et al. 2010; Gray et al. 2014; Malek 2017; Olazabal et al. 2018)	• Communicating differing views of system attributes, structures and functions via the shared FCM medium of model concepts and their relationships allows stakeholders to learn from each other
Builds a shared conception of the system (Özesmi & Özesmi 2004; Gray et al. 2015)	• Facilitating aggregation of individual understandings to build a shared map of cognition • Allowing a structured group modelling process to capitalise on social learning and reach a shared understanding of the system's key features and relationships
Generates new insights (Kontogianni et al. 2012; Gray et al. 2015; Olazabal et al. 2018)	• Exploring the outcome of interactions between system concepts over a number of FCM model cycles allows an understanding of the relative importance of their relationships to emerge • Providing a platform for group experimentation via changes in system concepts and the strengths of their relationships facilitates structured thought experiments
Bridges gaps between science and decision making (van Vliet et al. 2010; Malek 2017)	• Illustrating key differences between the perception of scientists and decision makers, and allowing a bi-directional exchange of information and ideas to fill gaps in systemic understanding • Providing a structured interface between complex computational projections and local scale perception of system structure and function • Building a system model which can be forced at its boundary by exogenous factors

Table 3: Claimed attributes of FCM found in the literature

Due to its many claimed attributes which would appear a good fit for Irish coastal adaptation contexts, it was selected for evaluation under this research. Further, while there is an early example of the use of fuzzy logic to assess climate vulnerability in the literature (Eierdanz et al. 2008), using FCM as a decision support tool to design climate adaptation responses remains relatively novel (Doukas & Nikas 2019). Meaningfully evaluating its potential role and value in facilitating the progress of adaptation processes is therefore timely.

1.6.4 Goodness of fit in overcoming Irish adaptation challenges

On the basis of available literature, both orthodox narrative scenario approaches and FCM-based adaptation planning approaches would appear to offer considerable promise in adaptation contexts, with either capable of fostering systemic, scale-appropriate and transformative approach to adaptation. Having been identified as a specific fit for the challenges of Irish coastal adaptation, FCM should nevertheless perform more capably in facilitating coastal adaptation processes.

Formulating a rigorous means of assessing FCM as decision tool in support of adaptation planning requires a worthy analytical framework. The specific contextual challenges of Irish coastal adaptation are nested among a range of barriers to adaptation that appear to be common to all adaptation processes. It is therefore possible to assess the capacity of both conventional scenario analysis and FCM to overcome known barriers to adaptation, providing a meaningful evaluation of their goodness of fit for addressing the particular challenges of Irish coastal adaptation.

1.7. Barriers to adaptation

The term 'barriers' is used here in the sense put forward by Adger et al. (2009) and Moser and Ekstrom (2010), as obstacles which are surmountable given sufficient resourcing, effort, and creativity, explicitly distinguishing adaptation barriers from the (predominantly biophysical) 'limits' to adaptation which in the shorter term at least may be less amenable to targeted intervention.

Between the publication of AR4 and AR5, considerable effort was invested in understanding and describing the barriers and limitations involved in adapting to climate change (EEA 2013; Klein et al. 2014; Mimura et al. 2014; Noble et al. 2014). This broadening of the knowledge base has included efforts to categorise (Moser & Ekstrom

2010) and assess (Biesbroek et al. 2013; Klein et al. 2014) barriers for their role in hindering adaptation progress.

In their comprehensive review of barriers to sea level rise adaptation, Barnett et al. (2013) find common threads across the literature in categorising barriers under four broad categories. The first are social and cognitive barriers, which involve the perception of risk and cultural/organisational attitudes to integrating information which may be novel in its format and potentially confronting in its content.

A second group are categorised as institutional barriers, centred on issues of coordination, capacity, legitimacy and leadership, and frequently, the relationship of these factors with scale.

Barnett et al. (2013) describe uncertainty as a third organising factor in describing adaptation barriers. Debates surrounding the extent to which uncertainty can legitimately be described as a barrier to adaptation are no doubt valid, given the relative ease with which economic or political uncertainties are discussed in the context of long-term decision making. However, while economic or political uncertainty are rarely if ever employed as a rationale to prevent a decision process from proceeding, climatic uncertainty is frequently so employed.

A final category of barrier identified by Barnett et al. (2013) is that related to the costs of adaptation. Something of a cross-cutting barrier, the imposition of costs becomes particularly problematic given a context of ongoing uncertainty, and problems of institutional and scalar fit which adaptation processes must overcome.

While broad categorisations such as that provided by Barnett et al. provide a useful entry point, ascertaining where and when barriers typically arise during a generic adaptation process (such as that illustrated in Figure 3) will likely provide greater insight into how they might best be overcome. Biesbroek et al. (2013) point to the diagnostic framework of Moser and Ekstrom as the only adaptation-specific analytic tool of its kind, and it is therefore employed here.

1.7.1 The Moser-Ekstrom diagnostic framework

The diagnostic framework of Moser and Ekstrom (2010) identifies specific barriers as they emerge in relation to the phases and steps typically undertaken in a generic adaptation process. These map relatively cleanly to the barrier groups of Barnett et al. (2013), and provide a useful insight into the extent to which a given decision support approach might offer a tractable means of overcoming them (Table 4).

1. UNDERSTANDING (or SCOPING) phase	BARRIERS	BARRIER GROUP(S)
Detect problem	Existence of a signal	SC/U
	Detection (and perception) of a signal	SC
	Threshold of concern (initial framing as problem)	SC/U
	Threshold of response need and feasibility (Initial framing of response)	SC
Gather/use of information	Interest and focus (and consensus, if needed)	SC
	Availability	SC
	Accessibility	SC
	Salience/relevance	SC
	Credibility and trust	SC/U
	Legitimacy	SC
	Receptivity to information	SC
	Willingness and ability to use	SC
(Re)define problem	Threshold of concern (reframing of the problem)	SC/U
	Threshold of response need	SC
	Threshold of response feasibility	SC/I
	Level of agreement or consensus, if needed	SC/I
2. PLANNING (or ANALYSIS phase	**BARRIERS**	**BARRIER GROUP(S)**
Develop options	Leadership (authority and skill) in leading process	SC/I
	Ability to identify and agree on goals	SC/I
	Ability to identify and agree on a range of criteria	SC/I
	Ability to develop and agree on a range of options that meet identified goals and criteria	SC/I
	Control over process	I
	Control over options	I
Assess options	Availability of data/information to assess options	U
	Accessibility/usability of data	U
	Availability of methods to assess and compare options	U
	Perceived credibility, salience, and legitimacy of information and methods for option assessment	U/SC
	Agreement on assessment approach, if needed	I
	Level of agreement on goals, criteria, and options	I
Select option(s)	Agreement on selecting option(s), if needed	I
	Sphere of responsibility/influence/control of option	I
	Threshold of concern over potential negative consequences	I
	Threshold of perceived option feasibility	I
	Clarity of authority and responsibility over selected option	I
3. MANAGING (or IMPLEMENTING) phase	**BARRIERS**	**BARRIER GROUP(S)**
Implement option(s)	Threshold of intent	I
	Authorization	I

	Sufficient resources (fiscal, technical, etc.)	C
	Accountability	I
	Clarity/specificity of option	U
	Legality and procedural feasibility	I
	Sufficient momentum to overcome institutional stickiness, path dependency, and behavioural obstacles	I/SC
Monitor outcomes & environment	Existence of a monitoring plan	I
	Agreement, if needed, and clarity on monitoring targets and goals	I
	Availability and acceptability of established methods and variables	I/U
	Availability of technology	I/U/C
	Availability and sustainability of economic resources	C
	Availability and sustainability of human capital	C
	Ability to store, organize, analyse, and retrieve data	I/C
Evaluate effectiveness of option	Threshold of need and feasibility of evaluation	I
	Availability of needed expertise, data, and evaluation methodology	I
	Willingness to learn	I/SC
	Willingness to revisit previous decisions	I/SC
	Legal limitations on reopening prior decisions	I
	Social or political feasibility of revisiting previous decisions	I

Table 4: The diagnostic framework of Moser and Ekstrom (2010) is tabulated in the first and second columns, and mapped against the barrier groups described by Barnett et al. (2013) in the third column. The barrier groups are socio-cognitive (SC), institutional (I), uncertainty (U) and cost (C).

Socio-cognitive barriers tend to dominate the early phases of an adaptation process. The mental frames employed by key decision makers in coming to conclusions regarding how climate risks should be prioritised are particularly influential during these early stages. Uncertainty in the mode described by Barnett et al. (2013) also plays a role and might figure disproportionately in the minds of decision makers where socio-cognitive barriers to the assimilation of new sources and types of information creates additional doubt.

Barriers stemming from institutional issues begin to dominate as the process gains momentum. This tends to occur as the need arises to broaden participation in adaptation decisions beyond the organisation, agency or ad-hoc group which has initiated the process, typically in order to see adaptation plans formally adopted and implemented. Inevitably, barriers relating to cost also begin to emerge during these stages of the process, often serving to amplify any unresolved socio-cognitive or uncertainty barriers when the difficult decision to commit scarce resources to the mitigation of future risk must be taken.

Socio-cognitive and uncertainty barriers therefore assume a role of relative primacy, both in respect to their appearance in the adaptation cycle, and also in the extent to which they can effectively derail adaptation progress if insufficiently addressed. It could therefore be posited that building a solid foundation in the adaptation process that effectively overcomes socio-cognitive (and their frequently interlinked uncertainty) barriers may provide the greatest scope for achieving tangible adaptation progress.

Directly targeting institutional barriers via decision support intervention is more difficult. Changing what are often rigid institutional structures and relationships is typically a slow process. Institutional barriers may nevertheless be mitigated to an extent by interventions which build capacity, the demonstrable credibility, expertise and procedural integrity of an adaptation process allowing its momentum to be maintained as adaptive decisions are promulgated more broadly within and beyond the organisations within which they originated.

Barriers relating to cost are perhaps the most difficult to turn a decision support lens to. However, the European Commission accounts for this in the framing of Action 4 (COM (2013) 216, p.7), separating cost/benefit information provision from the actions centred on "regional and local-level analyses and risk assessments" and "frameworks, models and tools to support decision-making and to assess how effective the various adaptation measures are" which are the central aims of the research presented here.

The literature on adaptation barriers, in conjunction with specific knowledge gaps referred to in EU and Irish policy documents, therefore builds a compelling case for the design of decision tools which in the first instance specifically address socio-cognitive and uncertainty barriers in the early stages of adaptation, and offer some degree of support in overcoming institutional barriers which arise as an adaptation process shifts into meaningful planning and implementation phases.

1.7.2 Barriers in the context of coastal adaptation in Ireland

The coastal case study sites referred to in this thesis are primarily Cork Harbour and Tralee Bay (geographic descriptions of which are provided in some detail in the papers that follow). A comparative reference to the Outer Hebrides is also made in Paper 4, but the bulk of the analysis offered in this research was funded by the Irish Environmental

Protection Agency and thus has an Irish focus. A brief re-cap of where these two case study sites lie in relation to the adaptation barriers described here is therefore useful.

Cork Harbour

At the outset of this research, no specific work had been undertaken in Cork Harbour to assess climate risk exposure, vulnerability, or adaptive capacity, and no climate change adaptation strategy had been developed. It was therefore unsurprising that early stage socio-cognitive and uncertainty barriers associated with problem detection, and the gathering and use of information, were strongly evident in Cork Harbour.

Local Authority planners and harbour managers were aware of the range of issues associated with climate change, but in a nebulous, abstract manner. The (spatial and temporally) specific impacts of climate change were unknown to them, and information available from national-scale analyses (i.e. McGrath et al. 2008; Sweeney et al. 2008) had not been drawn on in coming to decisions regarding the prioritisation of climate related risk.

The prevalence of these barriers in planning and decision-making processes initially masked the presence of institutional and cost-related barriers occurring later in an adaptation process. However, as the research programme progressed these became increasingly clear, with commitment points on decision making and resource allocation mired in institutional ambiguity.

Cost-related barriers also appeared to play a strong role in decision paralysis, with fears that acting in advance of central government decisions surrounding how adaptation should be prioritised (and funded) giving rise to a 'wait-and-see' mindset among the various planning and management teams with a role to play in adaptation decision making in Cork Harbour.

Tralee Bay

Early stage socio-cognitive and uncertainty barriers were also evident in Tralee Bay, though not to the same extent as had been noted in Cork Harbour. Recent Office of Public Works led flood risk analyses and remediation works had involved two key staff in Tralee City and Kerry County Council's, introducing them to the types of projection data available to support climate impact assessment and adaptation decision making. Although similar work had been undertaken in Cork, it's reach was much wider and impact appeared to be much more diffuse, with staff across a range of departments and disciplines having a more tangential relationship to climate risk assessment than the two individuals in Tralee Bay, who appeared to have been much more deeply involved and thus more aware of the types of projection data available for analyses of this nature and where they could be sourced.

Despite the greater data-literacy of key Tralee Bay decision makers, familiarity with the spatially and temporally specific impacts of climate change for Tralee Bay (beyond fluvial flood risk) was largely absent, preventing any framing of a climate risk threshold of concern or response. As in Cork, broad generalities of climate risk knowledge appeared to dominate, with no specific insight offered on factors such as potential temperature or sea level change for Tralee Bay at a given point in the future.

Institutional barriers to adaptation were also evident in Tralee Bay. These primarily involved the ambiguity surrounding coastal management in Ireland, where the delineation of roles and responsibilities can be sufficiently opaque that even willing and motivated actors can at times struggle to secure a mandate for proactive management action, often having to implement coastal management by proxy via other, more clearly defined policies and instruments such as those surrounding road and infrastructure maintenance.

These institutional barriers appeared more readily overcome than those encountered in Cork. The much smaller, less complicated nature of governance structures and relationships in the township of Tralee Bay resulted in fewer governance actors, enjoying bonds of strong social capital. These bonds appeared to enhance the potential for collaborative agreement on the distribution of roles, and even costs, as these forms of negotiated settlements were frequently necessary in order to progress local government actions.

1.7.3 Using the Moser-Ekstrom framework to evaluate decision support interventions

Mapping the claimed benefits of scenario analysis and FCM against the barriers encountered in early stages of an adaptation process provides a framework to evaluate each approach as an adaptation decision support tool.

Barriers encountered in adaptation cycle stages 1 – 3

Claimed benefits of scenario analysis	1. Assessing risks and vulnerability			2. Identifying adaptation options			3. Assessing options		
	Understanding the system	Detecting the problem	Gathering and using information	Re-defining the problem	Core adaptation assumptions	Identifying local adaptation stewards	Identifying adaptation options	Assessing options	Selecting option(s) to implement
Enhances perception	Strong	Strong	Weak	Strong	Strong				Strong
Deals with uncertainty	Strong	Strong	Strong	Strong	Weak		Strong	Strong	Moderate
Integrates planning	Strong	Strong	Strong	Strong	Moderate	Moderate	Weak		
Enhances communication	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong
Facilitates organisational learning	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong	Strong

Indicates a claimed benefit offering a strong potential to overcome a specific barrier

Indicates a claimed benefit offering a moderate potential to overcome a specific barrier

Indicates a claimed benefit offering a weak potential to overcome a specific barrier.

Table 5: Mapping the potential of scenario analysis to overcome the barriers encountered in the early stages of an adaptation cycle.

Claimed attributes of FCM	Barriers encountered in adaptation cycle stages 1 – 3: understanding and planning								
	1. Assessing risks and vulnerabilities			2. Identifying adaptation options			3. Assessing options		
	Understanding the system	Detecting the problem	Gathering and using information	Re-defining the problem	Core adaptation assumptions	Identifying local adaptation stewards	Identifying adaptation options	Assessing options	Selecting option(s) to implement
Copes with complexity	Strong	Strong	Moderate	Strong	Moderate	Moderate	Moderate	Moderate	Moderate
Integrates knowledge across domains and scales	Strong	Strong	Strong	Strong	Moderate	Weak	Moderate	Moderate	Moderate
Identifies, makes explicit contrasting system views	Strong	Strong	Strong	Strong	Strong	Strong	Moderate	Moderate	Moderate
Facilitates social learning	Strong	Strong	Strong	Strong	Strong	Moderate	Moderate	Moderate	Moderate
Builds a shared conception of the system	Strong	Moderate	Strong	Strong	Strong	Weak	Strong	Strong	Strong
Generates new insights	Strong	Strong	Strong	Strong	Strong	Moderate	Strong	Strong	Strong
Bridges gaps between science and decision making	Strong	Strong	Strong	Strong	Strong	Moderate	Moderate	Moderate	Moderate

Indicates a claimed benefit offering a strong potential to overcome a specific barrier

Indicates a claimed benefit offering a moderate potential to overcome a specific barrier

Indicates a claimed benefit offering a weak potential to overcome a specific barrier.

Table 6: Mapping the potential of FCM to overcome the barriers encountered in the early stages of an adaptation cycle.

It is clear from the mapping exercise of Tables 5 and 6 that although both approaches offer considerable strengths in addressing early stage adaptation issues, FCM would appear on first principles to have a stronger claim to be the decision support tool of choice. It is necessary to assess both approaches under ‘real world’ conditions, with the participation of coastal adaptation stakeholders in order to confirm or deny this hypothesis with any degree of confidence.

1.8. Co-production of climate services: recent insights

Adding to the work of Moser and Ekstrom, Barnett et al. and the IPCC, several scholars have recently described the benefits and drawbacks of participatory processes in determining adaptation outcomes. Hurlbert and Gupta (2015) describe an amendment to Arnstein's 1969 'Ladder of Participation' to reflect alternate modes of participation which correspond to differing levels of problem structure, uncertainty in science and values, and learning potential (Figure 6). Of particular relevance to this research, the authors describe climate adaptation problems as typically occupying Quadrant 4, where low levels of trust and low problem solving capacity encounter unstructured 'wicked' problems. Under such circumstances, Hurlbert and Gupta suggest more research is required to better understand how problems could traverse rungs on the ladder, or move between quadrants.

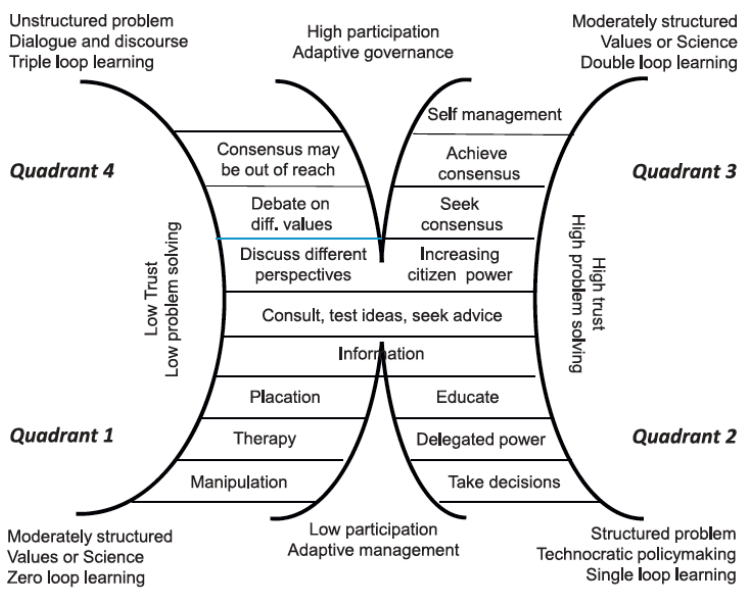


Figure 6: Hurlbert and Gupta's 'Split Ladder of Participation' (2015, p.104)

Participatory modelling approaches which facilitate triple loop learning could offer a valuable contribution here, potentially making a transition between Quadrant's 4 and 3 easier. FCM has a demonstrable record of facilitating the development of a shared view of the system of interest, despite differences in values and perspectives that might otherwise prove impossible to overcome (Özesmi & Özesmi 2004; Gray et al. 2015).

This is typically achieved by making conceptual differences in problem framing and analysis clear, in a neutral and relatively dispassionate manner, through FCM's participatory modelling process (Kontogianni et al. 2012; Helfgott et al. 2015).

Types and modes of participation are also a feature of emerging insights on the co-production of knowledge in climate services. 'Climate services' have been defined as differing from climate information "in that they are directly responsive to the needs of users of the services…[and] to be usable, they must be credible, legitimate and salient for a range of stakeholders" (WISER 2017, p.4). This conceptualisation is of direct relevance to the work presented here, in that both adaptation process methods experimented with in Cork Harbour and Tralee Bay incorporate the co-production of knowledge, with both methods attempting to pass the 'credible, legitimate and salient' threshold described above to substantively support adaptation decision making.

Vincent et al. (2018) (figure 7) describe criteria of success in co-produced climate services in terms of the extent to which they are decision-driven, process-based, and time-managed, and perhaps of greatest relevance to this research, view the quality of the process involved in producing climate services as being of equal importance to the product arrived at.

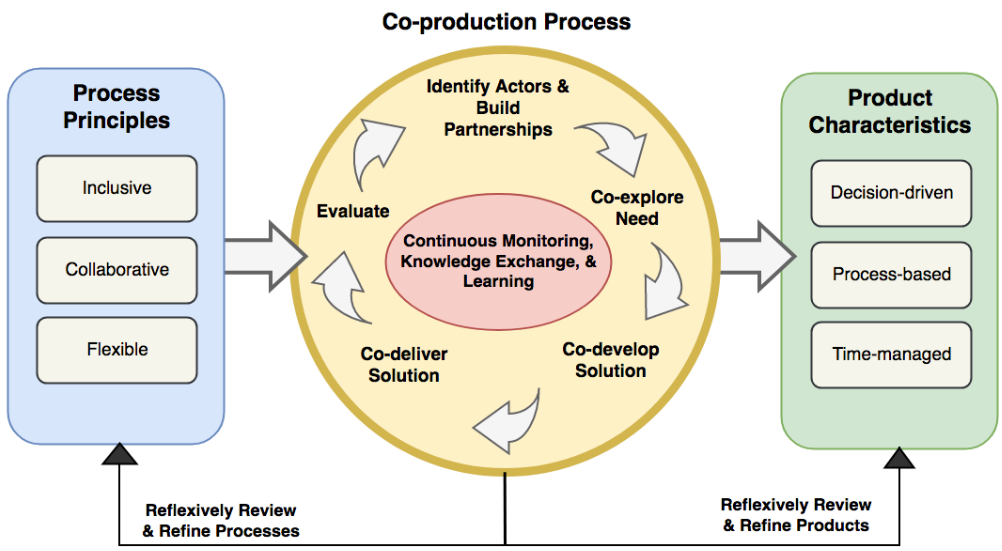


Figure 7: Product characteristics and process principles of the climate service co-production cycle (Vincent et al. 2018, p.49)

FCM is strongly aligned with the principles proposed by Vincent et al. as constituting good practice in climate service co-production. The flexible and collaborative nature of individual and group modelling using FCM ensures an inclusive approach to knowledge integration. Different conceptions of how the system under study is structured can be integrated using FCM, and co-produced individual and group models are also readily evaluated via the inbuilt capacity of FCM to produce a baseline scenario signature. The relationship of FCM outputs to climate service products is perhaps less clear, though 'climate service products' may in practice become contributory components of an FCM based adaptation process – positioning FCM as a means of ensuring process-based decision relevance.

1.9. Objectives: Assessing scenario analysis and FCM in support of improved coastal adaptation planning

The aim of this research is to address adaptation knowledge gaps in Irish coastal management, specifically supporting the generation of insights which help to answer the research questions underpinning the EPA funded CLAD project:

- How can coastal climate adaptation best be supported given existing conditions and governance structures in Irish coastal management?
- What role can the insights offered by the Adaptive and Collaborative management literatures play in securing greater coastal resilience in Ireland?
- How might climate impact and adaptation data best be scaled for use by Irish coastal planners?

This research formed one branch of the CLAD project, focussing on the decision support aspects of the research questions described above.[6] The design of decision support approaches, and evaluation of which is best suited to facilitating adaptation in Irish coastal management, draw on:

- the insights of the resilience and adaptive co-management literatures
- participatory modelling and futures research literatures
- the established literature on adaptation barriers

The papers in this thesis combine to address different aspects of these core research questions, including:

1. an assessment of how existing European 'best practice' in coastal adaptation centred on scenario analysis is suited to Irish coastal management;
2. the methodological strengths, weaknesses and participatory credentials of an alternative to scenario analysis in FCM;
3. an illustration of an FCM-based approach in practice via reference to an Irish case study;

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[6] For more information on the governance and institutional design aspects of coastal climate adaptation in Ireland see the CLAD final report: https://www.epa.ie/pubs/reports/research/climate/CCRP_28.pdf

4. an exploration of the analytical insight into barrier status provided by FCM via reference to case studies in Ireland and Scotland;
5. an assessment of to what extent the modelling artefacts produced using an FCM-based adaptation process could be used to analyse resilience.

How each paper specifically addresses these objectives is set out in greater detail below.

1.9.1 Paper 1 - "Strengthening coastal adaptation planning through scenario analysis: A beneficial but incomplete solution"

Overview

This paper provides a review of scenario analysis as a decision support tool in forward planning contexts, outlining its key strengths as described in the literature, before going on to evaluate the extent to which scenario analysis is capable of overcoming adaptation barriers in a coastal climate change adaptation process undertaken in Cork Harbour.

Objectives

To assess a scenario analysis-based approach to coastal adaptation by:

- Setting out (via reference to the literature) scenario analysis' credentials in respect to facilitating decision making in data scarce/uncertain contexts
- Describing a scenario analysis-based method of facilitating coastal climate adaptation
- Describing the use of the method via reference to a case study in Cork Harbour, Ireland
- Using a framework of adaptation barriers derived from the literature to determine how well the claimed strengths of scenario analysis perform in supporting a stakeholder driven coastal adaptation process
- Identifying where scenario analysis specifically works well and/or falls short as a decision support tool
- Gaining greater insight into the specific characteristics a futures/uncertainty oriented decision support method will require to in order to succeed

1.9.2 Paper 2 - "Fuzzy cognitive maps as representations of mental models and group beliefs"

Overview

This chapter introduces FCM as a decision support tool in environmental management contexts, describing its potential in not only illustrating individual perception of system structure and function, but also in serving as a platform for the development of a shared conception of which are the key elements and relationships of a given system. It attempts to clarify what can and cannot be defensibly inferred from the mathematical analysis of FCM, and in doing so, to establish a baseline understanding of the method's key strengths and weaknesses.

Objectives

To review the FCM literature and establish a baseline understanding of:

- How FCM can be appropriated to achieve various aims
- Why building FCMs with mixed, non-traditional expert groups can be valuable
- What the metrics of FCM might infer in complex adaptive systems analysis contexts
- What inferences might (and might not) be drawn from 'group models'
- What the strengths and weaknesses of the various ways to facilitate FCM development are

1.9.3 Paper 3 - "Caught by the fuzz: Using FCM to prevent coastal adaptation stakeholders from fleeing the scene"

Overview

Developing on the foundational insights of Paper 2, this chapter describes an adaptation decision support process, developed around FCM, which aims to specifically address the coastal adaptation challenges identified in Ireland. It goes on to evaluate the method in overcoming adaptation barriers via the Moser-Ekstrom diagnostic framework and describes a case study involving the use of the method in Tralee Bay. The method described shows considerable promise in overcoming barriers to facilitate better coastal adaptation outcomes, particularly in building a shared conception of the coastal system.

Objectives

To assess an FCM-based approach to coastal adaptation by:

- Setting out (via reference to the literature) FCM's credentials in respect to facilitating decision making in data scarce/uncertain contexts
- Describing an FCM-based method of facilitating coastal climate adaptation
- Describing the use of the method via reference to a case study in Tralee Bay, Ireland
- Using the barrier framework developed in paper 1 to assess the FCM-based method's capacity to overcome adaptation barriers
- Highlighting FCM's utility, potential for facilitating knowledge integration, and any other potential strengths or weaknesses of the approach that might warrant further inquiry

1.9.4 Paper 4 - "Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping"

Overview

This Paper illustrates an additional feature of the method described in Paper 3 in addressing coastal adaptation challenges. The encoding of key coastal decision makers' mental models allows an assessment of the extent to which various factors have entered into their thinking, and the effect of each in coming to coastal system decision making. Building on the conceptual foundations of Paper 2, the effects of disjunctures in perception regarding climate change between local and national level stakeholders are illustrated, via references to case studies in Tralee Bay in Ireland, and The Outer Hebrides in Scotland. Referring to the Moser-Ekstrom diagnostic framework, the chapter illustrates that conclusions may be drawn regarding how climate change impact knowledge gaps can be addressed in order for local scale decision makers to come to fully informed and nationally coherent adaptation decisions.

Objectives

To assess the utility of FCM in identifying and illustrating the impact of adaptation barriers by:

- Describing the analytical metrics and measures available via FCM
- Illustrating how these might be used to gain important insights into the problem framing of coastal adaptation decision makers
- Describing the use of the method via reference to case studies in Tralee Bay, Ireland, and the Outer Hebrides, Scotland
- Analysing the differences between stakeholders in key barriers encountered during the 'understanding' phase of an adaptation process
- Highlighting the implications of any differences in signal detection, problem framing, etc between central and local scale agents of adaptation action

1.9.5 Paper 5 - "Using Fuzzy Cognitive Mapping as a participatory approach to measure resilience, change, and preferred states of social-ecological systems"

Overview

The final chapter of the thesis assesses the extent to which FCM can serve as a tool to analyse systemic transition toward an alternate basin of attraction. This is a key feature of resilience analysis and would be of benefit in Irish coastal adaptation contexts given the potential need for transformative change in order to substantively reduce coastal vulnerability to climatic risk. The chapter finds that no truly objective, quantitative conclusion may be drawn with respect to shifts in system steady state using FCM alone. There may nevertheless be considerable benefit to stakeholders involved in an adaptation process envisioning change in these terms, with the limited effect of incremental change on the trajectory of key system nodes being made explicit.

Objectives

To assess whether progress toward (or away from) desired social-ecological system resilience attributes can be measured using FCM, by:

- Describing a method of participatory resilience analysis using FCM

- Establishing the FCM baseline scenario as a corollary of the resilience theory 'basin of attraction'
- Illustrating the role of variable 'clamping' and/or the addition of new concepts to create alternate scenarios, potentially indicating a transition to an alternate basin of attraction
- Assessing the extent to which the method might be employed in resilience assessment via reference to a case study in Tralee Bay, Ireland.

Supplementary material: This provides insight into the contribution of this work in seeking to fill the knowledge gaps highlighted by EC Adaptation Strategy Action 4 and the Irish NCCAF.

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Part II: THE EFFICACY OF SCENARIO ANALYSIS IN SUPPORTING COASTAL CLIMATE ADAPTATION

2.1. PAPER 1

*2.1.1 **Gray, S.**, O'Mahony, C. Hills, J. O'Dwyer, B. Devoy, R. and Gault J. **2016**, "Strengthening coastal adaptation planning through scenario analysis: A beneficial but incomplete solution", Marine Policy, doi.org/10.1016/j.marpol.2016.04.031*

This combined state of the art review and case-study analysis paper explores the role and value of conventional scenario analysis in overcoming barriers to coastal climate change adaptation at the local scale. The paper opens with a review of current thinking on adaptation 'best practice', going on to catalogue known barriers to achieving meaningful adaptation progress at the local scale, relating these to the stages of an idealised adaptation cycle.

The potential role of scenario analysis in overcoming these barriers is then established via reference to the literature, and a framework by which its efficacy as a decision support tool in the context of local scale climate change adaptation is set out.

The paper then moves on to describe a case study of scenario analysis in practice, drawing on primary research conducted in Cork Harbour, Ireland. The efficacy of scenario analysis in overcoming climate change adaptation is assessed, and the strengths and weaknesses of approaching climate change using the nascent orthodoxy of scenario analysis as a component of an adaptation cycle are discussed.

The paper concludes with suggestions on how current challenges in overcoming barriers might best be addressed.

CONTRIBUTION STATEMENT

Declaration of own contribution to the published (or intended for publication) scientific papers within my dissertation.

DISSERTATION TITLE: Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping

PAPER–1: **Gray, S.**, O'Mahony, C. Hills, J. O'Dwyer, B. Devoy, R. and Gault J. **2016**, "Strengthening coastal adaptation planning through scenario analysis: A beneficial but incomplete solution", Marine Policy, doi.org/10.1016/j.marpol.2016.04.031

OWN CONTRIBUTION IN THIS WORK: Concept development (fully), Literature search (fully), Methods development (fully), Research design (fully), Data collection (mainly), Data analysis (fully), Construction of the manuscript (fully), Argumentation (fully), Critical revision of the article (mainly).

Stefan Gray, MSC

July 11, 2019

Strengthening coastal adaptation planning through scenario analysis: A beneficial but incomplete solution

S. Gray, C. O'Mahony, J. Hills, B. O'Dwyer, R. Devoy, J. Gault

Abstract: Adaptation to climate change is an increasing priority for coastal management. European Union and Member State adaptation policies and strategies have been promulgated but associated with minimal delivery of adaptation interventions and tangible gains in resilience. Generic stages of adaptation and barriers to adaptation have been identified; various tools or instruments have potential to strengthen adaptation delivery. Scenario analysis is one tool which provides a description of alternate possible future states and has been used to support adaptation planning. This work aims to assess how readily those engaged in coastal management decision-making are able to develop and utilise scenarios of change for adaptation and whether it represents a 'best practice' approach for adaptation planning. The scenario analysis facilitated many aspects of the adaptation process, which ultimately led to a tractable adaptation strategy being produced. However, pathways for integrated approaches to co-deliver adaptation were less evident. The planning horizon, much beyond usual governmental budget and project cycles, the need for trade-offs and embedded institutional constraints meant that a majority of those who had started out on the scenario analysis became disengaged by its conclusion. The analysis undertaken concurs with theoretical work which projects a tail-off of the benefits of scenario analysis at the later stages of the adaptation cycle. The work concludes that scenario analysis offers the potential to overcome key barriers to adaptation progress. However, the gains may be limited as the institutional drivers for longer-term pro-active planning may be weak compared to present day roles, responsibilities and competitive pressures.

1. Introduction

With the evidence becoming ever clearer that adaptation to climate change must be a coastal management priority, the lack of notable progress in planning and implementing adaptation measures is concerning. Questioning the extent to which commonly advocated approaches to supporting adaptation might be taken up by the coastal management practitioner community is thus appropriate. Among such approaches, a practice which typically figures heavily is the development and use of scenarios of future change. The aim of this paper is therefore to assess how readily those engaged in coastal management decision making are able to develop and utilise scenarios of change, in particular assessing whether the manner of scenario work which is increasingly widely advocated in the academic and grey literatures as 'best practice' is fit for its intended purpose.

2. Climate change adaptation: 'best practice' and common barriers

The impacts of climate change on the world's coastal margins are likely to be profound [16]. Rising sea levels and increasing surge heights already pose a significant hazard to many islands in the Pacific, Indian and Arctic Oceans and the Caribbean Sea [19]. Similarly, sea level rise has acted in concert with developmental pressures to result in increasing saline intrusion within coastal aquifers [33]. A significant pole-ward biogeographical migration of cornerstone planktonic species [6], and in turn the highly valued commercial marine species of higher trophic levels who track their distribution [30], has seen further strain on an already vulnerable fisheries sector [3], and though the specific linkages between climate drivers and complex coastal pressures such as erosion, storm damage and extreme events are by no means yet unequivocally understood [21], there are nevertheless indications that alterations in the expression of climate controls on coastal systems will likely result in the increased severity of these impacts [18].

2.1 Adaptation progress in Europe to date

In Europe, high-level policies have now been in place at EU level (Adaptation White Paper; EC/COM/216), and also at Member State level in many cases (e.g. UK Climate Change Act 2008) for a number of years. Yet despite these supporting frameworks, and mounting evidence of the current and future risks associated with climate change, there has been relatively little indication of action being taken pre-emptively to adapt to its impacts. Berrang-Ford and colleagues report that the academic literature reflects a clear disjuncture in developed nations between the formulation of high level climate policy and effective, 'on-the-ground' adaptation, prompting in turn "concerns about the likelihood of effective adaptation given the speed of climate change and limited window of opportunity for action" [7], p.334). In a survey of adaptation undertaken in the UK, Tompkins et al. (2010) report a similar trend; top-down policy has spurred efforts within some sectors and public sector administrations to begin a rudimentary assessment of the risks and possible impacts of climate change, but there is little evidence of these efforts being translated into pragmatic adaptation steps at the local authority level.

Nevertheless, a number of plans, projects and actions with direct or ancillary adaptation benefits have been identified in Europe, providing path-finding examples which others might follow (Pijnappels and Dietl, 2013). It is also worth noting that autonomous (essentially reactive) adaptations that have traditionally taken place in economic and social systems as circumstances change are also likely to play an important role in adaptation to climate change [13]. A relatively rudimentary form of adaptation in Europe is therefore occurring, Tompkins and colleagues finding evidence of both ancillary and autonomous adaptation measures in their 2010 survey. These examples do not, however, meet the standards demanded by higher level policies (COM (2013) 216; [13]; [11]; 2002/413/EC). These various policies, strategies and recommendations advocate pre-emptive adaptation processes at the local scale, broad stakeholder participation, and long-term orientation. This shortfall may result in societally unacceptable levels of risk being borne prior to adaptation measures becoming effective, and at a much higher economic cost.

2.2. Barriers to overcome in effecting adaptation at the local scale

The potential causes of this disparity between top-down policy intent and bottom-up adaptation activity have recently come under scrutiny in the academic literature. [20] provide a comprehensive framework by which a number of generic barriers to adaptation might be diagnosed. Under this framework, potential barriers to the adaptation progress are differentiated via the stage of the adaptation process at which they typically occur. Barriers relating to stages one, two and three of the adaptation process, illustrated in Fig. 1, are those that might be potentially overcome through the development and utilisation of scenarios, and are tabulated in Table 1.

2.2.1. Coastal management practice in Europe: implications for overcoming adaptation barriers

The financial and human resources allocated to Integrated Coastal Management typically fall outside formalised institutional structures and government expenditure (McKenna and Cooper, 2006; [23]; [22]. Coastal management has developed strongly within the frame of Integrated Coastal Zone Management (ICZM) which, in Europe anyway, is best characterised by principles including communication, engagement, governance [4]. This broad and cross-government approach tends to lead to a reliance on higher level programmes (i.e. EU, World Bank, UNEP) to support implementation. In that context, much must be undertaken by a small number of (often local authority) staff, leading to a strong reliance on voluntarism, ad-hoc project-based initiatives and stakeholder goodwill if progress is to be made on coastal issues (McKenna and Cooper, 2006).

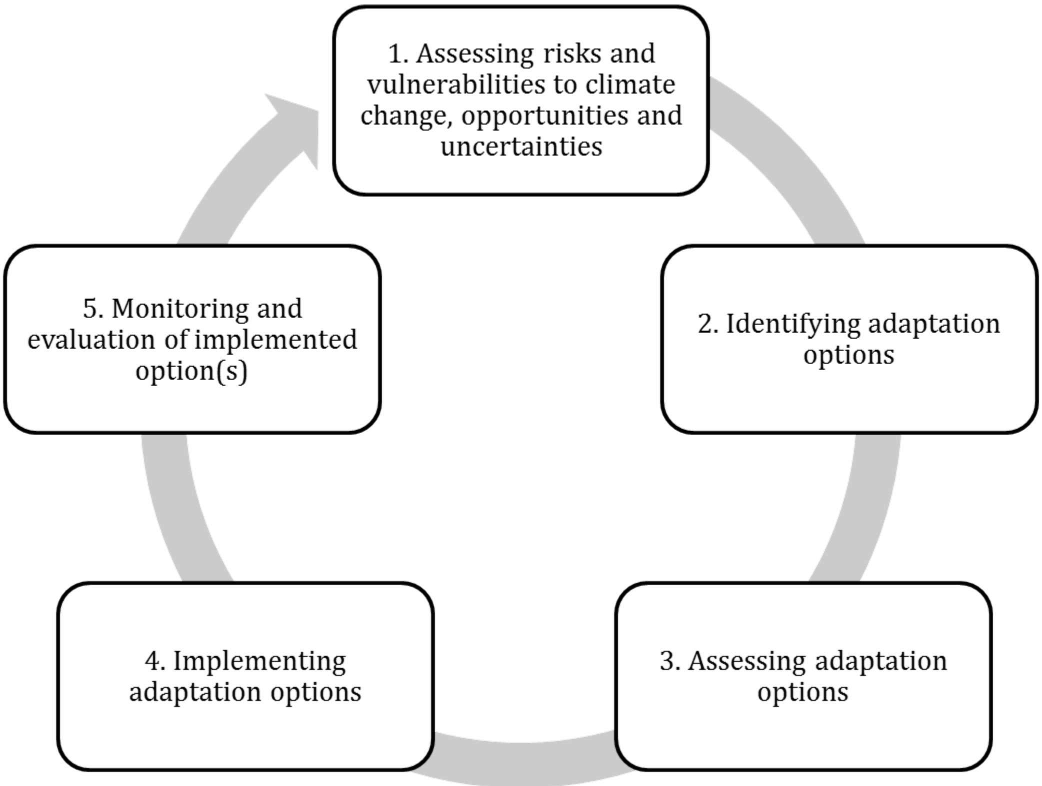

Figure 8: A generic adaptation process [13].

These financial and organisational constraints limit the capacity of coastal management practitioners to hire expert consultants or employ specialists to undertake an adaptation process (though doing so would likely weaken the integration of adaptation within wider coastal management practice in any case). It is therefore of utmost importance that all steps in an adaptation process are practical, pragmatic and readily accomplishable by those already active in coastal management.

3. Adaptation to the impacts of climate change: theoretical insights

A clear consensus regarding how adaptation should be undertaken is now beginning to emerge in the literature [1,14,20,26]. This nascent 'best practice' states that adaptation actions must be primarily locally devised and implemented, with top-down (transnational and national) policy forming a critical supporting structure [13]. The generic stages of an idealised adaptation process have been described in some detail in both the academic and grey literatures (Fig. 1). In practical terms, local contextual factors will determine the extent to which an adaptation process adheres to this idealised design [20]. Nevertheless, for the efficacy of adaptation efforts to be maximised, the tasks and actions described at each stage of the process must be addressed in some form.

3.1. Scenario methods and futures research

Scenarios embodying descriptions of alternate possible future states of social, political or environmental spheres have been a feature of human planning and discourse since the classical period [8]. [36] define scenarios as "purposeful stories about how the contextual environment could unfold over time", consisting of a description of an end state, an interpretation of how current conditions will evolve, and an internally consistent account of how the envisioned future might logically unfold. Planning exercises built around this conception of scenarios emerged as a tool for the development and analysis of military strategy in the early stages of the cold war [17]. Scenario planning methodologies have now been in use for some 60 years across a range of sectors and fields [9], most notably in the field of corporate strategy formulation via the RAND Corporation and Royal Dutch Shell [31].

Adaptation cycle stage:	**Adaptation barriers:**
1. Assessing risks and vulnerability to climate change, opportunities and uncertainties	• Understanding the system - Identification and agreement of core elements, functions and baseline conditions of the system • Detection of the problem – Signal detection, thresholds of concern and action, framing of the problem, perception of need for and feasibility of adaptation action at the local scale • Gathering and using information – Stakeholder interest and focus in the issue; availability, accessibility, salience, relevance, credibility and legitimacy of information; identification and engagement of local expert stakeholders; facilitating data/information/knowledge exchange between local and higher scales; receptivity of stakeholders to engage with and use new information; • (Re)-defining the problem – Re-framing of problem in light of climate change information (incl. thresholds of concern, response need, feasibility of action); reaching agreement on appropriate course of actions (incl. consensus if required to legitimise adaptation action)
2. Identifying adaptation options	• Core adaptation assumptions – Ability to identify and agree on adaptation objectives and criteria for evaluating their success; ability to identify and agree on expected effects of adaptation options within the system

	• Emergence of local leadership – Capacity to identify appropriate agents to effectively and legitimately enact local adaptation options; capacity to engage and incorporate local leaders within the adaptation process • Identifying adaptation options – Capacity to identify a range of adaptation options available to realise objectives; capacity to create and agree on experimentation with new adaptation options where appropriate
3. Assessing adaptation options	• Assessing options – Availability of data/information to assess options; capacity to access/use data; availability of methods to asses/compare options; perceived credibility, salience and legitimacy of option assessment methodology; • Selecting option(s) to implement – Ability to agree on appropriate adaptation option(s) to implement; ability to identify and agree on appropriate performance measures and thresholds of concern regarding selected option(s)

Table 7: Barriers to address during the stages one, two and three of an adaptation process (adapted from [20]).

3.1.1. Typology of scenarios

The futures research literature describes scenarios as falling into three broad categories, delineated by their method of generation, intended purpose and the central question they seek to resolve within a given decision context [28,5,9].

Predictive scenarios are typically quantitative and computer generated, offering data on the plausible evolution of a modelled system of interest given the occurrence of a theorised series of events, and the accuracy with which cause-effect relationships are parameterised [9]. These scenarios seek to determine what will happen in the future. Examples of predictive scenarios include climate model runs or traffic flow forecasts.

Explorative scenarios are typically qualitative in nature and look to explore a range of potentially plausible outcomes resulting from the interplay of significant but uncertain drivers of change [9]. Scenarios of this type are more explicitly subjective and intuitive than predictive scenarios (though both are ultimately reliant upon the subjective input of scenario-builders). Explorative scenarios attempt to understand what could happen in the future, with notable examples of this type of scenario being those employed by Royal Dutch Shell in strategy development prior to the oil shocks of the 1970s.

Normative scenarios fulfil a different role, in that rather than working toward a pre-determined future date, these scenarios are 'backcast' from an idealised future toward the present [12]. The circumstances described within a normative scenario thus represent an optimal, highly desirable future that those participating in the scenario planning process would wish to see realised [29]. Working back from this desired end point, participants describe the incremental actions and events upon which its realisation is contingent. This approach to scenario planning is used to help clarify to decision makers what should happen in a given circumstance.

In practice, these alternate scenario types are often hybridised or used sequentially within a broader scenario planning process [10]. Alcamo and Heinrichs (2008) describe scenario-planning processes that involve not only the development (or building) of scenarios, but also the subsequent evaluation of their consequences in support of decision-making regarding the future, as 'scenario analysis'. For the remainder of this paper, the term scenario analysis will be used in this sense.

3.1.2. Claimed strengths of scenario analysis

Scenario analysis could provide a range of tools for adaptation planning, ranging from a technical perspective of the possible "future" to contributing to dissemination and engagement. [37] identify a number of claimed benefits of scenario analysis in the futures research literature (Table 8).

It is possible to track these claimed benefits onto the barriers in the stages of an idealised adaptation management cycle to identify a potential role for the scenario approach. It can be seen (Table9) that scenario analysis has a major role in addressing most barriers associated with the early-stage assessment of risks of vulnerability. The benefits of the approach are less pervasive in the second and third stage of the adaptation cycle, although potential benefits in communication and organisational learning are consistent across all stages. This suggests that scenario analysis could have a significant role as one of a number of tools or instruments used in a robust adaptation approach. However, it is not clear how the benefits of scenario analysis would interact with the benefits of other tools to advance adaptation; the best group of approaches may differ depending on the local specificity, suggesting no one single optimal suite.

With the apparent adaptation barriers in the EU and the purported benefits of scenario analysis (Table 7), this paper therefore aims to assess how readily those engaged in coastal management decision making are able to develop and utilise scenarios of change and whether it represents a 'best practice' approach for adaptation planning.

Claimed benefit:	**Achieved through:**
Enhances perception	• Aiding in identification and understanding of key trends • Increasing managers sensitivity to change • Allowing managers assumptions about the system and the

	future to be made explicit • Diminishing ‘anchoring’ bias (viewing the perpetuation of present conditions into the future as the most likely outcome)
Deals with uncertainty	• Offering a structured approach to complexity, acknowledging the unknown • Allowing insight into what is of long-term significance and what is transient (and thus of less relevance in future planning) • Highlighting the plausibility of alternate futures diminishes bias toward underestimation of uncertainty
Integrates planning	• Providing a platform for the integration of formal and informal data, information and knowledge • Allowing the integration of disparate management functions and plan elements due to the flexibility of inputs within the scenario building process
Enhances communication	• Offering a logically argued and neutral framework for discussion of the future, both within and between organisations • Integrating a range of future issues and options into a coherent, communicable whole, spurring organisational action • Providing enduring channels of communication (opened among participants during the scenario development process) beyond its project lifecycle
Organisational learning	• Requiring conventional hierarchies and silos to be overcome during scenario development, stimulating intra- and inter-team creativity • Offering the opportunity for risk-free experimentation with strategic options under alternate futures • Highlighting inconsistencies in current thinking through demanding plausibility in the cause-effect relationships underpinning each scenario • Extending, challenging and altering the mental models of participants through requiring the research of and accounting for a diverse range of systemic drivers of change

Table 8: Claimed management benefits of scenario analysis found in the literature (adapted from [37]).

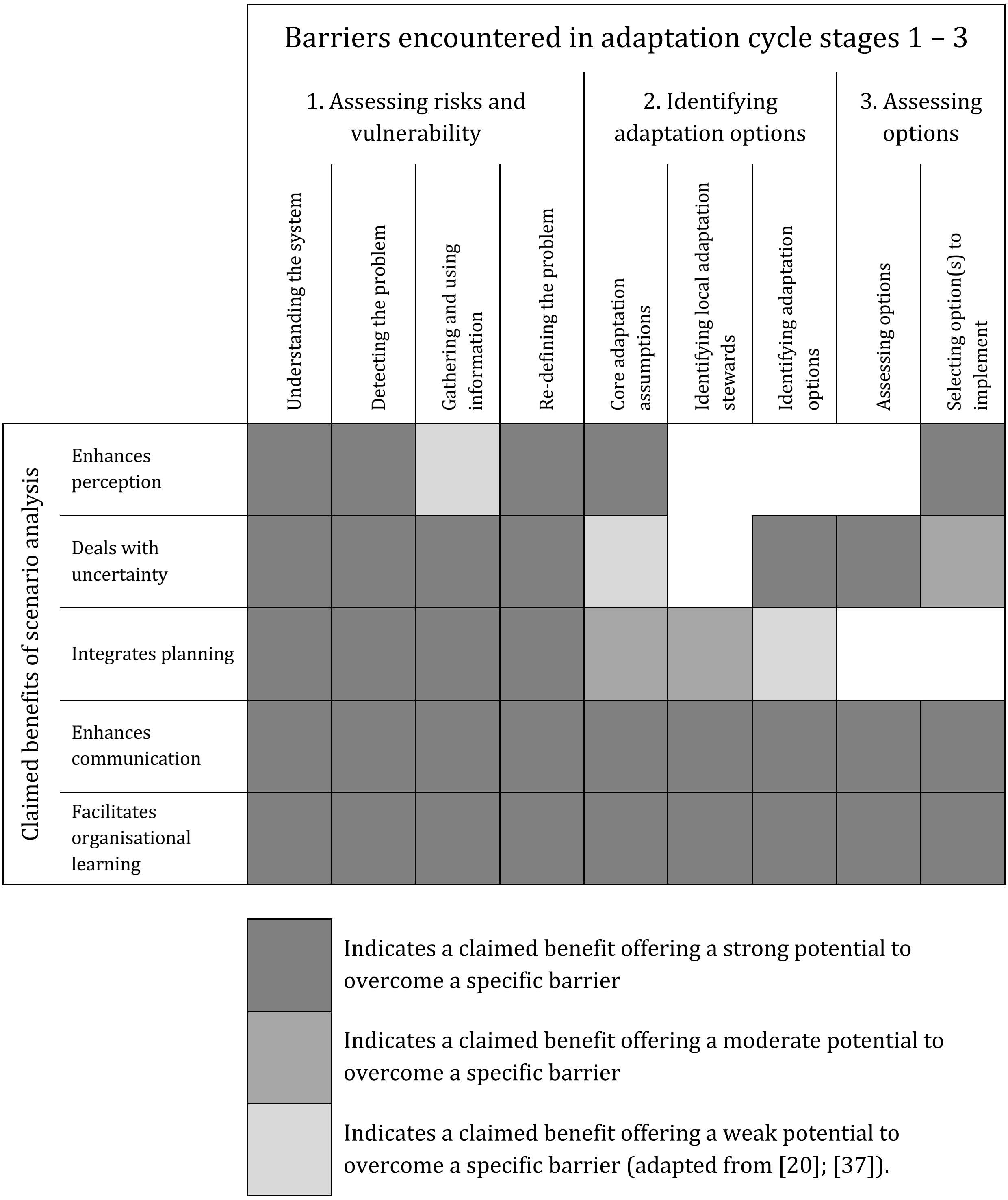

Table 9: Mapping the potential of scenario analysis to overcome the barriers encountered in stages 1-3 of an adaptation cycle.

4. Methods

4.1. Case study site description

The Cork Harbour case study site in Ireland was selected to assess the tractability of employing scenario analysis to overcome barriers to climate change adaptation at the local scale. Due to the novel Expert Couplet Node approach employed under the IMCORE project – where an academic institution is paired with local coastal management practitioners, the site provided an opportunity to work with active coastal management practitioners and stakeholders as equal partners alongside academic researchers throughout the process. Further detail on the approach of the IMCORE project and on the Cork Harbour field site can be found on the project website (www.coastaladpatation.eu). A majority of stakeholders involved (across both the practice and research spheres) had little or no previous experience of developing and using scenarios, and the site had not yet embarked on an adaptation process.

Positioned on the SW coast of Ireland, Cork Harbour extends approximately 20 km from a narrow channel entrance at Roches' Point to the urban centre of Cork city - Ireland's second largest city. Cork Harbour is a strategic location in terms of trade, industrial development and national infrastructure, as well as being important with regard to built and cultural heritage; a number of sites of national and international ecological significance can also be found within the confines of the harbour [24]; Gault et al., 2011). As part of a participatory-based process to support integrated management and climate adaptation, the Cork Harbour Expert Couplet Node collaborated with a range of statutory and non-statutory stakeholders with an interest and/or role in the management and spatial planning of the harbour (for further details of stakeholder engagement and ECN activity, see [24]; and [25]). Dialogue with numerous stakeholders revealed flooding to be the priority (direct and indirect) impact in the context of climate change and Cork Harbour; thus, making Cork more flood resilient became the focus of efforts to advance adaptation.

4.2. Scenario analysis methodology

The scenario analysis methodology used at the Cork study site emerged from a detailed literature review and series of transboundary working group meetings convened under the IMCORE project, and constitutes scenario analysis orthodoxy as interpreted by the academics and practitioners involved. It draws on the DPSIR framework as well as more recently on developments and definitions from various involved agencies (e.g. UNDP). The methodology had a number of stages in the development, selection and detailing of the future scenario:

1. Issues and drivers – identity issues and drivers over the planning horizon.

2. Plot issues – plot each issue on axes of significance and certainty.

3. Emerging axes – identify the main trends of the issues in the highly uncertain but significant quadrant of the axes.

4. PESTLE analysis – assess the four quadrants of the emergent axes in relation to the following characteristics: P for Political; E for Economic; S for Social; T for Technological; L for Legal; and, E for Environmental.

5. Scenario selection – select the most desirable scenario (quadrant) of the emergent axes based on the PESTLE.

6. Detailed scenario – provide more information on the various dimensions of the selected scenario.

7. Scenario backcast – identify the key phases or task which needs to implemented starting from the desired situation at the end of the planning horizon, backwards to present day.

Further explanation of each of these stages is provided in the next section and a full description of the methodology can be found on: www.coastaladpatation.eu.

5. Results

The case study site completed the full scenario analysis process as outlined previously. The results of the process are presented in Table 4 below.

5.1 Identify issues and drivers

An expert stakeholder group attended a facilitated workshop in Cork where drivers of change were elicited and characterised for a) the level of uncertainty surrounding the future expression of each driver, and b) the level of significance each would have in determining how climate adaptation issues would unfold in the future. A Likert scale was employed to allow stakeholders to categorise the drivers in a relatively quick and clear manner.

5.2. Plot issues

The drivers elicited from stakeholders were plotted on axes of 'significance' and 'uncertainty' using the Likert scale scores as a guide of where each should fall (Fig. 9). This offered the stakeholder group another opportunity to view the respective positions of drivers against each other with respect to their significance and certainty.

5.3. Select emerging axes

The next stage of the process involved selecting those drivers of change considered by stakeholders to be most highly significant and uncertain. These drivers were plotted against each other to form new axes of polarity around which exploratory scenarios were subsequently developed (Fig. 10).

5.4. PESTLE analysis

A PESTLE (political, economic, social, technical, legal and environmental) analysis was carried out on each of the four quadrants of the emergent axes, describing the evolution of each of these categories under the future conditions each quadrant would plausibly promote. These four possible futures constitute exploratory scenario (Fig. 11).

5.5. Scenario selection

Stakeholders were asked to identify a single scenario (or hybridised mix of elements of more than one scenario) which they would prefer to see realised in the future.

5.6. Detailed scenario

The scenario selected by stakeholders was subject to a further PESTLE analysis, this time going into much greater detail than previous analyses in order to build a relative rich depiction of what the desired future entailed with respect to adaptation. Again, this scenario was circulated among stakeholders for comment, amendment and finally validation.

5.7. Scenario backcast

A further facilitated workshop was convened in order to conduct a backcasting exercise. At this event, stakeholders were asked to describe the incremental actions under each PESTLE category that they saw as necessary in order for the desired future to plausibly be realised (as indicated in Fig. 12). A critical dependencies approach was taken to the facilitation of the workshop, wherein stakeholders were asked to identify each critical factor required in order to allow subsequent dependent factors to be plausible (Fig. 12).

Scenario analysis stage	Cork results
1. Issues and drivers	66 drivers
2. Plot issues	5 significant/uncertain drivers
3. Emerging axes	'Attitude to climate science'/'Economic vision'
4. PESTLE analysis	4 internally consistent, plausible exploratory scenarios
5. Scenario selection	1 hybridised '5th scenario'
6. Detailed scenario	1 A4 page description of the preferred scenario; images accompanying the description
7. Scenario backcast	12 action categories, giving rise in turn to 40 adaptation activities

Table 10: Scenario analysis stages

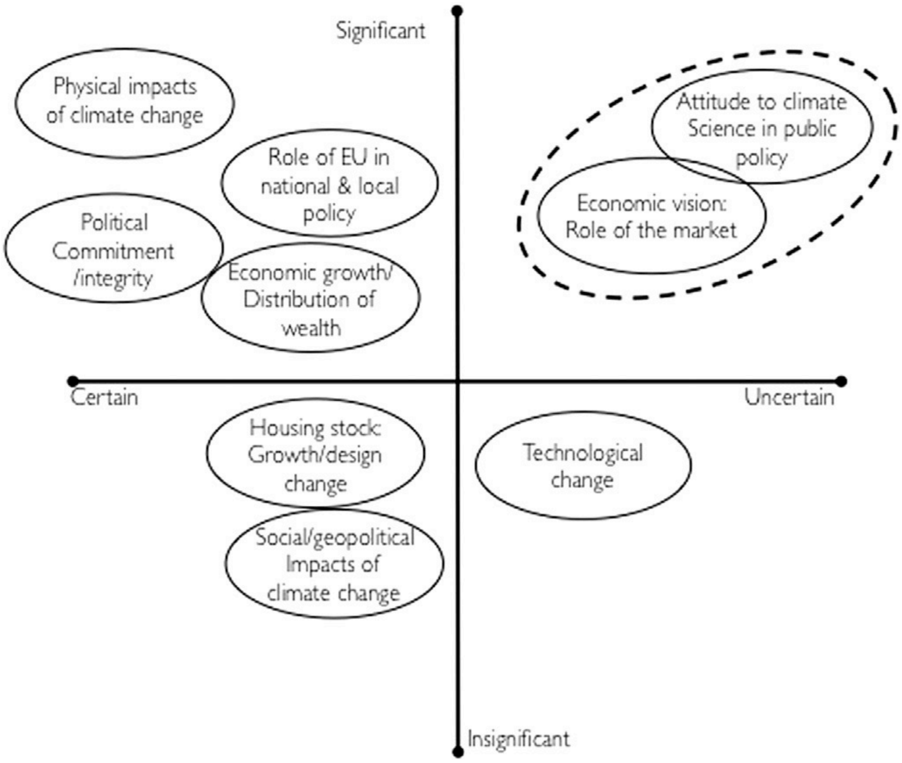

Figure 9: Drivers of change plotted on axes of significance and uncertainty

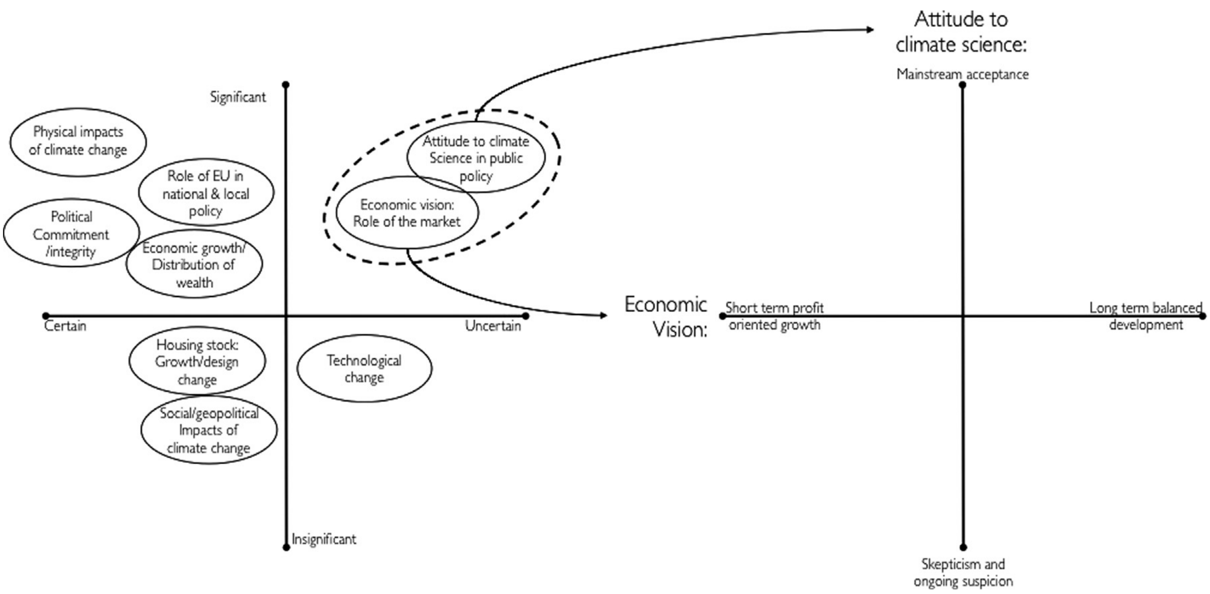

Figure 10: Building new 'axes of polarity' from the most significant and uncertain drivers of change

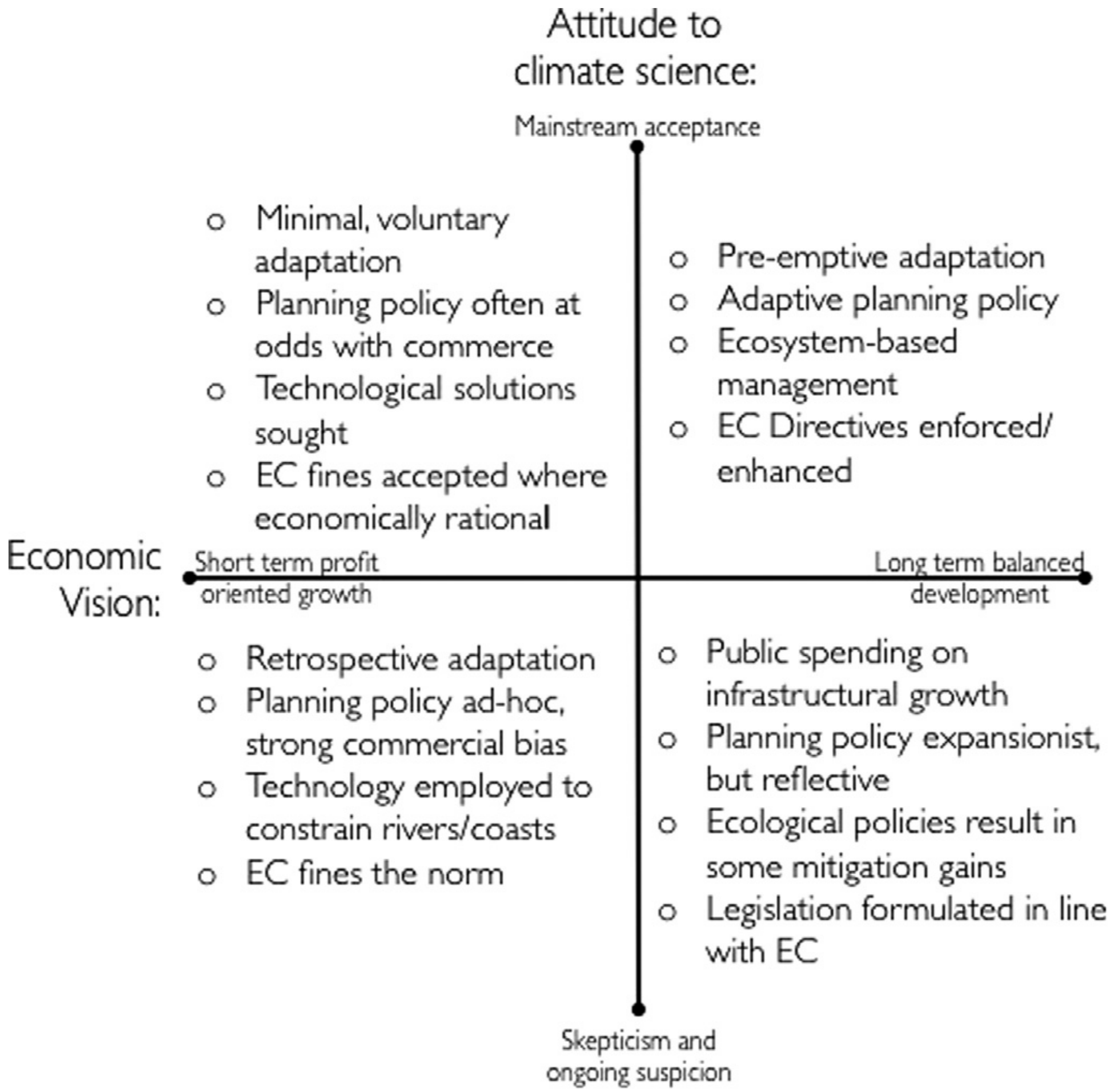

Figure 11: Outline of the four exploratory scenarios. Each scenario was developed in detail, and a drafted single page description of the future circumstances that might see each occur was circulated among stakeholders for comment and amendment.

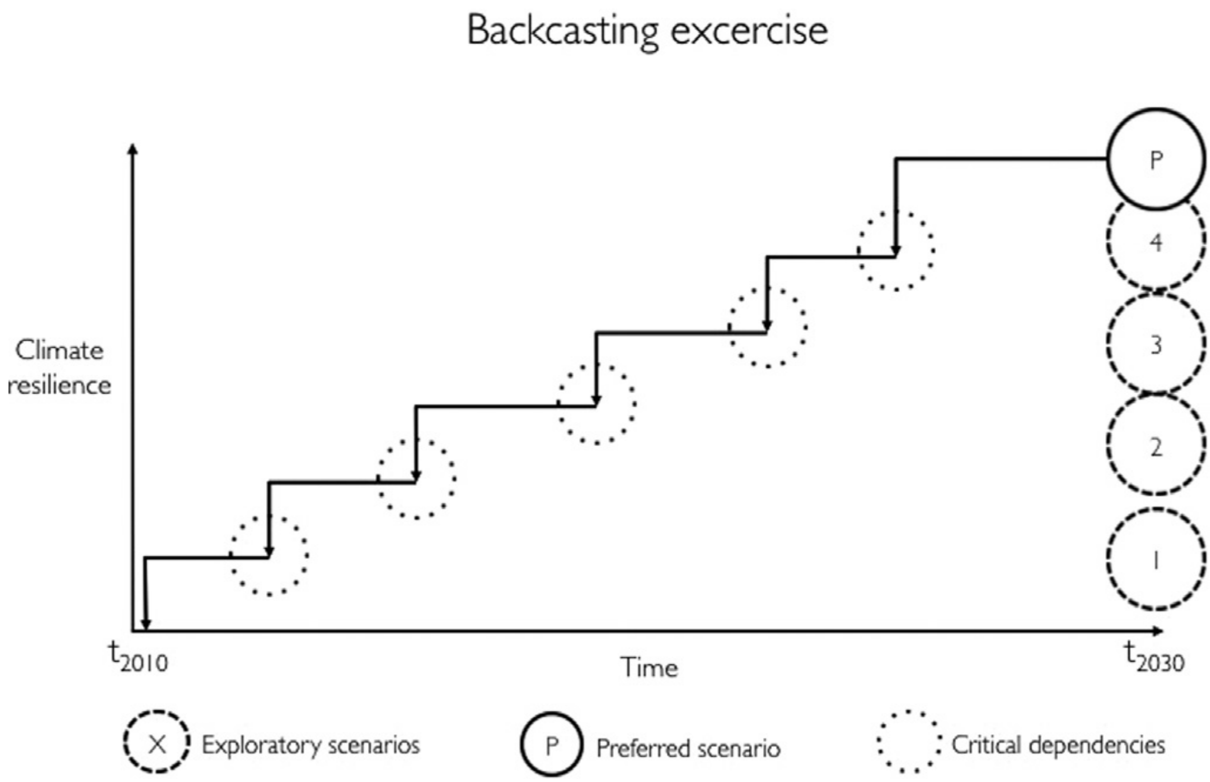

Figure 12: A schematic illustrating the concept of critically dependent factors – those required to be in place before the preferred scenario can be realised. This approach was used to facilitate the backcasting exercise.

6. Discussion

The scenario analysis undertaken in Cork proved effective in facilitating many aspects of the adaptation process, which ultimately lead to the production of a tractable adaptation strategy. However, some elements of scenario analysis were appreciably more effective in achieving their stated aims than others. By referring back to the matrix of claimed benefits of scenario analysis in overcoming the barriers to adaptation, these limitations might be more clearly illustrated.

Table 5 maps the scenario analysis onto the matrix, with each number representing a stage of the analysis where a claimed scenario benefit might most readily be harnessed in overcoming an adaptation barrier. Discussion of the scenario analysis stages is thus structured around their performance in overcoming these barriers.

6.1. Assessing risks and vulnerability to climate change, opportunities and uncertainties

As Table 11 illustrates, the elements of scenario analysis offering a strong potential to overcome barriers to adaptation were most prominent during this phase of the adaptation process. The relative clarity and illustrative power of the driver elicitation stage of the analysis was well suited to enhancing stakeholders' understanding of how the coastal system functions. Encouragingly, stakeholders had very little difficulty in identifying and characterising key drivers of change; with a number of expert stakeholders who attended the driver elicitation workshop confirming that the cause-effect relationships hypothesised by the group were scientifically valid. Furthermore, feedback from participants highlighted that a majority found this aspect of the process

		Barriers encountered in adaptation cycle stages 1 – 3								
		1. Assessing risks and vulnerability				2. Identifying adaptation options			3. Assessing options	
		Understanding the system	Detecting the problem	Gathering and using information	Re-defining the problem	Core adaptation assumptions	Identifying local adaptation stewards	Identifying adaptation options	Assessing options	Selecting option(s) to implement
Claimed benefits of scenario analysis	Enhances perception	1	2	3	3	5				6
	Deals with uncertainty	1	2	3	3	5		6	7	7
	Integrates planning	1	2	4	4	5	1	6		
	Enhances communication	1	2	3	5	5	1	4	5	6
	Facilitates organisational learning	1	2	3	5	5	1	4	7	7

Table 11: Mapping scenario analysis method steps onto the matrix of claimed scenario benefits and adaptation barriers. Each number represents a step in the IMCORE scenario analysis method at which the claimed benefit of scenario analysis was harnessed to move the adaptation process forward.

very useful in promoting the sharing of knowledge, establishing trust and providing a clearer overall picture of how the coastal system might be sustainably managed. These exchanges allowed a relatively fluid exploration of how problems might emerge in the management of each coastal system under climate change. Alternate hypotheses were put forward and discussed in an open and constructive manner, with little sign of common conflicts that can arise in mixed stakeholder coastal management fora. The ease of facilitation of the workshops, in conjunction with the relative simplicity of post-workshop data analysis, made scenario analysis particularly strong in overcoming barriers regarding system understanding and problem identification.

Where scenario analysis performed somewhat below expectation was with respect to overcoming barriers to the gathering and using of information and re-definition of adaptation problems. Steps one and two of the scenario analysis had gone some way toward opening the minds of stakeholders to synthesising new information and framing problems differently in light of the perspectives these insights offered them. However, as the analysis moved into the selection of emerging axes and drafting of exploratory scenarios, a degree of confusion, and in some instances even disengagement with the process, became evident among stakeholders. Obvious ambiguities in the scenario method led some to question the extent to which its outputs might be considered objective and scientifically replicable. This led to stakeholders investing greater energy in debating the method underpinning the process than how adaptation could best be pursued.

6.2. Identifying adaptation options

Despite a clear willingness by all participants to share knowledge and collaborate more readily to develop a fuller understanding of Cork Harbour as a coastal system in the context of climate change, the pathways for integrated approaches to co-deliver adaptation were less evident. While agreement was forthcoming on the general nature of adaptation actions needed (for all PESTLE categories), and to a lesser extent the types of activity required to implement these actions, participants were more reluctant to proffer a leading role. This is perhaps expected as the process was a relatively new departure in terms of management approach (integrated) and focus (adaptation), and participants were unclear about the implications of taking on a lead responsibility for the co-ordination of certain actions (e.g. a full cost-benefit analysis; concerns regarding overstepping jurisdictional boundaries and institutional roles). Furthermore, at the time of the scenario process, national policy with regard to climate adaptation was not yet formalised and would have been ambiguous to many participants. Therefore, some concerns existed amongst participants that what was being undertaken at a local level might ultimately be inconsistent with national policy; and, despite being viewed as a beneficial process with regard to capacity building, awareness raising and information sharing, the process was undermined by the policy and legislative vacuum in which it was conducted. The uncertainty regarding national policy influenced the allocation of responsibility for adaptation actions, with a clear onus being placed on local government by all participants to lead and deliver many of the activities identified within the PESTLE analysis.

6.3. Assessing adaptation options

The backcasting exercise and associated timelines (2030 and beyond) proved even more difficult for participants to navigate. Participants demonstrated a stronger preference for identifying actions necessary to bring about the desired future that were achievable in the immediate to near future. The profiling (activities, roles and responsibilities) of longer-term actions was shackled by contemporary institutional, legal and economic constraints, and a hesitancy about the level of reform needed –

leading participants to relegate what should happen in preference to actions that were more aligned with what was likely to happen. The planning horizon used was also outside the typical planning cycle used by participants. This is significant as the long planning horizon means that there is no present day "worry" factor, which is an important driver in management decisions [32], as well as a pervasive perception that climate change has been exaggerated [34]. This lack of a "worry" factor as well as the perception of "exaggeration", coupled to the uncertainty that accompanies longer planning projections, perhaps contributed to this element of the scenario process being less effective, and ultimately, resulting in a majority of those who had started out on the scenario analysis becoming disengaged from it by its conclusion.

6.4. A critical examination of the role of scenarios in adaptation

Scenarios have been identified as playing role in improving the degree of local adaptation through promoting a move from autonomous (essentially reactive) to pre-emptive adaptation [27], which may provide increased social and economic stability as well as more cost-effective adaptation [15]. The work presented previously had identified from literature sources the constraints of the adaptation process and potential benefits of the scenarios process in overcoming these constraints. The suggestion of this linkage is that scenario analysis becomes weaker at delivering the later stages of the adaptation cycle (as demonstrated in Table 3). The analysis undertaken at Cork concurs with this tail-off of the benefits of scenario analysis at the later stages of the adaptation cycle. However, in practise the tail-off of benefits was even greater at the final stage of the adaptation cycle than might be theoretically predicted (as in Table 5); suggesting additional barriers to the adaptation process.

Experiences at Cork, and experiences of the authors in other case studies within the IMCORE project, suggested that practitioners were comfortable with scenario exercises as thought-experiments. However, when the scenario approach narrows down to the consideration of alternative adaptation measures in its final stages, the operational implications of and trade-offs involved in taking action typically brings participants back to earth with a jolt. This interrupts the dialogue and parlance used freely up to that point and institutional constraints start to increasingly suffocate the process; in particular the mismatch between the long timescales employed in the development of scenarios underpinning adaptation strategies and the relatively short timescales of institutional project planning and budget cycles. This suggests that barriers for moving to pre-emptive adaptation are not necessarily in the adaptation and scenario methodology alone, but also in the particular institutional domain of the stakeholders involved in the local adaption initiative. This conclusion is reinforced by other work, for example [35] who in a study of adaptation pathways concluded that it was the reorganisation of institutional structures that were likely to lead to more sustainable trajectories. Maybe this helps to explain the assessment of [5] that there is limited application of futures and exploratory scenarios at local levels and the necessity of pilot or demonstration projects, such as IMCORE, to help promulgate uptake.

6.5. Promoting adaptation in the EU

The EU provides guidelines for development of adaptation strategies for Member States (SWD(2013) 134 final "Guidelines on developing adaptation strategies"). The process includes a number of steps, including step 4 which is entitled "Choosing adaptation options" which is similar to the third and final stage of the adaptation cycle ("assessing options") used in the work presented here (see Table 5). In step 4, the EU propose for prioritisation of adaptation options, the use of weighted / scored multi-criteria such as cost-benefit ratio, urgency with respect to existing threats, time–effectiveness, etc. However, to what extent such a technocratic process would be able extend the institutionalised mind-set blockage experienced in the Cork case study and elsewhere remains unclear. The EU identifies its support for adaptation to be aligned along three lines: knowledge-base (e.g. databases and vulnerability assessments); mainstreaming framework; and, funding instruments. However, promotion of institutional sensitisation and strengthening at the local level where adaptation happens, does not emerge as a priority. In fact, the EU is no different to many international entities which promote adaptation through frameworks and technocratic steps, but fails to identify the key role of institutional mind-set in the delivery of adaptation at the local level.

Warnings of inappropriate, or maladaptation are apparent, even in the EU. For example, [2] in a review of nine regional climate change responses, including a coastal area in the UK, concluded that the studied response strategies run the risk of reducing system resilience if not carefully conceived and implemented. The authors further state that the "real challenge, therefore, is to make use of the issues of climate change to find opportunities to transform social– ecological systems into development pathways that may improve human conditions". Thus, although the work presented here has shown how scenario analysis can strengthen the adaptation process, it would appear that increased technocratic detail and eloquence would not necessary lead to further enhancements, particularly at the later stages, of the adaptation cycle. For the EU, the technocratic adaptation framework forms a robust regional platform but for effective adaptation the quality of the process of subsidiarity to Member States and then to local institutions will be a key factor in positioning adaptation as a transformative opportunity rather than a de facto technocratic response.

7. Conclusion

The use of scenario analysis has been claimed to form a crucial factor in fostering coastal climate adaptation. Scenario analysis offers the potential to overcome key barriers to adaptation progress, facilitating the envisioning of alternate plausible futures. Across a number of case study sites, including that forming the focus of this paper, we have found that scenario analysis does indeed carry a number of useful benefits, particularly in the early stages of an adaptation process. However, as an adaptation process unfolds, the need to ultimately commit time, resources and political capital to one or more courses of adaptation action means the stakes are raised considerably. The driver for this longer-term proactive planning may be weak compared present day roles, responsibilities and competitive pressures.

Participants must therefore be entirely invested in the development and use of future scenarios within the adaptation process in order for progress to be made. If this critical suspension of disbelief is lacking, an adaptation process can rapidly dissolve into disputes surrounding the plausibility of scenarios, and tractable progress on adaptation decision making will falter. This outcome may be more likely in areas which are not party to such a data and capacity-rich environment as northern Europe and which are used to more analytical approaches. For many lesser developed countries, the challenge is more about introducing the concept and approach of evidence-based planning into environmental governance systems, than tribulations on the degree of technological eloquence of adaptation approaches.

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2.1.2 *Post-publication reflections*

Outside of the constraints of the publication process there are further, subjective, reflections which can be offered regarding the difficulties encountered in making headway on an adaptation strategy in Cork Harbour. These provide some useful context to the role that scenario analysis was (and was not) able to play in overcoming adaptation barriers.

The stakeholders involved in the scenario-based adaptation strategy development process in Cork were influential decision makers, short of time to engage with the process, but with a strong understanding of their organisation's role in supporting adaptation locally. Over the course of a number of workshops it became increasingly obvious that they were used to approaching decision making processes with an engineering mindset, and were drawn to viewing the issue of climate change as one requiring impacts to be narrowed down to a 'most likely' outcome, with the expectation that these impacts could then primarily be mitigated via altering the design threshold of infrastructural works.

This mental model of the issue is difficult to reconcile with an intuitive logic scenario process. The limitations of climate impact downscaling prevent any easy reduction of impact risk to a manageable number for variables of interest, with uncertainty bounds typically rendering any given value too imprecise to be of use. Complex interdependencies of coastal climate change impact and adaptation planning at the local scale, where vulnerability is a function not only of exposure and sensitivity, but also of adaptative capacity, further complicates matters.

However, at the early stages of the scenario-based process these limitations were not yet obvious, and stakeholders wholeheartedly embraced the Likert-scale categorisation of drivers of change on the basis of significance and uncertainty, perhaps anticipating this quantification to cascade through the rest of the process to allow a numerical solution at the other end which would be amenable to their decision making norms.

Moving from driver elicitation and categorisation to intuitive logic structure is where difficulties first emerged. This is also the stage at which it became clear that complexity and uncertainty were not to be resolved, but instead explored, with the potentially plausible outcomes of the complex interplay of uncertain drivers to be made clear and adaptation planning to follow as a result. The struggle of participants to let go of probability and consider plausibility began to become increasingly clear as they were asked to reflect on the potential consequences of coherent sets of the drivers they had provided and categorised (i.e. scenarios).

The lack of a replicable methodological structure underpinning scenario creation became an obstacle for participants here, preventing the necessary suspension of disbelief required to fully invest in the process. Losing their committed engagement at this crucial stage meant subsequent steps were less well attended, and stakeholders became increasingly reticent to contribute in workshop settings or in providing offline review of documents and findings. This appeared to be linked to an unwillingness to appear foolish in front of peers in their own and other agencies – once the group had reached a tacit conclusion that the method was in some sense weak or flawed, being seen to be maintaining whole-hearted involvement could signal to others that its limitations had gone unnoticed. With senior stakeholders from Cork City Council, Cork County Council, the port and harbour all in attendance, none could comfortably risk giving others the impression that they lacked the wit to read the reticence of the room.

Although their causes are difficult to pin down entirely, the facilitation team felt these break-points were triggered by the method, rather than resulting from difficulties in the group dynamic, or the vagaries of external politics. The point at which participants began to disengage was clearly discernible to the facilitation team, and anecdotally, was experienced elsewhere in other IMCORE case study locations at the same stage of the process.

2.1.3 Key conclusions and linkages to subsequent papers

The review and case study analysis research presented in this paper provided insight into the value and limitations of scenario analysis in overcoming barriers to climate change adaptation at the local scale. While there is no doubt that scenario analysis may be beneficial in overcoming many early stage barriers to adaptation progress, the depth of stakeholder buy-in required to secure solid commitments to invest (often financial) resources in fostering adaptation cannot easily be secured using conventional scenario analysis tools. As stated, obvious shortcomings of rigour and replicability may preclude the level of investment in the process stakeholders require in order to suspend disbelief.

In order to overcome this credibility deficit among the type of quantitatively minded stakeholders who typically must make coastal climate change adaptation decisions at the local scale, it is therefore necessary to explore alternative, more readily replicable and defensibly rigorous modes of illustrating potentially plausible future states than narrative scenario analysis tools can. The book chapter and research articles to follow explore the role and value of Fuzzy Cognitive Mapping in achieving this aim.

Part III: EVALUATING THE POTENTIAL OF FCM AS A PARTICIPATORY MODELLING TOOL IN STAKEHOLDER-DRIVEN DECISION MAKING CONTEXTS

3.1. PAPER 2

*3.1.1 S. A. Gray, E. Zanre and **S. R. J. Gray** (2013) Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs. In: Papageorgiou E. (Eds) Fuzzy Cognitive Maps for Applied Sciences and Engineering. Intelligent Systems Reference Library, Vol 54. Springer, Berlin, Heidelberg*

This state of the art review chapter explores the potential of Fuzzy Cognitive Maps in group decision contexts where uncertainty is high and access to data is poor. Under these conditions, reaching consensus as to how individual perceptions regarding key system structures and functions might best be integrated to inform decision making can be highly problematic. Reaching an acceptable compromise in such circumstances often proves impossible.

The chapter therefore begins by establishing the credentials of FCM in the context of concept mapping, cognitive mapping and mental models, and explores the type of use-cases in which FCM have been developed to address uncertainty. These have typically involved domain experts (i.e. medical professionals, mechanical engineers, computer scientists) pooling their expertise to provide a diagnostic tool for the resolution of domain-specific illnesses, faults or failures. However, the chapter goes on to discuss contexts in which group perception among disparate (non-domain specifc) stakeholder groups may also benefit from a form of knowledge integration which might support improved decision making, and some of the challenges to overcome in attempting to do so.

The chapter then describes important methodological issues which might call into question the validity of any claim regarding the construction of a model representing ‘group beliefs’ among disparate stakeholders, unless specifically addressed in the model facilitation and aggregation stages. The chapter closes with a discussion of the practical trade-offs involved in adopting the differing approaches available to develop group models in uncertain decision contexts.

CONTRIBUTION STATEMENT

Declaration of own contribution to the published (or intended for publication) scientific papers within my dissertation.

DISSERTATION TITLE: Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping

PAPER–2: S. A. Gray, E. Zanre and **S. R. J. Gray** (**2013**) Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs. In: Papageorgiou E. (Eds) Fuzzy Cognitive Maps for Applied Sciences and Engineering. Intelligent Systems Reference Library, Vol 54. Springer, Berlin, Heidelberg

OWN CONTRIBUTION IN THIS WORK: Concept development (mainly), Literature search (mainly), Methods development (mainly), Research design (partly), Construction of the manuscript (mainly), Argumentation (partly), Critical revision of the article (mainly).

Stefan Gray, MSC

July 11, 2019

Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs

S. A. Gray, E. Zanre and S. R. J. Gray

Abstract Fuzzy Cognitive Maps (FCM) have found favour in a variety of theoretical and applied contexts that span the hard and soft sciences. Given the utility and flexibility of the method, coupled with the broad appeal of FCM to a variety of scientific disciplines, FCM have been appropriated in many different ways and, depending on the academic discipline in which it has been applied, used to draw a range of conclusions about the belief systems of individuals and groups. Although these cognitive maps have proven useful as a method to systematically collect and represent knowledge, questions about the cognitive theories which support these assumptions remain. Detailed instructions about how to interpret FCM, especially in terms of collective knowledge and the construction of FCM by non-traditional 'experts', are also currently lacking. Drawing from the social science literature and the recent application of FCM as a tool for collaborative decision-making, in this chapter we attempt to clarify some of these ambiguities. Specifically, we address a number of theoretical issues regarding the use of Fuzzy Cognitive Mapping to represent individual "mental models" as well as their usefulness for comparing and characterizing the aggregated beliefs and knowledge of a community.

1. Introduction

There is a wealth of literature from the fields of cognitive science, psychology, and systems science that discusses the use of individuals' knowledge structures as representations or abstractions of real world phenomena. However, before we can begin our discussion of how Fuzzy Cognitive Mapping (FCM) contributes to these fields, we must first reconcile the various definitions and approaches in the literature used to characterize internal cognitive representations of the external world. Understanding the theoretical foundations of concept mapping, cognitive mapping, mental models and the notion of "expertise" in the elicitation of a subject's knowledge is of particular interest to our discussion on FCM construction and interpretation. Further, we discuss issues related to analysing FCMs collected from non-traditional experts, which is a growing area of research that seeks to characterize group knowledge structure to inform community decision-making and compare knowledge variation across groups. In this chapter, we address: how FCM can be used to understand shared knowledge and what trade-offs should be considered in the selection of FCM data collection techniques.

2 Concept Mapping, Cognitive Mapping and Mental Models as Representations of Knowledge Structures

FCM has its roots in concept and cognitive mapping. Concept maps are graphical representations of organized knowledge that visually illustrate the relationships between elements within a knowledge domain. By connecting concepts (nodes) with semantic or otherwise meaningful directed linkages, the relationships between concepts in a hierarchical structure are logically defined [49, 55]. The argument for representing knowledge with concept maps emerges from constructivist psychology, which postulates that individuals actively construct knowledge by creating mental systems which serve to catalogue, interpret and assign meaning to environmental stimuli and experiences [61]. Knowledge "constructed" in this manner forms the foundation of an individual's organized understanding of the workings of the world around them, and thus influences decisions about appropriate interaction with it. Influenced by cognitive psychology's developmental theory of assimilation and accommodation, as theorized by the Swiss cognitive psychologist Jean Piaget, the use of concept maps as representations of an individual's organized knowledge is further supported. According to Piaget's developmental theory of learning, individuals' assimilate external events and accommodate them to develop a mental structure that facilitates reasoning and understanding [17, 58]. Using this theoretical framework, concept maps can be elicited to represent an organized understanding of a general context, thereby providing an illustrative example of a person's internal conceptual structure [49].

Another form of structured knowledge representation commonly referred to in the social science literature is cognitive mapping. A cognitive map can be thought of as a concept map that reflects mental processing, which is comprised of collected information and a series of cognitive abstractions by which individuals filter, code, store, refine and recall information about physical phenomena and experiences. Popularized by psychologist Edward Tolman as a replication of a geographical map in the mind, the term has since taken on a new meaning. Robert Axelrod [5] was the first to use the term in reference to the content and structure of individuals' minds, thereby shifting its applied meaning from referring to a map that is cognitive, to a map of cognition [14, 27]. Using Axelrod's definition, cognitive maps are visual representations of an individual's 'mental model' constructs, and are therefore analogous to concept maps that represent a person's structured knowledge or beliefs.

Although both concept and cognitive maps are often used as external representations of internal mental models, it is important to note that these graphical representations and mental models are not the same. Cognitive maps, of which FCMs are an extension, are themselves extensions of mental models, but are distinct since cognitive maps are physical constructs, whereas mental models only exist in the mind [14]. First introduced by Craik [11], today the notion of mental models and their usefulness for understanding individual and group decision-making is a widely accepted construct in the social science literature [1, 28], and justifies the methodological appropriation of FCM as external representations of a person's internal understanding. It is hypothesized that in order to successfully achieve a given objective, individuals must possess sufficient knowledge of their immediate environment in order to craft appropriate responses to a given decision context [47]. In such contexts, mental models are considered to provide the structures that form the basis of reasoning [28]. The perceived utility of internal mental models in decision making contexts lies in their simplicity and parsimony, which permits complex phenomena to be interrogated and salient components selected to form judgments. Inferring causal relationships between a range of factors based on available evidence or beliefs facilitates the generation of workable explanations of the processes, events and objects an individual may encounter within their environment. By encoding these inferences into a heuristic structure, individuals can accrue knowledge incrementally over time, thereby offsetting the limitations of human cognition under conditions of complexity and uncertainty [65]. This process enables individuals to construct an internal model that both integrates their existing relevant knowledge of the world, as well as meets the requirements of the domain to be explained. To enable individuals to make a context-appropriate decision, mental models mediate between knowledge stored in the long-term memory and knowledge that is constructed in the short-term working memory [48]. Therefore, it is hypothesized that individuals constantly rely on mental models to structure their understanding, explain the world, and to some extent, make decisions that reflect this internal process of reasoning.

Combining the notion of "mental modelling" with cognitive mapping, FCM utilizes fuzzy logic in the creation of a weighted, directed cognitive map. FCMs are thus a further extension of Axelrod's definition of cognitive maps, and can therefore similarly be considered a type of mental model representation [21, 29, 35, 52]. Given FCMs may serve as semi-quantitative, detailed representations of individual and/or group knowledge structures, either through aggregation of individual's models, or through group FCM building exercises, they are attracting increased attention in applied research contexts seeking to promote collective decision-making or better understand community knowledge [3, 18, 52]. Using the imprecise nature of common language, FCM permits individuals to interpret and express the complexity of their environment and experiences by combining their knowledge, preferences and values with quantitative estimations of the perceived relationships between components within a particular context of interest [28, 29, 39, 52]. Similarly, from a social science research perspective, employing FCMs as representations of mental models can generate understanding of how different people filter, process and store information, as well as elucidate how these perceptions may guide individuals decisions and actions in a particular context [7]. In a manner analogous to the *mental modelling* that structures an individual's cognitive decision making process, eliciting the reasoning and predictive capacity of experts' mental constructs via FCM has proven to be a useful decision support tool [2, 18, 21, 52]. Although FCM have been proposed as a method to understand mental models, issues regarding whose knowledge is represented, how group knowledge is collected and interpreted, and what constitute best practices for combining mental models in different applied research contexts, have largely not been addressed.

3. Traditional 'Western' Expertise and Non-traditional Expertise

The collection of FCMs as representations of mental models can be divided into two general categories in terms of 'whose knowledge is being structured?'. The first, and perhaps most long standing use, is related to FCMs as representations of "traditional" expert knowledge. There is a long history of representing expert knowledge systems using FCM and fuzzy-logic in areas of research where system uncertainty is high and empirical data to validate a hypothesized model is unavailable or costly to collect. This FCM research encompasses a wide range of applications including: risk assessment [25, 43], work efficiency and performance optimization [29, 71] strategic deterrence and crisis management [38, 57], scenario/policy assessment [3, 32] spatial suitability and prediction mapping [4, 45] and environmental modelling and management [2, 24, 26, 40, 60]. FCM based on expert knowledge, attempts to make tacit, expert knowledge more explicit in an effort to represent complex systems and their inherent dynamics that would otherwise not be well understood. "Traditional western experts" in this sense reflect the common use of the term and characterize social elites including physicians [6], scientists [10, 24], and engineers [3]. By collecting mental models from experts considered to hold the 'best' knowledge about a system, structure is provided to what would otherwise be loosely-linked, highly complex, or unavailable understanding of a system domain.

The second and more recently emerged category of FCMs as representations of mental models, are those collected from non-traditional western experts. These FCMs are most often employed in participatory planning and management and/or environmental decision-making contexts, and are primarily used to gain an understanding of how stakeholders internally construct their understanding of their world or a particular issue of interest [33, 34]. For example, non-traditional expert FCMs have been elicited from bushmeat hunters in the Serengeti [50], fishermen [40, 70], pastoralists and farmers [16, 51] as well as a range of other stakeholders during participatory planning and modelling contexts [10, 18, 30, 44, 52, 56] Collecting FCMs from non-traditional experts serves as a way to characterize community understanding of a system or collect data intended to help characterize a system that might not be represented by information provided by traditional experts alone [7, 33]. Though there may be some degree of overlap in the need for or desire to use tacit or local knowledge to inform the decision making process, the appropriation of FCM in the collection of local stakeholder knowledge is commonly associated with decision-making in the local community context rather than to pool expert knowledge in conditions of uncertainty, where data is limited or not comprehensively linked [34]. Since knowledge exists on a continuous spectrum of expertise from novice to expert, and the degree of expertise is not usually easily determined, the collection of FCMs from non-traditional experts has been largely influenced by research questions and to date, there has been little consideration of the differentiation or potential protocols of FCM collection from experts and non-traditional experts.

4. Disentangling Group Knowledge

In addition to questions associated with 'whose knowledge is being structured?', there are also research context dependent issues associated with FCM in terms of appropriately representing group knowledge. FCMs are often collected from groups of individuals and aggregated as a way to support decision-making and promote understanding of system dynamics. However, interpreting the cognitive structures of FCMs within the group context raises questions about what this pooled knowledge represents, and how it is useful for research, analysis and interpretation. Although the literature defines mental models as individual's internal representations of the world, consensus is currently lacking with regard to the theoretical basis of shared cognition as it relates to concept and cognitive mapping. Therefore, there are still questions about what collated representations of individual mental models represent [31, 67]. In the literature, this ambiguity is demonstrated by the variable use of research methods and terms employed in the study of shared cognition [8, 46]. To date, the FCM literature has largely ignored this ambiguity, despite the fact that FCMs are strongly influenced by the individual characteristics and cognitive processes of those who construct them [59], as well as the method by which FCMs are aggregated and analysed [53]. While it is commonly accepted that individuals within a given community are exposed to the same "reality", it is also acknowledged that their interpretation of that reality may not be shared [12, 67]. This is because individual mental models are socially-mediated, created with diverse knowledge abstractions, reliant on personal experience and highly dependent on prior knowledge [65]. As evidence of this, the aggregation of individuals' knowledge structures has been shown to show considerable variation and when aggregated, the group level "knowledge structures" sometimes fail to reflect the sum of individual members' mental models [31, 67].

FCMs have been proposed as a unique tool for aggregating diverse sources of knowledge to represent a "scaled-up" version of individuals' knowledge and beliefs [52]. The product of the aggregation of individual's FCMs is sometimes referred to as a "social cognitive map" and is often considered a representation of shared knowledge [18, 52]. The concept of shared knowledge in the form of social cognitive maps has been used in a variety of distinct applications using FCMs including: to gain a more comprehensive understanding of complex systems; to describe consensus in knowledge among individuals and to define differences in individual and group belief or knowledge structures. Further, as FCM evolves beyond its foundations as representations based on traditional expert systems towards the integration of more non-traditional expert knowledge for participatory engagement, it is necessary to understand the nature and appropriateness of FCM aggregation in order to ensure that interpretations are theoretically sound. Therefore, in an effort to further expand the appropriation of FCM to a new generation of social science researchers, it is of critical importance to: (1) understand what is meant by "shared" knowledge of individuals and (2) establish data collection protocols based on common FCM research goal typologies.

5. Understanding the Meaning and Measurement of 'Shared Knowledge' with FCM

There is little consensus across the literature regarding the aspects of knowledge that are shared in group decision-making [8]. Differences in interpretation of "shared knowledge", however, tend to emerge along disciplinary lines generated largely from the organizational behaviour and social psychology literature. For example, shared team knowledge has been described as knowledge relevant to team work and task work [8, 63] while others have referred to shared cognition as an intersubjective process related to transactive memory shared within a community, which influences learning, and therefore, the knowledge held within a group [46]. Still other researchers promote the idea of collective learning through shared frames of reference, or alternatively, through achieving consensus, which reflects shared beliefs among individuals [5, 31, 67]. In essence, studies of shared knowledge highlight the importance of identifying pre-existing discrete dimensions of structural and content knowledge found across individual mental models [8].

In an applied research context, FCM have implications for assessing the degree of shared knowledge distributed across individuals by using a range of structural measures. Comparing FCMs allows researchers to uncover trends in reasoning, as evidenced by similarities in cognitive map structure, to be used to measure the degree of conceptual agreement. Research focused on capturing pre-existing knowledge in a community seeks to understand similarities in how individuals and groups conceptualize contexts of inquiry on a systems level [34]. Understanding the degree of shared knowledge through FCM is important to explaining some aspects of social dynamics since shared knowledge is important for promoting trust, cooperation and since it may influence interaction between individuals and groups [19].

In terms of specific structural measurements available to researchers, the last ten years have seen considerable advances in both network and FCM analyses. These advances have yielded a range of routine metrics to uncover shared knowledge structure by measuring discrete dimensions of an individual's mental model structure, thereby permitting comparisons across individuals and groups (see Table 12 for a summary) [18, 52]. Although we assume the reader is familiar with the basic FCM collection and transcription techniques of cognitive maps into matrices [35], we briefly outline common measures facilitated through matrix calculations. The calculation of these measures allows the degree of shared knowledge to become estimated when the FCM modelling activity is standardized across individuals or groups. Based generally in network analysis, FCM can be analysed for any number of dimensions, which can detect differences in how individuals view the dynamics and components in a given domain. For example, the amount of connections indicates increased or decreased structural relationships between system components or the degree of connectedness between components that influence system function and emergent properties. Centrality score of individual variables represents the degree of relative importance of a system component to system operation. Number of transmitting, receiving, or ordinary variables and the complexity scores indicate whether the system is viewed as largely comprised of driving components or whether the outcomes of driving forces are considered (i.e. that some components are only influenced). Higher complexity scores have been associated with more "expert views" of systems [42, 64] and therefore it is assumed that the FCMs generated by individuals with deeper understanding of a domain will have higher complexity scores relative to others with less understanding. Density scores are associated with the perceived number of options that are possible to influence change within a system as the relative number of connections per node indicate the potential to alter how a given system functions. Hierarchy scores indicate the degree of democratic thinking [41] and may indicate whether individuals view the structure of a system as top-down or whether influence is distributed evenly across the components in a more democratic nature. Centrality scores for an overall FCM indicate the overall perceived degree of dynamic influence within a system.

Although the implications for understanding shared structural knowledge through FCM are somewhat straight forward given the structural metrics available, understanding the degree of shared content knowledge across individuals using FCM is as clear quite as clear. In their review, Cannon-Bowers and Salas [8] outline that shared content includes aspects of knowledge such as task knowledge (both declarative and procedural), contextual knowledge, attitudes, beliefs, expectation and predictions. Although these dimensions of knowledge are more tightly linked to the team decision-making literature, there are still general implications for FCM, however this research area of FCM is somewhat underdeveloped. For example, comparing the outcomes of scenario analyses across several FCM through "clamping" the same variables [35] may allow for qualitative interpretation of how a domain may react under an established pre-set condition to be compared which is thought to be analogous to scenario heuristics used by individual decision-makers [69]. By evaluating these scenario outputs, researchers can make inferences regarding the degree of shared expectations and predictions across individual mental models or different aggregated group models. Additionally, coding or grouping FCM variables into discrete categories may provide a useful means by which agreement or concurrence of a particular problem and for a given system can be identified and assessed. Employing complementary tools, such as standardized surveys, may facilitate the assessment of attitudes and beliefs which could be correlated with quantitative FCM structural measurements [34]. When used in tandem, such an approach may improve understanding and help disentangle the interaction between of structural and content knowledge, and develop more robust assessments.

Mental model structural measurement	**description of metric and cognitive inference**
N (Concepts)	Number of variables included in model; higher number of concepts indicates more components in the mental model [52]

N (Connections)	Number of connections included between variables; higher number of connections indicates higher degree of interaction between components in a mental model [52]
N (Transmitter)	Variables that only have forcing functions; indicates the number of variables that influence other system variables, but are not influenced by other variables. Sometimes referred as "driver" variables [15]
N (Receiver)	Variables that only have receiving functions; indicates number of variables that are influenced by other variables but do not influence other variables [15]
N (Ordinary)	Variables with both transmitting and receiving functions; indicates the number of variables that influence but are also influenced by other variables [15]
Centrality	Absolute value of either (a) overall influence in the model (all + and – relationships indicated, for entire model) or (b) influence of individual concepts as indicated by positive (+) or negative (−) values placed on connections between components; indicates (a) the total influence (positive and negative) to be in the system or (b) the conceptual weight/importance of individual concepts [35]. The higher the value, the greater the importance of all concepts or the individual weight of a concept in the overall model
C/N	Number of connections divided by number of variables. The higher the C/N score, the higher the degree of connectedness in a system [52]
Complexity	Ratio of receiver variables to transmitter variables. Indicates the degree of resolution and is a measure of the degree to which outcomes of transmitter/driving forces are considered. Higher complexity indicates more complex systems thinking [15, 52]
Density	Number of connections compared to number of all possible connections. The higher the density, the more potential management polices exist [15, 22]
Hierarchy index	Index developed to indicate hierarchical to democratic view of the system. On a scale of 0-1, indicates the degree of top-down down (score 1) or democratic perception (score 0) of the mental model [41]

Table 12: Structural metrics that can be applied to matrix forms of FCMs (adapted from Gray)

6. Research Aim: Typologies and Trade-offs of FCM Data Collection

In addition to ambiguities associated with FCMs as representations of mental models and their implications for understanding and measuring shared knowledge, the literature to date has also not dealt with the issue of knowledge heterogeneity or routine variations of FCM collection procedures toward different research goals. The theory behind both mental models and FCM suggest that their usefulness for decision-making significantly depends upon the quality of knowledge used in their construction [36, 68]. Consideration of the potential implications of integrating diverse sources of knowledge using FCMs is timely, particularly given their utility as a participatory modelling approach and as a tool for operationalizing diverse sources of knowledge for improved system understanding, multi-objective multi-stakeholder decision support and expansion to investigate general community understanding [20, 33, 34]. Additionally, assessments of expert selection methods, qualification of expert knowledge, and assessment of knowledge quality are currently lacking [13]. In an effort to provide some clarity on these issues, we identify 4 possible FCM collection strategies related to individual FCM collection and group FCM generation using freely associated or predetermined/standardized concepts (Table 13). Further, we outline the research goals afforded by each method and compare the trade-offs of each FCM collection technique.

6.1 Collecting Individual FCM or Facilitating Group Modelling?

FCM and other cognitive mapping techniques have a unique methodological history since they can be used both as a measurement tool for use in applied research, but can also serve as an intervention to promote model-based reasoning and social learning in group settings. Differences in their appropriation are partially determined on the basis of whether FCM are constructed by individuals to be analysed and manipulated by researchers, or whether groups construct them socially as an external representation of shared knowledge that can also be revised.

Model collection technique	Aggregation technique	Methodological trade-offs: Pros	Cons
Individual mental model: Standardised concepts provided	Average individual FCMs together; assessment of expertise and weighting individual FCMs may be required for small sizes[8]	• Aggregated models permit standardized functional analysis and scenario modelling • Careful expert selection can improve model exactness and reduce sample size demands • Standardization of concepts allow for large sample sizes to be collected and aggregated to draw conclusions about the	• Model element chosen may not reflect full range of system components perceived by individuals • Interviews required first to generate list of standardized components • Multi-person multi-objective decision making validity dependent upon concept and expert selection Constraining model components may bias FCM

		knowledge of large communities • Standardized concepts facilitate ease of aggregation	construction and significantly constrain representation of a domain
Individual mental model: Concepts chosen freely by individuals	Researcher subjectively condenses individuals mental model concepts and then averages	• Facilitates equitable multi-person multi-objective individual mental models together to produce a decision making across diverse knowledge group model domains to be guided by the individuals constructing the model [9, 35] • Model confidence requires larger sample sizes determined by an accumulation curve [52] • Allows for full representation of domain components as perceived by individuals • Weighting is not necessary with sufficiently large sample sizes	• Larger role of the researcher in interpreting and condensing domain components when group model is developed • Concept condensation is time intensive and subjective • Group validation of aggregated model required to ensure representativeness Sufficient sample size may be costly to collect
Group model: Standardized concepts provided to group and collectively modelled	Group creates model together, percent agreement may be useful for deciding group model structure [8]	• Time efficient data collection compared to methods which allow groups to select concepts or individual mental model collection • Providing concepts allows for scaffolding of group model building • Real-time revision of model is possible as participant time allows • Detailed discussion of structural agreement possible • Facilitates social learning	• Group members should be experts in the domain of inquiry since the provision of predefined concepts limits the capture of variability in individuals' knowledge/ideas • Model's meaning is limited to the group context since socially constructed, negotiated, and validated [31] • Knowledge represented dependent upon group power dynamics [62, 66] • Expert facilitation skills necessary to moderate group dynamics and ensure group model is not biased toward views of

			more vocal/forceful individuals
Group model: Concepts chosen by individuals, but condensed and modelled collectively	Concept brainstormed then condensed, group creates model together; percent agreement may be useful for deciding group model structure [8]	Accommodates diverse knowledge domains of group members, pools unconstrained knowledge into map construction • Time efficient compared to individual mental model collection • Facilitates social learning	Model's meaning is limited to the group context since it is socially constructed, negotiated, and validated [31] • Knowledge represented dependent upon group power dynamics [62, 66] • Expert facilitation skills necessary to moderate group dynamics and ensure group model is not biased toward views of more vocal/forceful individuals • Group modelling activity and map may deviate from original domain slightly given conceptual freedom and group dynamics

Table 13: Trade-offs involved in different FCM data collection techniques

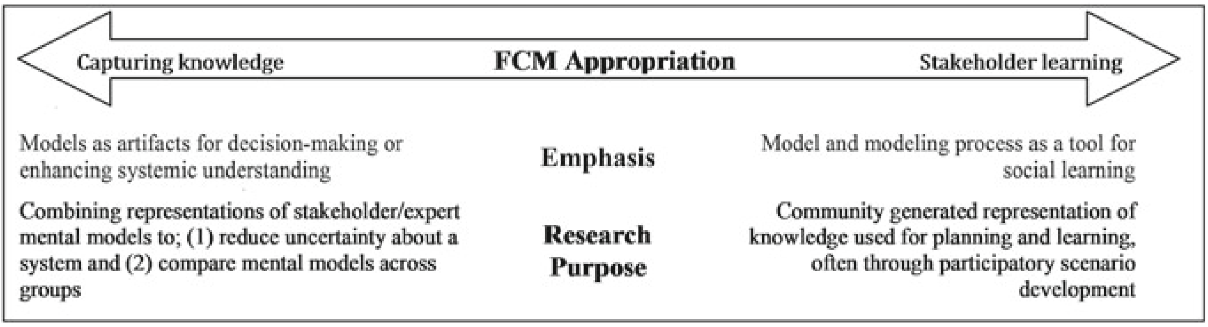

Figure 13: Conceptual model of spectrum of FCM appropriation

In an applied research context, the difference between individual and group map creation rests on the research context, which may seek to characterize individual or community understanding, promote social learning, or a mixture of the two (see Fig. 13). The strengths of individual model development include the ability of the researcher to standardize and aggregate model variables at will, as well as the ability to ensure that the resulting model representation meets the research goals. Since the collection of individual FCMs are not influenced by group dynamics, which can often be prone to power struggles, individual models provide a more robust representation of individual understanding, reveal differences in individual concepts, and highlight unbiased consistencies or inconsistencies in knowledge through comparison. This potentially allows for more equitable knowledge representation, which may more accurately characterize collective knowledge compared to group FCM construction. However, collecting individual FCMs may be resource intensive, and knowledge heterogeneity across maps may complicate aggregation and related structural and scenario-based analyses.

Conversely, an alternative option is to engage in group modelling, whereby a group of participants constructs an FCM as a collective. Group FCM construction is most often aligned with research priorities that seek to promote and represent the outcome of social learning. In these research contexts, more emphasis is placed on model building as a process, and less emphasis placed on capturing individual-level representations of knowledge. The FCM is therefore an outcome of social interaction and represents the group construction of knowledge, achieved through the collective sharing of aspects of individuals' mental models. Group modelling is often less resource intensive compared to the collection of individual models since members of a community can be organized to create a model in a workshop or group setting. In these cases, model aggregation reflects community knowledge, and the role of the researcher is less pronounced since more control of group knowledge representation is afforded to the community. Given that the integration of individuals' knowledge structures is socially negotiated in the group model building context, the resulting consensus model is ultimately dependent upon the personalities, strength of expertise, relationships and level of equality of the group. It may, however, be difficult to accurately assess the distribution of contributed knowledge across group membership or weight each member's expertise. In such contexts, the resulting FCM is most appropriately used as a tool for creating consensus related to the context of inquiry, and for facilitating group discourse for the promotion of shared understanding and collective learning. The model itself represents a socially negotiated form of collective knowledge that can be used to represent community understanding; however, it cannot be scaled down to represent individual understanding [23].

6.2 Standardizing Concepts or Free Association of Concepts?

Related to the choice of FCM collection is the question of whether to construct FCMs using a list of standardized concepts or freely associated concepts. The standardization of concepts involves providing participants with the same list of predefined concepts from which to construct their individual FCMs On the other hand, FCM elicitation through free association of concepts allows individuals to populate FCMs with their own freely chosen concepts [18, 52].The standardization method facilitates knowledge combination via aggregation of individuals' maps by eliminating the need for the researcher to subjectively categorize and reduce the large quantity of concepts typically resulting from FCM elicitation using free association. However, while easing the task of model aggregation and reducing the role of the researcher in determining the concept aggregation scheme, time investment in stakeholder discussions and preliminary research is still required to define an appropriate list of standardized concepts. Additionally, when model concepts are standardized, accumulation curves cannot be used to determine the appropriate sample size of individuals [52]. Further, although standardizing model structures facilitates the ease of scenario modelling with aggregated maps, the reliability of model structure and function may be biased since predefined concepts shape individuals' cognitive abstractions [59, 64]. Therefore, variation in knowledge perceived by individuals with high degrees of knowledge heterogeneity may not be captured. To mitigate some of these challenges in the group contexts with standardized concepts, it is recommended that researchers attempt to reduce knowledge variability and increase reliability of knowledge contributions by attempting to homogenize expertise by the type of experts constructing FCMs. These homogenized expertise FCMs can then be integrated with other groups FCMs after they are collected. It is important to note, however, that homogenized expertise also has trade-offs associated with it since map construction with overlapping expertise may limit the application of FCM as a tool for facilitating multi-person, multi-objective decision making in diverse group settings. In more heterogeneous expert contexts, freely associated concepts provide obvious advantages; however, this freedom has the ability to overwhelm individuals, especially if they are non-traditional experts, or if FCM or concept mapping is not a familiar activity.

Despite the notion that standardized concepts pose some analytical constraints, some research benefits are provided in terms of measuring shared knowledge. For example, in a group context, the use of standardized concepts may scaffold participants and promote social learning as a result of the group discussion and through the model validation process. Additionally, there are also considerations of ease of collection that should be considered in the selection of FCM collection techniques.

While the research objective should be the first criteria used to inform FCM collection, availability of funding, and/or staff and participant time availability often influence the choice of data collection as well. When resources are limited, standardized concepts offer many benefits by facilitating the collection of larger sample sizes, which can be useful in drawing conclusions about the knowledge of communities and take less time to elicit as well as to aggregate. In the group context, they can also save time which may permit real time revision, and therefore create a more useful discussion of structural agreement. In contrast, FCM collection using freely associated concepts can require increased time dedicated to FCM elicitation, aggregation, analysis and follow-up validation. While there are variations on FCM collection options, careful consideration of the research goals as well as the community and expert context should be undertaken so that methodological limitations are diminished to the greatest extent possible. Obviously, hybrid methods that combine pre-selected components and freely associated concepts are also possible, and to some extent can mitigate drawbacks associated with both options.

7. Conclusions

Structuring human knowledge through the collection of FCMs has obvious use beyond simply characterizing traditional expert systems, and also provides a way to represent community understanding as a form of scaled up "mental modelling". As the field of FCM continues to evolve and the usefulness of FCM continues to be seen through novel appropriations, continued research is needed to establish best practice standards which match specific techniques with different research contexts, backed by discipline appropriate theoretical foundations. Although FCM provide a powerful tool for both traditional experts and non-traditional experts to model complex systems, evaluate structural differences between the knowledge held by groups and individuals, and functionally determine the dynamic outcome of this understanding, there are still issues regarding the interpretation of FCMs as artefacts of individual knowledge and group beliefs. In this chapter, we have sought to provide a theoretical background to inform the collection and interpretation of FCM as representations of shared knowledge when individual FCMs are aggregated together, compared across individuals within the context of group interaction, or created collectively by individuals within a group context. More specifically, we can summarize the lessons learned as follows:

- When FCMs are used as representations of individual mental models or group knowledge or beliefs, the research objective should be carefully aligned with the appropriate cognitive theory and data collection method.
- FCMs, like all concept maps, have the ability to be used as both measurements of individual and group understanding and as a tool to promote social learning to facilitate group decision-making. Researchers should be clear about their

appropriation when drawing conclusions about FCM as representation of knowledge and beliefs.

- Researchers engaged in FCM research should justify, based on trade-offs, the selection of FCM data collection and aggregation techniques.
- Continued evaluation of existing methods, and the development of new methods, is currently needed in the areas of aggregation tests, sample size sufficiency, knowledge heterogeneity, and expert credibility.

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3.1.2 Post-publication reflections

FCM is by design a subjective tool, explicitly capturing the interior mental model (and thus subjective perceptions) of the model builder and giving it external expression. The scope for this process to become a blend of not only the internal mental model of the modelling subject but also that of the model facilitator is clearly an issue that must be addressed.

There are facilitation methods available to prevent the biases and judgements of the facilitator from skewing the models, certainly at the stage of individual model creation. The key factor here is to hand control of the process to the modeller to as great a degree as possible, leaving the facilitator as a sounding board on procedure only. Before moving on to a live modelling process with coastal adaptation stakeholders, three steps touched on in the preceding chapter which aim to prevent undue facilitator influence were taken and built into the facilitation method used in the chapter to follow. Given how important they have subsequently proven to be when using FCM in the field, these warrant further explanation.

1. **Concepts to model with**: My co-authors and I agreed that this issue risked introducing the single greatest bias of all in regard to participatory FCM creation. If the modeller is presented with what is effectively a loaded deck of 'important concepts' from which to build a model the degree to which it could be said to accurately represent her or his internal mental model of the system in question must be dubious at best. But we had also found to our cost in early experimentation with the method that presenting modellers with a blank page and no pre-prepared concept material made the process of facilitation so taxing that again it was highly unlikely that the model produced could be an accurate facsimile of the modeller's internal view of the system. We found that a workable solution to this dilemma is a two stage data collection and pre-facilitation process, where:
    a. the full pool of potential modellers are surveyed for the concepts they believe to be of most importance in determining resilience outcomes in the coastal social-ecological system

b. providing this broad range of concepts for modellers to choose among in building their individual FCM (while also offering the potential to add new or amend concepts as the modeller sees fit).

This avoids the paralysis induced by a blank page without introducing (external, facilitator induced) biases in concept creation. While each modeller is presented with a wider range of concepts than might have originally occurred to them, these are in a sense 'internal' to the social-ecological system in question, rather than the product of external (researcher) induced perspectives, and there is no requirement for an individual modeller to select concepts which have no relevance to them.

2. **Model building medium**: A second means of handing over control is to allow the modeller to literally hold the pen in building the model. Ideally, this would be achieved via a sophisticated web based interface and tablet solution, useable in the field via a 4G internet connection (a co-author subsequently developed just such a tool for this purpose: http://www.mentalmodeler.org/). However, at the time the research detailed in the following chapters was carried out this was not yet complete, and a lower-tech option was employed involving a portable whiteboard, whiteboard markers and magnetised tiles (Figure 14). This allowed each modeller to build their own FCM as they saw fit, guided only by an unrelated FCM example to illustrate the method.

Figure 14: Using whiteboards, markers and magnetised labels allowed modellers to have complete control of the process of FCM construction.

3. **Participatory model calibration:** A third issue which may introduce bias is the collation of individual models to form a group model. The process of developing individual FCMs can be relied on to retain a relatively strong fidelity to the internal mental model of the individual in question via the facilitation techniques described above, but these are unable to mediate the risk of facilitator bias from skewing the process of group model construction. This can require judgement calls to be made

by the facilitator. For example, if two modellers select the same concepts to model with, but choose conflicting relationships between them, the result can be to cancel each other's influence in the subsequent group model. This is rarely a satisfactory result, leaving the facilitator to either:

a. weight the views of one or both of the modellers, or
b. highlight the discrepancy in a facilitated workshop setting to try to come to a negotiated compromise.

Selecting option (a) would require a means of calibrating model inputs. This is feasible using techniques such as Structured Expert Judgment[7], and some would perhaps even say it is advisable where the model itself is to be used as a decision-marking artefact. However, where stakeholder engagement and bi-directional knowledge exchange is the priority, techniques involving calibration and weighting may be counterproductive. For this reason option (b) was selected in the case study example described in the chapter to follow, with each case of contradictory modelling results highlighted for resolution before the group model (average of all individual model inputs) was finalised for use in the subsequent stages of the adaptation process.

The process followed in arriving at the group model is illustrated in figures 15-19 below.

[7] (see for example: Colson and Cooke (2018) Expert Elicitation: Using the Classical Model to Validate Experts' Judgments, *Review of Environmental Economics and Policy*, Volume 12, Issue 1, Winter 2018, Pages 113–132, https://doi.org/10.1093/reep/rex022)

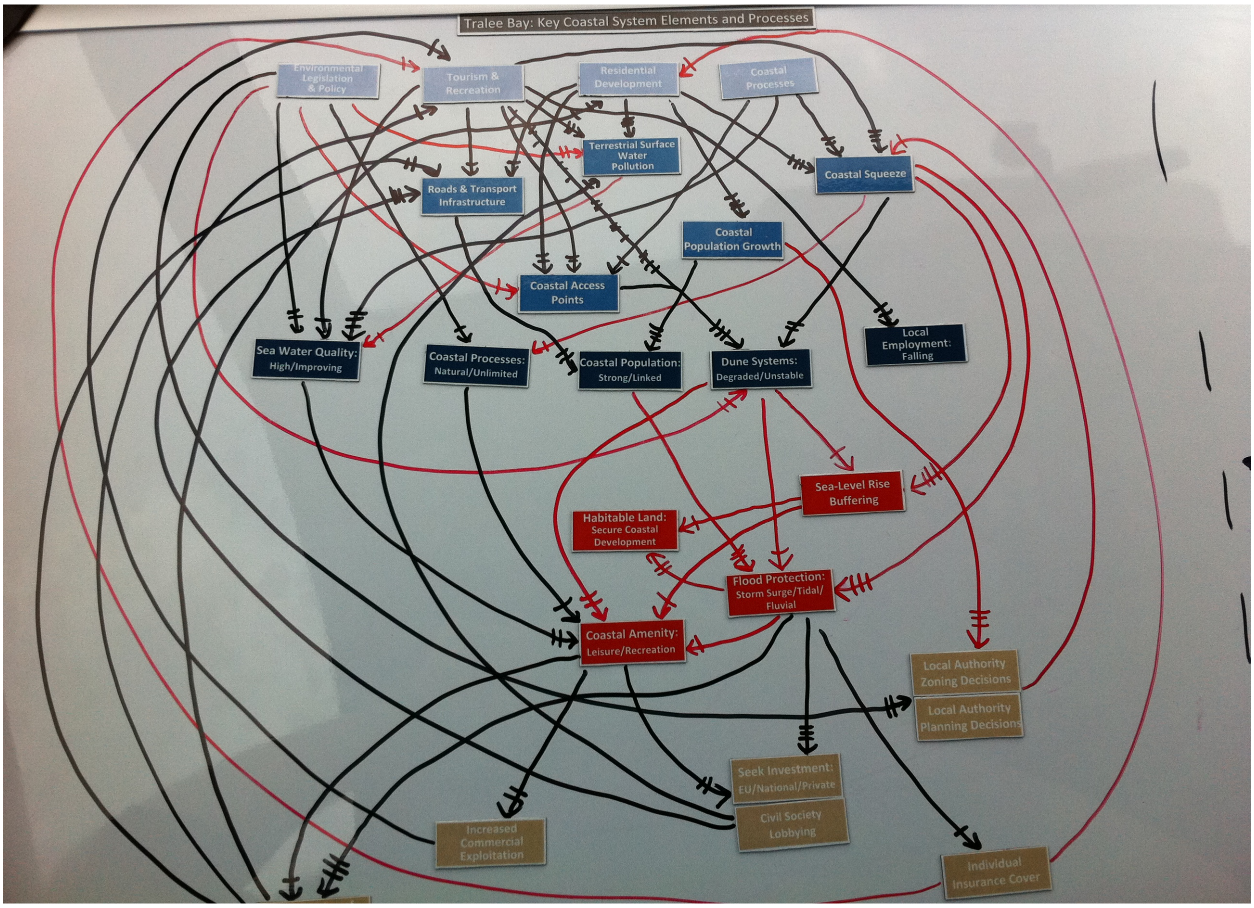

Figure 15: A whiteboard capturing the FCM of a Tralee Bay modeller.

Tralee Bay - Modeller 1	Environmental Legisl	Tourism and Recreat	Residential Developm	Coastal Processes	Roads and Transport	Terrestrial Surface W	Coastal Population G	Coastal Squeeze	Coastal Access Points	Sea Water quality: H	Coastal Processes: Na	Coastal Population: S	Dune Systems: Degra	Local Employment: F	Sea Level Rise Buffer	Flood Protection: Sto	Habitable Land: Secu	Coastal Amenity: Leis	Local Authority Plann	Civil Society Lobbying	Increased commerci	Construction of Coast	Individual Insurance
Environmental Legislation and Policy	0	0	0	0	0	-0.5	0	0	-0.75	0.5	0.75	0	-0.5	0	0	0	0	0	0.5	0	0	0	0
Tourism and Recreation	0	0	0	0	0.5	0.5	0	0.75	0.5	0.5	0	0	0	-0.5	0	0	0	0	0	0	0	0	0
Residential Development	0	0	0	0	0.5	0.75	0.75	0.75	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coastal Processes	0	0	0	0	0	0	0	0.5	0.25	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0
Roads and Transport Infrastructure	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Terrestrial Surface Water Pollution	0	0	0	0	0	0	0	0	0	-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0
Coastal Population Growth	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0	-0.75	0	0	0	0
Coastal Squeeze	0	0	0	0	0	0	0	0	0	0	-0.25	0	0.5	0	-0.75	-0.75	0	0	0	0	0	0	0
Coastal Access Points	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0	0	0	0	0
Sea Water quality: High/Improving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
Coastal Processes: Natural/Unlimited	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0
Coastal Population: Strong/Linked	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.75	0	0	0	0	0	0	0
Dune Systems: Degraded/Unstable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.25	-0.25	0	-0.5	0	0	0	0	0
Local Employment: Falling	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Level Rise Buffering	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.25	-0.25	0	0	0	0	0
Flood Protection: Storm Surge/Tidal/Fluvial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	-0.25	0	0.75	0	0.75	0.25
Habitable Land: Secure Coastal Developme	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coastal Amenity: Leisure/Recreation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0.25	0
Local Authority Planning/Zoning	0	0	0	0	0	0	0	-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Civil Society Lobbying - Seek Investment	0	0	0	0	0.75	-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Increased commercial Exploitation	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction of Coastal/Flood Defences	0	0.25	0.25	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Individual Insurance Cover	0	-0.25	-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 16: The model transcribed into an adjacency matrix using FCM-compatible values (strong, moderate and weak connections being coded as 0.75, 0.50 and 0.25 respectively. Negative values are marked in red).

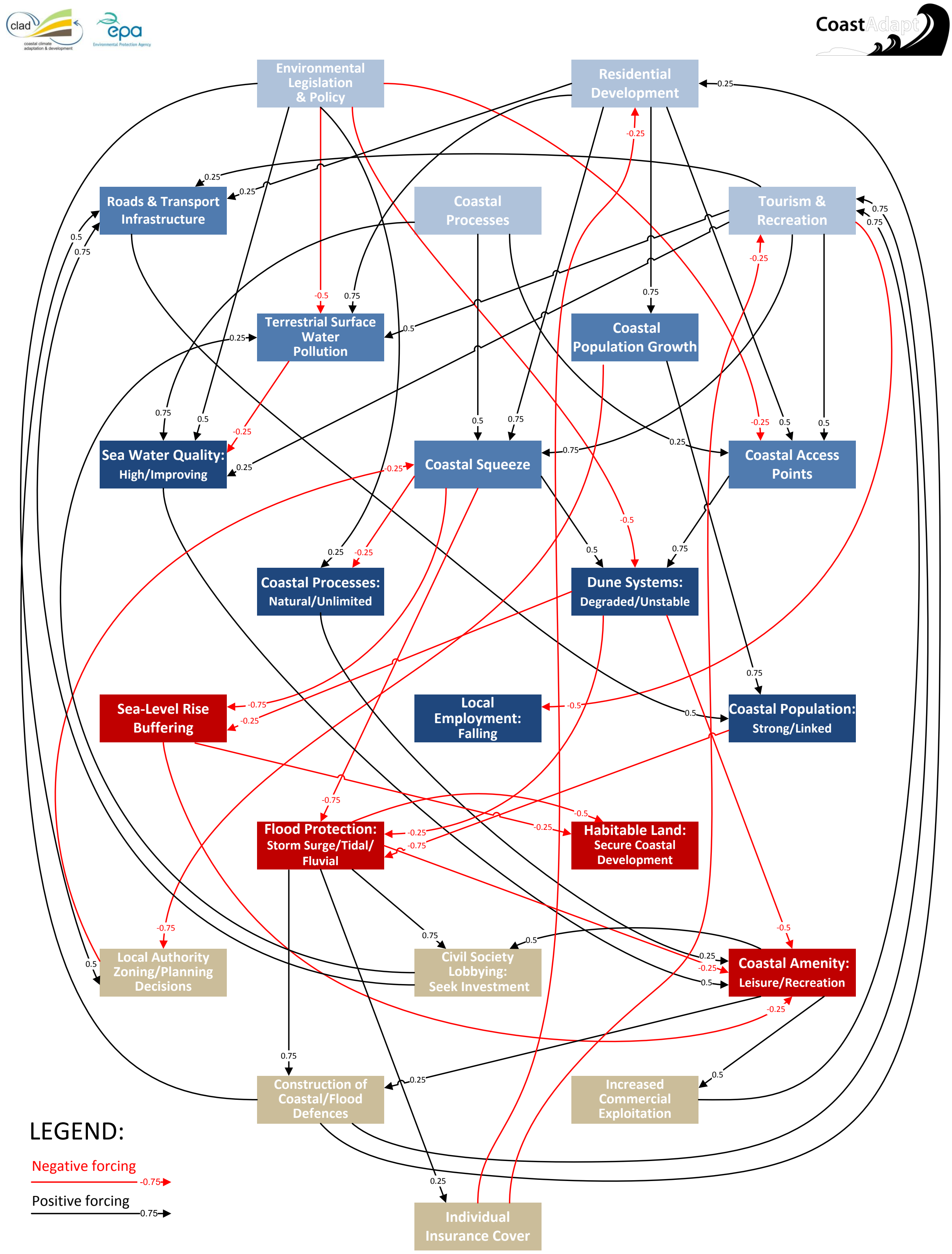

Figure 17: The individual model from the whiteboard entered into Microsoft Visio. These were sent to each modeller to check for consistency and provide a further opportunity for revision prior to the group modelling workshop.

Figure 18: Deliberating over what would constitute a valid representation of the group's joint perception of the coastal system. Points of contention were specifically highlighted for discussion and resolution.

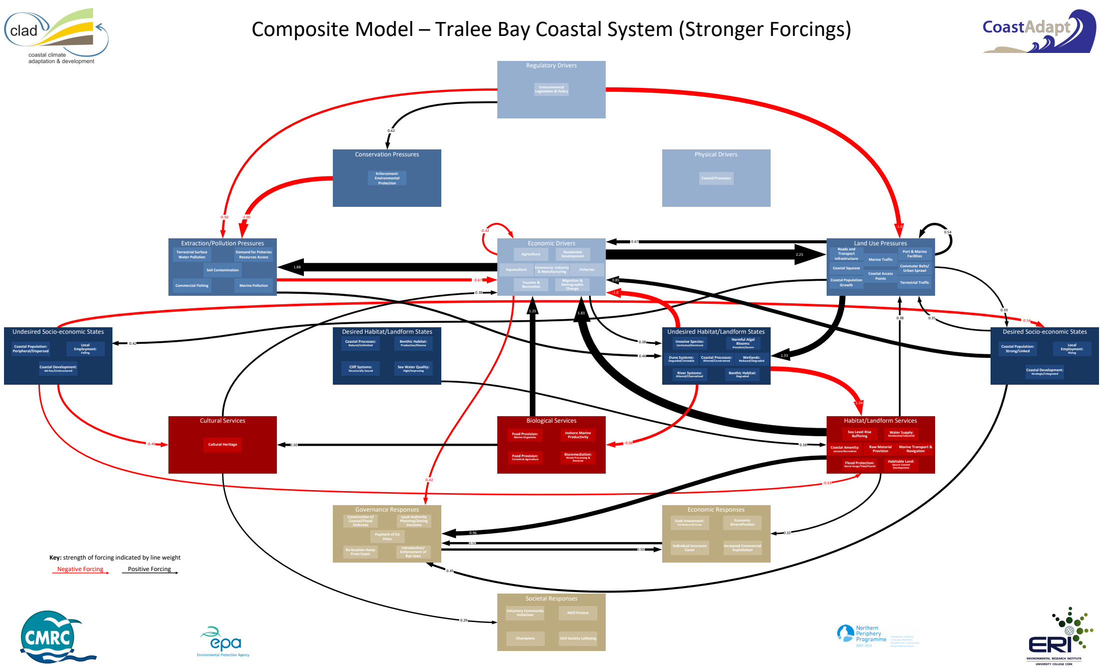

Figure 19: An example of the type of facilitation materials provided (in poster form) during the group model validation workshop. This illustrates an aggregated group model created by collating the individual models. The size of the arrows between concepts illustrates the strength of the relationship between them (red arrows indicating a negative relationship).

3.1.3 Key conclusions and linkages to subsequent chapters

This chapter has explored how structuring knowledge through the integration of individual FCMs can be beneficial beyond traditional expert system characterisation. Although at a relatively early stage in FCM appropriation under highly uncertain environmental management contexts, the research underpinning this chapter points to a number of insights which might enhance the rigour of efforts to form and analyse group FCMs.

These important methodological constraints are relatively limited in number and scope, pointing to a still evolving understanding of what form any 'best practice' in the aggregation of individual FCMs in group contexts might take. The recent rapid growth in the number and variety of contexts within which FCMs have been appropriated nevertheless points to a growing recognition of their utility, signalling a potential for the method to reach a more mature stage where conclusions may be drawn on best practice in FCM deployment.

In order for such insights to emerge, methodological innovations and novel use cases must be evaluated and described in the literature. Doing so may illustrate the potential of FCM in diverse and currently pressing decision contexts, such as group decision making under uncertainty. The paper to follow attempts such an evaluation.

Part IV: THE DEVELOPMENT AND IMPLEMENTATION OF AN FCM-BASED ALTERNATE TO CONVENTIONAL SCENARIO ANALYSIS IN COASTAL CLIMATE ADAPTATION

4.1. PAPER 3

4.1.1 ***Gray, S.****, O'Mahony, C., O'Dwyer, B., Gray, S. A., and Gault J.* ***2019*** *"Caught by the fuzz: Using FCM to prevent coastal adaptation stakeholders from fleeing the scene", Marine Policy, doi.org/10.1016/j.marpol.2019.103688*

This combined state of the art review and case-study analysis paper explores the role and value of FCM in overcoming barriers to coastal climate change adaptation at the local scale. The potential role of FCM in overcoming the adaptation barriers (as previously set out in Paper 1) is established via reference to the literature. This potential is then estimated using the framework of analysis employed in Paper 1, giving an indication of the method's capacity to overcome adaptation barriers. This explicit repetition of the experimental approach of Paper 1 allows a more direct comparison of the relative merits of each decision support approach than might otherwise have been possible.

The paper then moves on to describe a case study of scenario analysis in practice, drawing on primary research conducted in Tralee Bay, Ireland. The efficacy of FCM in overcoming climate change adaptation is assessed against initial estimation, and the strengths and weaknesses of approaching climate change using a novel participatory modelling approach such as FCM are discussed.

The paper concludes with suggestions on how the method might best be employed in local scale climate change adaptation, and suggests areas of future research into how the method might also be appropriated to gauge stakeholder capacity building needs.

CONTRIBUTION STATEMENT

Declaration of own contribution to the published (or intended for publication) scientific papers within my dissertation.

DISSERTATION TITLE: Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping

PAPER–3: ***Gray, S.,*** *O'Mahony, C., O'Dwyer, B., Gray, S. A., and Gault J. (submitted) "Caught by the fuzz: Using FCM to prevent coastal adaptation stakeholders from fleeing the scene", Marine Policy*

OWN CONTRIBUTION IN THIS WORK: Concept development (fully), Literature search (fully), Methods development (fully), Research design (fully), Data collection (mainly), Data analysis (fully), Construction of the manuscript (fully), Argumentation (fully), Critical revision of the article (mainly).

Stefan Gray, MSC

July 11, 2019

Caught by the fuzz: Using FCM to prevent coastal adaptation stakeholders from fleeing the scene

S. R. J. Gray[8], C. O'Mahony, B. O'Dwyer, S. A. Gray, J. Gault

ABSTRACT

Adaptation to climate change is an increasingly urgent priority for coastal managers. At the highest levels of governance, European Union and Member State adaptation policies and strategies are now well established, but meaningful adaptation interventions illustrating tangible gains in resilience remain scarce. A clear framework for generic adaptation processes, along with barriers to their smooth progress, have now been identified in the literature, and equally generic scenario analysis tools have been put forward to strengthen adaptation delivery by assisting coastal managers to overcome them. Fuzzy Cognitive Mapping (FCM) is a relatively novel option in this respect, having yet to achieve the kind of widespread uptake and trial that more orthodox futures approaches such as intuitive logic scenarios have. FCM is however growing rapidly in its range of uses and breadth of uptake, and its utility in overcoming the barriers to adaptation among coastal managers is therefore worthy of analysis. This case study, in which FCM was employed in place of intuitive logic scenario analysis within an adaptation strategy development process, found FCM to carry a number of key strengths that intuitive logic scenario analysis has been found to lack. Through enabling a more detailed and granular level of participatory development of the 'engine' of the futures process than possible under an intuitive logic approach, the level of buy-in and commitment to the adaptation strategy development process achieved among coastal managers and stakeholders was significantly greater.

Keywords: Coastal adaptation; FCM; scenario analysis; participatory modelling

1. Introduction

The impacts of climate change on the world's coastal margins are already apparent, and, regardless of the success of global efforts to mitigate emissions, likely to continue to worsen over the course of the century (Wong, et al., 2014). The lack of significant progress in planning and successfully implementing coastal adaptation measures is therefore concerning, and the extent to which commonly advocated approaches to supporting adaptation might be taken up by the coastal management practitioner community has come under scrutiny (Gray, O'Mahony, Hills, O'Dwyer, Devoy, & Gault, 2016).

Engaging in some form of futures-oriented analysis in order to identify signals of change, conceptualise their potential impacts, and frame an appropriate adaptive response, has become

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widely accepted as a central component of a nascent 'best practice' in adaptation (Moser & Ekstrom, 2010). In this regard, scenario analyses built upon the intuitive logic framework have now been relatively widely utilised (Rickards, Ison, Fünfgeld, & Wiseman, 2014; Gidley, Fien, Smith, Thomsen, & Smith, 2009; Tompkins, Few, & Brown, 2008), and found to offer significant benefits with respect to overcoming early-stage barriers to adaptation (Gray et al 2016). It is nevertheless clear that given limited evidence of adaptation implementation progress to date, and the sheer scale of the task confronting the coastal management community, there is likely to be significant value in developing and evaluating futures approaches with the potential to address additional barriers that crop up at key stages of the adaptation process, particularly at points where the stakes are raised and tangible commitments must be made. Doing so may help to facilitate adaptation breakthroughs at the local scale, where the level of conviction displayed by influential individuals behind a given course of action can be vital in securing wider community buy in.

A growing body of literature indicates that Fuzzy Cognitive Mapping (FCM) may hold considerable promise in this regard (Gray, et al., 2015; Helfgott, et al., 2015; Gray, Zanre, & Gray, 2014; Kok, 2009), potentially going further than intuitive logic scenario analysis in overcoming barriers to adaptation in local scale coastal climate adaptation. The aim of this paper is therefore to assess the extent to which a futures approach based on FCM can overcome adaptation barriers, and to explore to what extent FCM may offer a tractable alternative to intuitive logic scenario analyses within generic adaptation processes.

1.1 Climate change adaptation at the local scale: praxis, insights and known barriers

The building blocks of an idealised adaptation process are now reasonably well established in the literature (IPCC, 2014; EEA, 2013). These place adaptation actions as primarily devised and implemented locally, but with critical supporting frameworks, services and resourcing provided by top-down (trans-national and national) policy and institutions. The generic stages of such a process are re-produced below (Fig. 20).

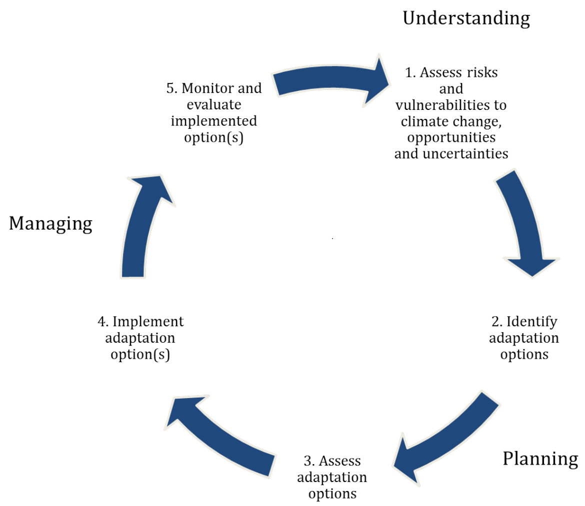


Figure 20: A generic adaptation process

Instances of this process being broadly translated into practice are now becoming more common (Gray, O'Mahony, Hills, O'Dwyer, Devoy, & Gault, 2016; Oswald-Beiler, Marroquin, & McNeil, 2016; Rutherford, Hills, & Le Tissier, 2016), generating insights into the nature of barriers to overcome in order for adaptation to progress.

These barriers have been categorised in relation to the stage at which they occur in the adaptation planning cycle (Moser & Ekstrom, 2010). Of greatest interest with respect to the role and value of futures research in facilitating adaptation are those that occur during the 'understanding' and 'planning' stages (Table 14).

	Adaptation process step:	Adaptation barriers typically encountered:
Understanding	1. Assess risks and vulnerability to climate change, opportunities and uncertainties	• Understanding the system – Identification and agreement of core concepts, functions and baseline conditions of the system
		• Detection of the problem – Signal detection, thresholds of concern and action, framing of the problem, perception of need for and feasibility of adaptation action at the local scale
		• Gathering and using information – Stakeholder interest and focus in the issue; availability, accessibility, salience, relevance, credibility and legitimacy of information; identification and engagement of local expert stakeholders; facilitating data/information/knowledge exchange between local and higher scales; receptivity of stakeholders to engage with and use new information
		• (Re)-defining the problem – Re-framing of problem in light of climate change information (including thresholds of concern, response required, feasibility of action); reaching agreement on appropriate course of actions (including consensus if required to legitimise adaptation action)
Planning	2. Identify adaptation options	• Core adaptation assumptions – Ability to identify and agree on adaptation objectives and criteria for evaluating their success; ability to identify and agree on expected effects of adaptation options within the system • Emergence of local leadership – Capacity to identify appropriate agents to effectively and legitimately enact local adaptation options; capacity to engage and incorporate local leaders within the adaptation process • Identifying adaptation options – Capacity to identify a range of adaptation options available to realise adaptation objectives; capacity to create and agree on experimentation with new adaptation options where appropriate
	3. Assess adaptation options	• Assessing options – Availability of data/information to assess options; capacity to assess/compare options; perceived credibility, salience and legitimacy of option assessment methodology • Selecting option(s) to implement – Ability to agree on appropriate adaptation option(s) to implement; ability to identify and agree on appropriate performance measures and thresholds of concern regarding selected option(s)

Table 14: Barriers typically encountered during the understanding and planning phases of an adaptation process

1.2 FCM

FCM is a participatory modelling method (Malek, 2017) which builds a 'map of cognition' representing an individual's thought processes in relation to a given problem space (Kosko, Fuzzy cognitive maps, 1986; Axelrod, 1976). FCMs provide a visual and dynamic external representation of an individual's internal perceptions of the structure and function of a given system or problem domain (Gray, Zanre, & Gray, 2014; Özesmi & Özesmi, 2004). Using simple mathematical relationships, internal qualitative beliefs are semi-quantitatively encoded to create fuzzy dynamic models comprised of model concepts and weighted edge relationships that describe the causal linkages between them (Wei, Lu, & Yanchun, 2008). Graph theory then allows inferences to be drawn regarding the role each element plays in the networked system, and what the influence of changes in its expression may indicate relative to other concepts through a series of model iterations (Kok, 2009; Kosko, Fuzzy cognitive maps, 1986).

1.3 Claimed strengths of FCM

Having commonly been employed in complex industrial (Salmeron, Ruiz, & Mena, 2017) or medical problem diagnoses (Yamin, Mengmeng, Xiaomin, Zhiwei, & Jianhua, 2017), FCM is now increasingly being employed in environmental decision-making contexts (Bosma, Glenk, & Novo, 2017; Misthos, Messaris, Damigos, & Menegaki, 2017; Solana-Gutiérrez J. , Rincón, Alonso, & García-de-Jalón, 2017; Olazabal & Pascual, 2016; Christen, Kjeldsen, Dalgaard, & Martin-Ortega, 2015); this is perhaps the case because FCM is a method which has been claimed to be particularly well suited to decision-making under uncertainty.

A capacity to semi-quantitatively integrate disparate, loosely defined qualitative and quantitative inputs based on a modellers understanding of the system has been cited as marking out FCM as a particularly versatile tool in this regard (Gray, et al., 2015; Helfgott, et al., 2015; Vliet, Kok, & Veldkamp, 2010), allowing contrasting views to be explicitly highlighted and negotiated in the process (Helfgott, et al., 2015; Kontogianni, Papageorgiou, Salomatina, Skourtos, & Zanou, 2012). Further, FCM's capacity to generate and explore the consequences of scenarios involving different system states has been illustrated to ably facilitate structured thought experiments, which, although relatively simple to parameterise, account for sophisticated systemic interactions to produce meaningful 'what-if' outputs (Jetter & Kok, 2014; Kok, 2009). This latter feature is considered to be one of the most compelling points in FCM's favour where complexity and a lack of data cloud decision contexts (Solana-Gutiérrez J. , Rincón, Alonso, & García-de-Jalón, 2017; Gray, et al., 2015; Helfgott, et al., 2015; Kosko, 1986). Crucially, FCM-based future planning is also claimed to serve as a structured platform which might successfully bridge the divide between highly technical, quantitative analyses of a given situation or problem and the more subjective, qualitative assessments of knowledge holders and decision makers faced with uncertainty (Malek, 2017; van Vliet, Kok, & Veldkamp, 2010; Kok, 2009), much more readily facilitating social learning (Olazabal, Chiabai, Foudi, & Neumann, 2018; Malek, 2017; Gray, et al., 2014; van Vliet, Kok, & Veldkamp, 2010) and allowing new insights to be generated (Olazabal, Chiabai, Foudi, & Neumann, 2018; Gray, et al., 2015; Kontogianni, Papageorgiou, Salomatina, Skourtos, & Zanou, 2012). These attributes also facilitate the emergence of a shared conception of the system (Vasslides & Jensen, 2016; Gray, et al., 2015; Özesmi & Özesmi, 2004)

The key decision support attributes of FCM as cited in the literature (after Gray et al., 2016) are tabulated below (Table 15).

Claimed attribute:	Achieved via:
Copes with complexity	• Incorporating qualitative and quantitative inputs • Facilitating the inclusion of loosely defined concepts and relationships within the modelling process • Providing a simple, semi-quantitative description of the system under analysis via the identification of its key concepts and their relationships • Allowing sophisticated system models to emerge via a simple, iterative series of cause-effect relationships parameterised using descriptive terms
Integrates knowledge across domains and scales	• Making modelling process accessible to participants from any background or level of domain expertise • Flexibility of modelling framework allowing analysis of system domains ranging from micro to macro scales • Providing a modelling platform across which differing forms of (lay and expert, local and general) information and knowledge can be combined to provide semi-quantitative outputs
Identifies and makes explicit contrasting views of the system	• Providing a simple, visual illustration of where a given stakeholder's internal mental model of the system differs from another's • Facilitating a semi-quantitative analysis of the relative impact of contrasting perceptions on the system as a whole
Facilitates social learning	• Communicating differing views of system attributes, structures and functions via the shared FCM medium of model concepts and their relationships allows stakeholders to learn from each other
Builds a shared conception of the system	• Facilitating aggregation of individual understandings to build a shared map of cognition • Allowing a structured group modelling process to capitalise on social learning and reach a shared understanding of the system's key features and relationships
Generates new insights	• Exploring the outcome of interactions between system concepts over a number of FCM model cycles allows an understanding of the relative importance of their relationships to emerge • Providing a platform for group experimentation via changes in system concepts and the strengths of their relationships facilitates structured thought experiments
Bridges gaps between science and decision making	• Illustrating key differences between the perception of scientists and decision makers, and allowing a bi-directional exchange of information and ideas to fill gaps in systemic understanding • Providing a structured interface between complex computational projections and local scale perception of system structure and function • Building a system model which can be forced at its boundary by exogenous factors

Table 15: Claimed attributes of FCM found in the literature which might have a role to play in overcoming understanding and planning stage barriers to climate change adaptation

The key decision support attributes of FCM may in turn be mapped against barriers to adaptation progress that are typically encountered in the early stages of an adaptation process (Figure 21). Doing so provides a framework of analysis through which the capacity of an FCM-based futures methodology to address adaptation barriers might be gauged.

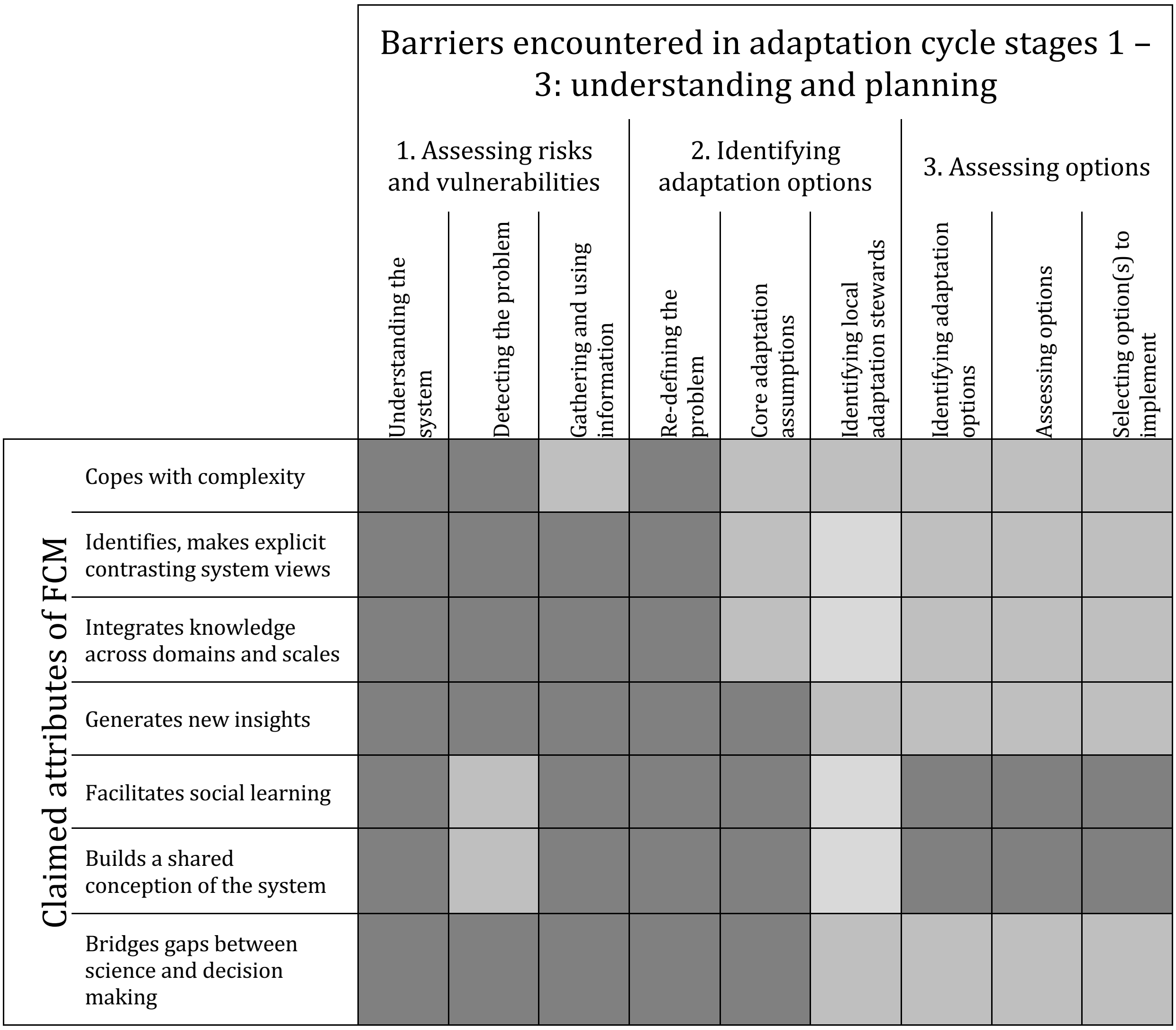


Figure 21: Mapping claimed attributes of FCM against known barriers to adaptation progress at the local scale.

2. Methods

2.1 Case study site description

Tralee Bay is situated in southwest Ireland, forming the northern side of a popular tourist and fishing destination – the Dingle Peninsula. The Tralee Bay coast is comprised of a mix of sand-gravel beaches backed by low cliffs or dune barriers, sand-cobble barriers with flanking mudflats and Cord Grass dominated salt marsh, and eroding low cliff coast with narrow cobble sediment. Cliff erosion rates are commonly 0.5-1.0 m per year on soft stretches of coast(Devoy, 2008).

Tralee has been accorded Special Protection Area status under the EU Birds Directive. Among the more than 20,000 wintering water birds the Bay supports annually are an internationally important population of Pale Bellied Brent Goose (*Branta bernicla hrota*), and 21 other nationally important species, including three (Whooper Swan, Golden Plover and Bar-tailed Godwit) which are listed as threatened under the Birds Directive Annex 1. Tralee Bay is also a Ramsar designated wetland of international importance.

Tralee town is the main settlement in the area, with a population of around 23 000 inhabitants. In the period following the global financial crisis of 2008, economic growth has primarily been focussed on retail, commerce, residential development and tourism. On the northern side of the bay lies Fenit, Ireland's most westerly commercial port.

Tralee Bay's principal climate threats are flooding and erosion (Gray, et al., 2014). For the southwest of Ireland, climate projections indicate an increase in the frequency of heavy precipitation days, particularly in winter, resulting in increased levels of runoff and flooding. This is particularly problematic for Tralee town where increased levels of development over the recent past have resulted in a decreased capacity of the area to absorb flood waters from low-lying areas.

Climate projections also indicate a sea level rise of c. 40cm for southwest Ireland (Devoy, 2008), which will result in inundation of low-lying coastal areas. Importantly, when increases in sea levels are combined with projected changes in Atlantic wave heights and storm surges (Lowe, et al., 2009; Devoy, 2008), increased levels of coastal inundation and erosion can be expected. This is particularly the case when storm surges combine with high astronomical tides to overtop coastal defences. Increased sea level rise will also result in increased tidal penetration of estuaries, which will exacerbate problems of seasonal flooding. Summer average temperatures are projected to rise by 0.9-1.7C by the 2050s, which in concert with projected decreases in summer precipitation (ranging from 0-20%) (Nolan, 2015) may result in enhanced potential to attract tourism.

2.2 An adaptation process based on an FCM and futures analysis methodology

The literature describes various ways that participatory FCM's might be developed, including via desktop study, survey, Delphi method, or facilitating participants through the process of directly building an FCM themselves (Jetter & Kok, 2014). The method used here aimed to maximise the extent to which the local expert stakeholders involved could take ownership of model development and the subsequent scenarios analysis for which it would serve as a platform, ensuring it would be fully reflective of the stakeholders' understanding of the local coastal system.

As illustrated in Figure 22, the FCM-based adaptation process designed for this research involved the development of a conceptual model of the Tralee Bay coastal system by individual expert stakeholders. The resulting individual FCMs were then aggregated to form a draft group model, which was subsequently edited and calibrated by the group in a workshop setting. The calibrated group model was then forced by the introduction of scenarios of future change, the impacts of which were discussed with the group, and a range of potential adaptation options were identified. The group then came to a conclusion regarding which of the options were to be evaluated via scenario analysis within the model, and used the results of the analysis to inform the development of an adaptation strategy.

2.2.1. Identifying coastal management stakeholders, compiling key system concepts

With time and resources limited, and the ease with which a larger group could be successfully facilitated through an adaptation process unknown, the stakeholder engagement process adopted here closely followed that advocated by Olsson et al. (2006) in their description of navigating transitions to adaptive governance in Kristianstad, Sweden, and the Everglades, USA. In those instances, the adaptive process built momentum through the development of a small, informal network of key stakeholders who shared not only a strong desire for change, but also the necessary expertise and systemic insight required to understand what would be required to realise it (Olsson, et al., 2006).

A purposive survey of coastal management stakeholders was undertaken to identify potential candidates for a small, informal network of this nature. For the purposes of this research, 'coastal management stakeholders' were defined as those with responsibility for, or long standing expertise and local influence over coastal planning and development, emergency preparedness, pier and harbour management, inshore fisheries, aquaculture, conservation and environmental protection, and other coastal sectors of activity relevant to the geographical setting. The survey involved the completion of a Likert scale questionnaire followed by a semi-structured interview lasting approximately an hour. The interview explored participant's views of which (if any) coastal climate change issues were considered to be of primary concern, over which timeframe adaptation measures were considered likely to be necessary, and what sources of information the participant had made use of in coming to the positions they held in relation to climate impacts and adaptation.

From the initial pool of survey respondents (n=32), a smaller group was identified (n=6) whose involvement in local coastal adaptation decision-making and implementation was deemed essential in order for it to succeed (both by the research team, and most crucially, by the survey participants themselves). Lead-in stakeholder interviews were also used to identify and note prevalent system concepts that interviewees referred to in describing the coastal social-ecological system.

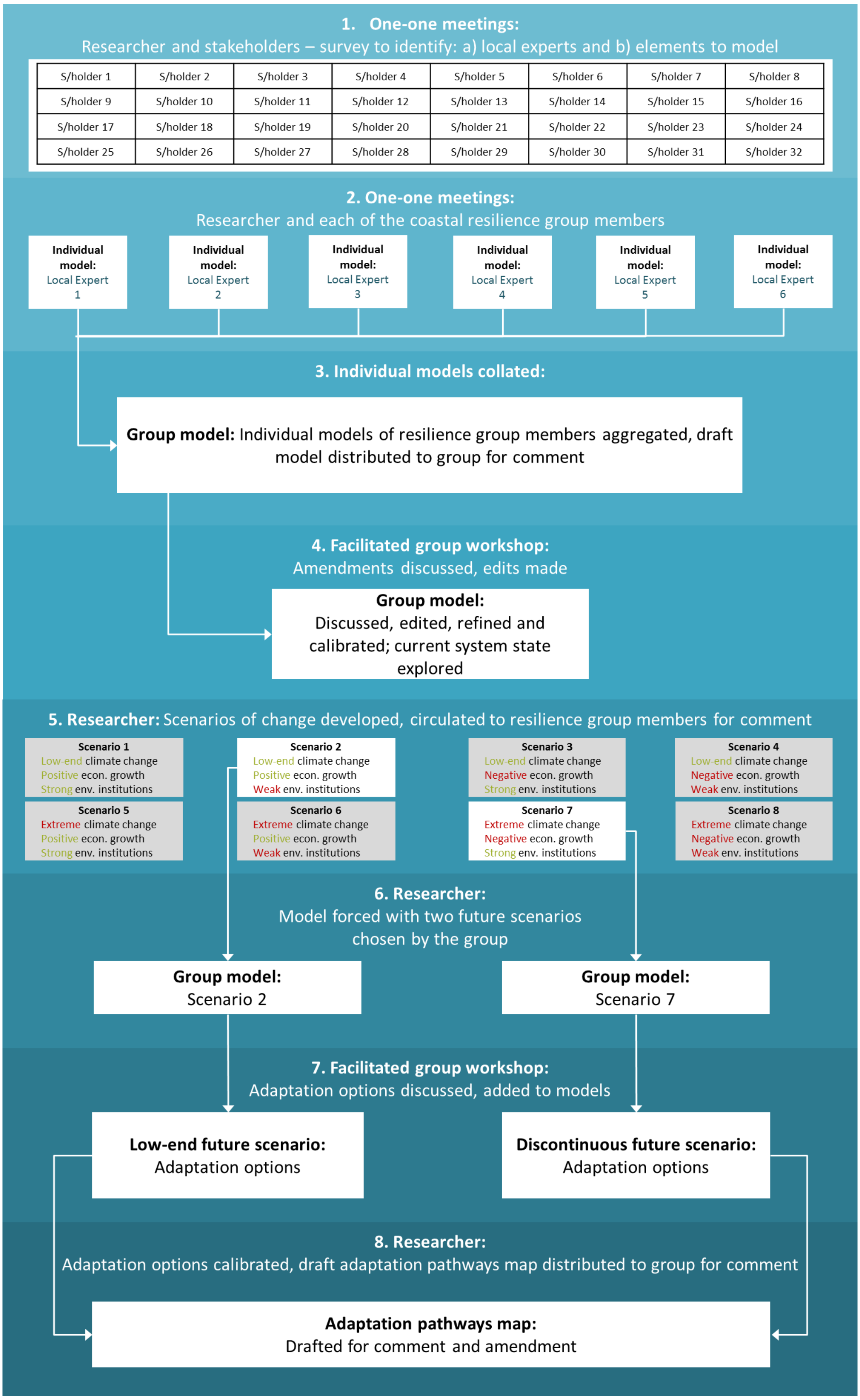


Figure 22: An FCM-based adaptation process methodology

2.2.2. Constructing individual models of coastal social-ecological system resilience

The FCM process began with each resilience group member being facilitated through a process of 'modelling the resilience of the Tralee Bay social-ecological system'. Each member first selected a system boundary of the coastal social-ecological system they were about to model on a printed map of the wider Tralee Bay area (Figure 23). This served to help constrain the thinking of the modeller, allowing them to focus on key system concepts which were endogenous to Tralee Bay social-ecological system as they perceived it, rather than include exogenous factors which are likely to fall beyond local capacities to adaptively manage.

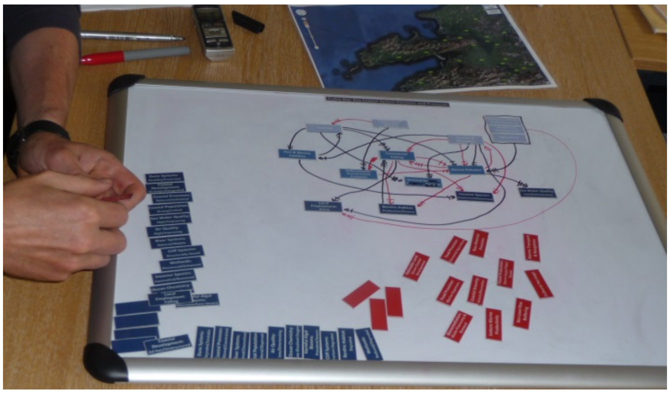


Figure 23: The process of building an individual FCM, with an image of the Tralee Bay system boundary above the model.

Each modeller then began selecting concepts for inclusion in their model. The issue of model element selection was specifically discussed with each modeller, clarifying the origin of the model concepts that had been provided, and pointing out that the option to disregard them and create new concepts, or mix and match between predetermined and new concepts remained open.

To ease the cognitive burden involved in doing so, the 'driver-pressures-state-impact-response' (DPSIR) framework was used to structure each model, with drivers of change being the first concepts modellers selected, continuing to move through the DPSIR framework to end with responses. The concepts modellers selected are included in Appendix 1.

2.2.3. Analysing and aggregating individual models to form a preliminary group model

Each individual model was transcribed into an adjacency matrix (see Table 16 for encoding values) and analysed using 'FCMapper' (Wildenberg, et al., 2010), a spreadsheet-based analytical tool facilitating the analysis of a number of key FCM parameters of relevance to the selection of adaptive interventions, including density, centrality and the model's baseline scenario (Gray, Zanre, & Gray, 2014).

Coding of edge relationships			
Weak positive	0.25	Weak negative	-0.25
Moderate positive	0.50	Moderate negative	-0.50
Strong positive	0.75	Strong negative	-0.75

Table 16: Encoding values used to transcribe individual models into adjacency matrices

The term 'density' describes the number of connections between concepts in the FCM as a proportion of the total number of connections possible (Özesmi & Özesmi, 2004). The higher the density of the FCM the greater the potential for adaptive intervention it embodies, as opportunities to effect change are more abundant (Gray, et al., 2014).

The measure 'degree centrality' ($C_D(V)$) describes the relative importance of a concept within the structure of an FCM. The greater the centrality of a concept, the greater its importance in determining the behaviour of the system as modelled. Centrality is calculated by a simple summation of the concepts absolute incoming (indegree) and outgoing (outdegree) connection weights:

$$C_D(V) = \sum(id(V) + od(V)) \quad (1)$$

where indegree id*(V)* is the summation of all edge relationships entering concept (*V*) outdegree od*(V)* is the summation of all edge relationships exiting concept (*V*) (Gray, Zanre, & Gray, 2014).

Measures of 'indegree' and 'outdegree' indicate, respectively, the degree to which a given concept is affected by and affects other concepts within the FCM (Gray, Zanre, & Gray, 2014).

Calculating the output of an FCM's adjacency matrix over a series of iterations provides a 'baseline scenario' – a representation of the steady state of the system in the absence of change or intervention, with all feedback loops played out:

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j \equiv i}}^{N} A_j^{(k)} w_{ji}\right) \quad (2)$$

where, $A_i^{(k+1)}$ is the value of element V_i at iteration step k+1

$A_i^{(k)}$ is the value of element V_i at iteration step *k,*

$A_j^{(k)}$ is the value of element V_j at iteration step *k*,

and w_{ji} is the weight of the edge relationship between V_i and V_j

A threshold function f (typically a logistic or sigmoidal function) is often used to normalise the values at each iteration step, ensuring the dynamic analysis remains constrained, although this is not essential.

Analysing these aspects of each model individually allows inferences to be drawn regarding what specific information would be useful to provide in order to appropriately integrate broad-scale knowledge of climatic change with the finer scale, locally specific coastal management knowledge of each modeller (Gray, et al., 2014) (See Appendix 1 for baseline scenario outputs).

With these analyses complete, the adjacency matrices were then combined into a single aggregate matrix (Kosko, Fuzzy cognitive maps, 1986). The process adopted here for doing so was simple addition, with the resulting values then divided by the number of individual modellers to give a mean value for each edge relationship recorded across the individual FCMs (Kosko, 1988).

At this stage, system concepts were also grouped into higher order categories for ease of communication in a workshop setting. This reduced the 67 individual modelling concepts to represent graphically down to 16 aggregated categories. The underlying model remained unchanged and subsequent resilience assessment and calibration would occur at the level of individual system element relationships.

2.2.4. Facilitated workshop 1: Calibrating and amending the preliminary group model

A workshop involving the group as a whole was held where the group model in its preliminary form was introduced, discussed, amended and calibrated to more accurately reflect the group's perception of the resilience of Tralee Bay.

To begin this process, the baseline scenarios of each individual's model, and of the aggregated group model, were presented to the group. The similarities and differences between models were highlighted, and any possible errors or omissions discussed. To help facilitate this discussion and introduce differences in perspective, an FCM of Tralee Bay created by a national-level expert on climate change and coastal geomorphology was also presented to the group.

Edge relationships within the group model which represented a significant departure from those in any of the individual models contributing to it were highlighted for group appraisal (i.e. those involving the introduction or removal of an edge relationship, those involving a switch between positive and negative influence of an edge relationship, or those involving a substantial reduction or increase in the strength of an edge relationship).

Graphical representations of the key relationships in the preliminary group model were presented and discussed. Participants were then facilitated through the process of calibrating the draft model in a series of stages based on the DPSIR framework.

2.2.5. Developing scenarios of future change

Building on information provided during the individual modelling process, and the group model calibration workshop, simple narrative scenarios were developed to reflect the group's view of the most significant and uncertain drivers of change with respect to the resilience of the Tralee Bay coastal social-ecological system.

2.2.6. Simulating the calibrated group model's resilience to perturbation under alternate scenarios of future change

Scenarios were used to simulate the impacts of future climatic, economic and legislative changes on the Tralee Bay social-ecological system. This involved the creation of three exogenous drivers which forced the model at its boundary, with variations in the strength and polarity of the edge relationships emanating from them representing alternate future scenarios.

A literature review of the projected climate change impacts for the south-west of Ireland was undertaken to produce a coastal sensitivity index. The index identified the 10 physical phenomena by which climate change impacts were likely to be manifest, and these phenomena were added to the model as physical driver concepts, their expression parameterised using a scaled FCM notation. To provide a suitable interface for these phenomena at its boundary, three additional physical pressures were added to the model.

New baseline scenario outputs were generated using the matrix algebra of equation 1, providing a broad indication of the impacts the simulated changes would have on the system.

2.2.7. Facilitated group workshop 2: Selecting adaptive interventions and modelling their efficacy

The scenario simulation outputs to the coastal resilience group were presented through a second workshop. The narrative of each scenario was first discussed, followed by an explanation of how the scenario had been simulated to interact with the group model. As with the earlier baseline scenario analysis, the implications of each of the scenarios of future change were explained via reference to graphical output derived from the matrix algebra of equation 1. Concepts of the system which increased or decreased in a manner indicative of specific vulnerabilities or adaptive capacities were highlighted for discussion.

Workshop participants were then split into two groups (one per scenario), each with the task of proposing adaptive interventions which could address the vulnerabilities and enhance adaptive capacities the scenario in question gave rise to. Participants were asked to be as specific as possible regarding the system concepts the intervention would interact with, and to give thought to the spatial and temporal factors that might influence the selection of adaptive measures. At the end of the workshop, adaptation options from each group were collated and entered into the model, providing a preliminary simulation of adaptation efficacy.

2.2.8. Drafting an adaptation pathways map

Working from the material provided by the group during the modelling and scenario analyses, an adaptation pathways map was drafted for circulation and comment.

3. Results

The primary aim of this research was to assess the extent to which an alternative decision support methodology to conventional scenario analysis can assist in overcoming adaptation barriers at the local scale. Referring back to Figure 2's mapping of FCM's claimed benefits against barriers to adaptation at the three early stages of an adaptation cycle, it is possible to locate the various methodological steps of the FCM-based approach employed through this research within it (Figure 24). The presentation of results to follow will be structured by this approach.

	Barriers encountered in adaptation cycle stages 1 – 3: understanding and planning								
	1. Assessing risks and vulnerabilities			2. Identifying adaptation options			3. Assessing options		
Claimed attributes of FCM	Understanding the system	Detecting the problem	Gathering and using information	Re-defining the problem	Core adaptation assumptions	Identifying local adaptation stewards	Identifying adaptation options	Assessing options	Selecting option(s) to implement
Copes with complexity	2,4,7	2,4	4,5,7	4,5,7	7	1,4,7	7	7	7
Identifies, makes explicit contrasting system views	4	4,7	4,7	4,7	5,7	1	5,7	7	7
Integrates knowledge across domains and scales	2,4,7	5,7	4,5,7	4,5,7	5,7	5,7	7	7	7
Generates new insights	4,7	4,7	4,7	4,5,7	4,5,7	4,7	5,7	7	7
Facilitates social learning	4,7	4,7	4,7	4,7	5,7	4,7	7	7	7
Builds a shared conception of the system	4	4,7	4,7	4,5,7	4,5,7	4,7	5,7	7	7
Bridges gaps between science and decision making	4 ,7	7	7	5,7	5,7	5,7	5,7	7	7

Figure 24: Locating stages of the FCM-based adaptation process within the matrix of claimed benefits of FCM and known barriers to adaptation at the local scale.

3.1.1. Copes with complexity

Individual model building and workshop phases of the process facilitated the emergence of a rich systemic understanding among participants. The broad number of concepts initially modelled with and the number of interconnections between them signalled the capacity of the method to incorporate complexity and build it into the process (Figure 25). Similarly, information use and problem re-definition proved simple barriers to overcome, with the conceptual modelling platform of FCM effectively cutting through the potentially confusing array of coastal management issues to allow space for the influence of climate to be introduced for meaningful consideration. Later stage barriers were predictably less well addressed, with the complexity of adaptation option identification, assessment and selection only meaningfully addressed at process step 7.

Where the capacity of FCM to cope with complexity arguably offered less assistance in overcoming early stage adaptation barriers was in regard to problem detection. Process steps 2 and 4 offered scope for participants to develop sophisticated, complex models of the coastal social-ecological system. However, these were by their nature constrained by the perception of each modeller, with the incorporation of signals of change dependent upon their ex-ante detection and attribution by participants, prior to any involvement in the process. The individual models are also a discrete snapshot in time, perhaps subsequently triggering the curiosity of participants to gather and use information to enhance their understanding of the complex systemic structures and functions they were describing, but they do not specifically facilitate them in doing so.

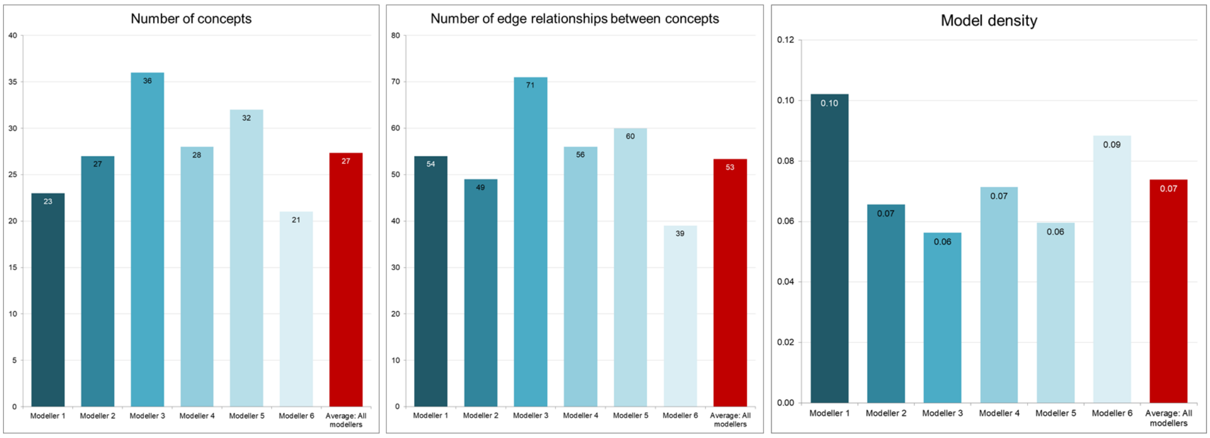


Figure 25: The number of concepts (left), edge relationships between concepts (middle) and model density (right) figures resulting from process step 2.

3.1.2. Identifies, makes explicit contrasting system views

The graphical nature of FCM came to the fore in overcoming ‘system view' adaptation barriers. In particular, making the contrasting perceptions of participants explicit and readily comprehensible helped to facilitate broader systemic understanding and the re-definition of adaptation problems (see Appendix 1). Individual concepts which were perceived by participants to have contrasting effects on others within the system were readily identifiable and became the focus of discussion in workshop settings (Figure 26).

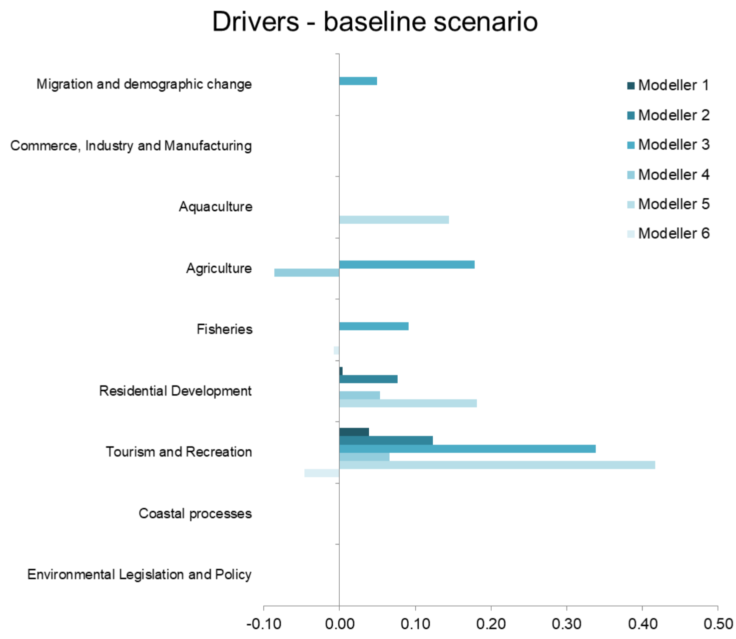


Figure 26: An illustration of how contrasting views of the system can be illustrated for discussion and further elaboration. In this instance, five of the six modellers believe the concept Tourism and Recreation is likely to grow given the configuration of the coastal social-ecological system. The sixth modeller perceived the system configuration to result in a slight decline in Tourism and Recreation. Similarly, Agriculture was viewed in starkly different terms by Modellers 3 and 4.

The selection of scenarios with which to force the group model also offered a platform for contrasting views of which potential states of the system were considered plausible and thus worth investigating further, allowing assumptions regarding the future to be made clear.

This particular strength of the FCM-based process also served as a useful platform for the identification of adaptation stewards, with the early stage of data gathering in advance of individual modelling helping to identify who might champion the process, and also who might feel unsure or in some sense challenged by it. These insights are useful to be armed with in attempting to build adaptive momentum in the early stages of the process.

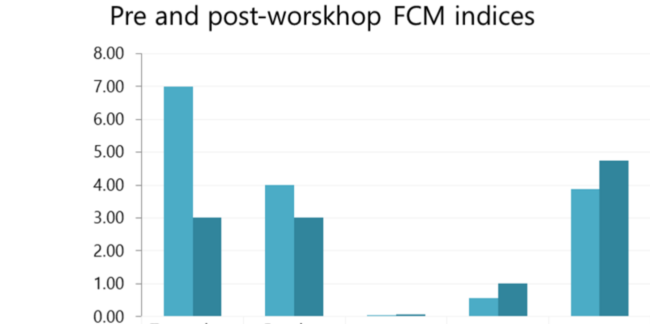
3.1.3. Integrates knowledge across domains and scales

The capacity of an FCM-based adaptation process to integrate knowledge across domains was most clearly evident in workshop settings. The move from individual to group models, followed by scenario forcing and the modelling of adaptation intervention, provided ample scope for stakeholders representing different knowledge domains to share their expertise with the group, often encoded in FCM modelling terms, which eased explanatory overhead and provided a neutral language for debate and reappraisal of views.

The scope for integration of knowledge across scales is likely to be just as great given the participation of representatives from the appropriate knowledge domains. In this instance, scalar knowledge was introduced in the most structured manner via boundary scenarios during process step 5. This served a useful purpose in helping to introduce new sources and types of information to participants, challenge both problem definitions and core adaptation assumptions in the process.

3.1.4. Generates new insights/Facilitates social learning

These attributes of FCM typically coincided and are thus reported together here. The 'new' insights generated during the process were in many cases known to at least one member of the group previously, but on occasion appeared to be genuinely new to all – such as the discovery that gains in ecosystem service provision may be realisable through a minor refocussing of economic activity, an insight which emerged under a 'low growth' scenario assessed in process step 7.



	Transmitter variables	Receiver variables	Density	Complexity	C/N ratio
Pre-workshop	7	4	0.0555	0.5714	3.8857
Post-workshop	3	3	0.0677	1	4.7429

Figure 27: Changes in the FCM indices between pre and post-workshop group models indicate an altered conception of the coastal system among participants, with a richer understanding of its complexity and degree of interdependence emerging as a result of social learning and knowledge integration.

Some insight into the generation and sharing of new insights is offered by an assessment of how the group model evolved. During workshop deliberations, participants agreed a total of 77 amendments to edge relationships in their original model, 60 of which constituted new connections between concepts. This saw model density increase from 0.056 prior to the workshop to 0.068 after it, representing a 22% increase in the potential for adaptive intervention (Gray, Zanre, & Gray, 2014). FCM measures indicative of systems thinking such as complexity and C/N ratio also increased (Figure 27). The addition of edge relationships between concepts in the model also saw centrality values increase. Only 16 of 70 concepts in the group model saw no change in centrality post calibration, while two concepts – 'payment of EU fines' and 'marine transport and navigation' – declined slightly in centrality (Figure 28).

This pattern of general enrichment of the description of interdependence within the model resulted in a number of concepts rising in prominence relative to others. Most notably, the group re-evaluated the influence of environmental policy, and the role of local authority planning in enforcing it. These factors also increased in expression in the calibrated model's baseline scenario. The influence of local authority planning decisions in particular was modelled as increasing strongly.

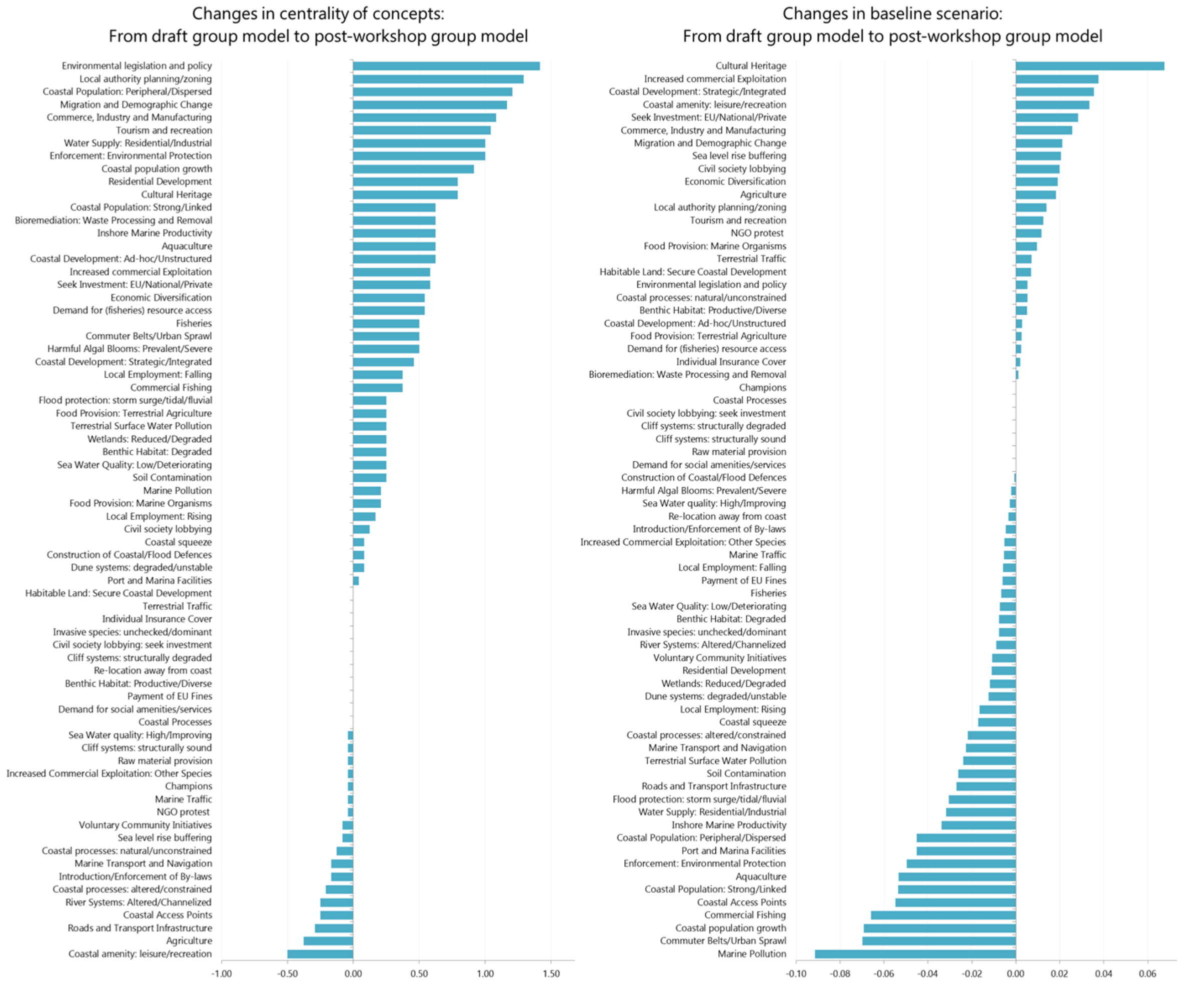


Figure 28: Changes in centrality (left) and baseline scenario output (right) occurring as a result of workshop deliberation over the group model. Centrality scores increased for most concepts, illustrating an enriched understanding of the interconnections and strength of influence between concepts in the model, leading to substantive changes in baseline scenario output. These changes are illustrative of not only social learning and knowledge integration, but also the emergence of a shared system view among the group.

Insights which emerged during group workshop model analyses appeared to be 'jointly owned' knowledge among participants (rather than emerging via didactic learning), resulting in measurable shifts in the group's perception of the system's functions and behaviours (Figure 28). This feature of the FCM-based process allowed adaptation problem re-definition and the recalibration of core assumptions to take place with relative ease.

This communal approach continued as participants navigated the boundary scenario phases of the adaptation process, with the exploration and analysis of adaptation options also emerging as social learning opportunities in a facilitated workshop setting.

3.1.5. Builds a shared conception of the system

The emergence of a shared conception of the system is an aspect of FCM-based processes which is perhaps regarded as inevitable, given the explicitly systematic nature of FCM construction and analysis. The extent to which such a shared conception can specifically be identified is nevertheless interesting to assess.

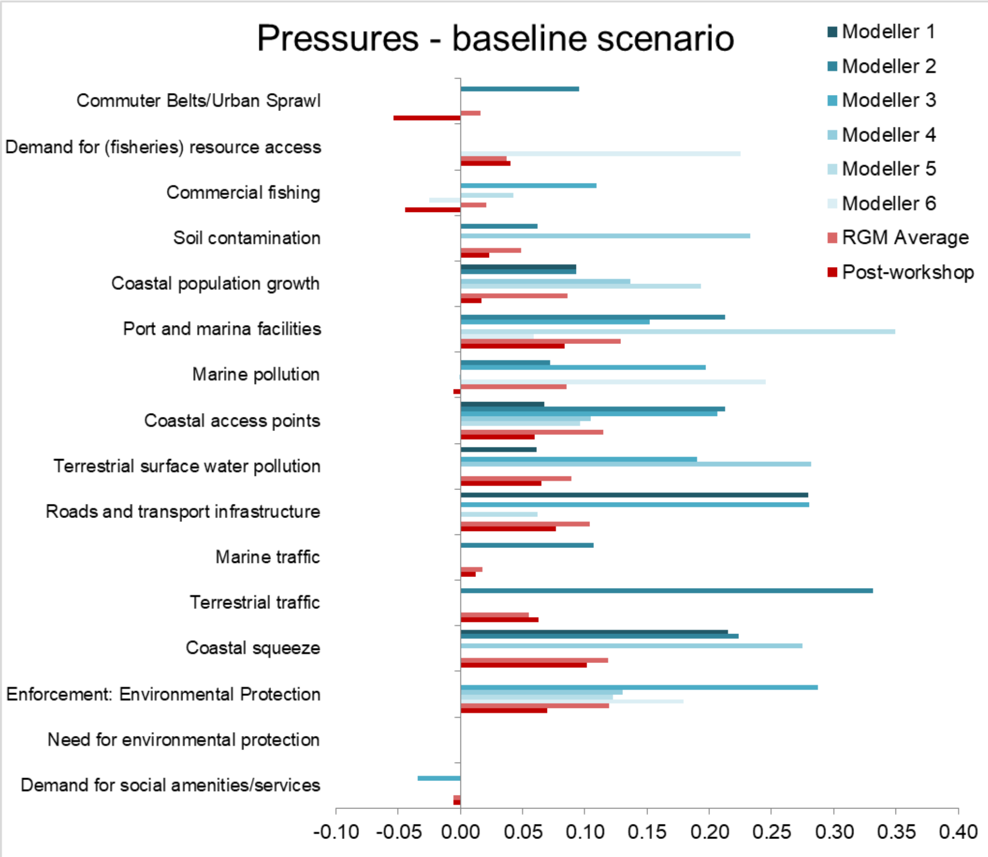


Figure 29: An illustration of the different baseline scenario signatures of the coastal system – represented in this instance by pressure concepts (concepts were split into groups on the basis of DPSIR categories). As individual models were aggregated into a shared model, which was subsequently amended and calibrated by the group, an identifiably different baseline scenario signature emerged.

The shared system conception appeared to emerge in two stages. The first involved a dampening down of the effect of outlier perceptions via simple averaging of individual model relationships to form the draft group model. Presenting this raw assemblage model to the group for analysis and calibration allowed a second stage of shared system view development to occur, as illustrated by Figure 29. In some cases this resulted in refining the baseline scenario signature of the model (coastal access points, coastal population growth) in and in others reversing it (commuter belts, commercial fishing).

3.1.6. Bridges gaps between science and decision making

The most difficult attribute of FCM to evaluate in this instance was the capacity to bridge gaps between science and decision making. While there are clear opportunities created by an FCM-based adaptation process to incorporate scientific information in the development of models, in a participatory, stakeholder-driven process such as is described here, participants must explicitly choose to do so. Many made reference to their grasp of the science surrounding various aspects of the coastal social-ecological system, though it's incorporation within the resultant model was mediated by the explicitly perceptual nature of the model-building process.

However, to facilitate the simulation of the impacts of climate over the short term (20-30 years) for stages 5-7 of the process, 10 physical driver concepts were added to the model by the authors. These concepts were given edge relationships to other concepts reflective of their anticipated future impact. Three additional pressure concepts were also added to the model in order to facilitate the simulation of changing coastal climate dynamics – 'erosion', ‘flooding/coastal inundation’ and ‘drought’. These concepts were also given edge relationships reflecting their anticipated future impact under each scenario.

The addition of these concept nodes and edge relationships provided a rich opportunity for discussion and analysis by the group with respect to scientific projections of climatic change, and the impacts these would have for the coastal social-ecological system. This capacity for structured incorporation of climatic impacts creates the theoretical space for the bridging between science and decision making to readily occur, provided that the scientific expertise and data are available to do so.

4. Discussion

Two, at times conflicting, objectives underlie the design of the FCM methodology adopted here. The first – ensuring that all stages of the scenario analysis remained firmly grounded in local conceptions of both the system under study and its plausible future states – emerged through the authors’ previous experiences in working with the intuitive logic scenario analysis method at the local scale (Gray, O’Mahony, Hills, O’Dwyer, Devoy, & Gault, 2016).

The second objective the method sought to achieve is that of (relative) ease of replication. As previous research has noted (Gray, O’Mahony, Hills, O’Dwyer, Devoy, & Gault, 2016; McKenna, Cooper, & O’Hagan, 2008), local-scale endeavours such as integrated coastal zone management or climate change adaptation projects undertaken in Ireland (and generally around Europe’s coast) rely almost entirely on the efforts of a small number of often poorly resourced, habitually multitasking local authority staff, and any short-term contractors they might be allocated. Any proposed futures methodology must therefore be designed with these operational constraints in mind if it is to gain traction and meaningfully contribute to overcoming barriers to coastal climate adaptation at the local scale.

Despite the FCM-based adaptation process’ many strengths in overcoming adaptation barriers, it is in meeting this second objective that the method described here may fall short. Participatory modelling can be a mentally taxing process, even for those accustomed to working conceptually to develop a theoretical representation of the material world. The cognitive burden imposed on participants should therefore ideally be minimised to allow energies to be focussed on the issue at hand rather than the process of model development itself.

With respect to FCM development, this creates a tension between ease of model facilitation and the authenticity of the information captured within the model (Paolisso & Trombley, 2017). Providing participants with pre-determined model concepts serves to suggest what is of value or importance in the system under study, but not doing so can lead to an overwhelming sense of the enormity of attempting to codify a complex system on a blank page (or in this case, whiteboard). In the typically short time frames available to coastal management stakeholders tasked with effecting adaptation, this may perversely create a new barrier rather than overcome known ones.

To strike a balance between these positions, the lead-in stakeholder interview process was used in this instance to identify and note prevalent system concepts that interviewees referred to in describing the coastal social-ecological system. It also ensured that each stakeholder was offered an opportunity to clearly elucidate their point of view with respect to the Tralee Bay coastal social-ecological system, free of the influence of others, or any inhibitions a group setting of stakeholders of various backgrounds and levels of seniority might introduce. This may highlight a route forward that could offer the benefits of an FCM-based adaptation approach without the potentially crippling facilitation overheads.

It may be possible to develop a generic coastal social-ecological system model using material such as that gathered during stakeholder interviews described above, academic and grey literatures, and the expert opinion of scientists. This could serve as something of a straw-man argument or template/framework which could be made locally specific in a much shorter timeframe and with a much reduced cognitive burden on participants. It would also be naturally amenable to forcing with scenarios of change at its boundary if constructed with such an aim in mind.

Developing an adaptation process along these lines would require the commitment of time and resources at national and/or regional scales. However, a commitment to invest in supporting work of this nature has been enshrined in supra-national and national adaptation policy in Europe for many years (COM (2013) 216, 2013; DCCAE, 2018). Approaches such as FCM are now becoming increasingly commonplace in public policy decision contexts. The argument for supporting their widespread uptake in futures-oriented, complex and uncertain fields such as climate change adaptation would therefore appear to be becoming increasingly difficult to ignore.

5. Conclusions

Scenario analysis has been recognised as a means to overcome barriers to adaptation planning at the local scale but progress on adaptation remains limited. FCM has been widely applied to understand and communicate systems dynamics and is considered particularly appropriate in the context of decision-making under uncertainty. As demonstrated through this paper, through a structured model building process, FCM can be usefully applied in the context of planning for climate change adaptation and provides an appropriate means of overcoming remaining barriers to planning for adaptation at the local scale.

Not only does FCM seek to identify and assess the local scale implications of climate change, combining qualitative and quantitative understanding of the system, it also provides stakeholders with the opportunity to participate in management decisions around climate adaptation and supports discourse to develop a structured and shared understanding of complex and uncertain environmental issues. Moreover, FCM provides a platform for stakeholder deliberation and testing of management solutions.

Notwithstanding the above, it is important to recognise the constraints on local scale decision makers (in terms of time and resources) who are tasked with the development of local scale adaptation plans. The proposed framework seeks to minimize these by providing a structured framework for the application of FCM at the local scale and with multiple stakeholders integrating preferences and values and where connections and outputs can be judged relative to inputs. As such, the approach show benefits of using FCM to co-construct explanatory models of the system on which predictions and subsequent actions can be tested which is particularly appropriate when addressing wicked problems such as local scale planning for climate change.

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Appendix 1: Model concepts used and individual FCM baseline scenarios[9]

	Model concept:	Modeller: 1	2	3	4	5	6	No. of modellers using this concept
DRIVERS	Tourism and recreation	■	■	■	■	■	■	6
DRIVERS	Environmental legislation and policy	■		■	■	■	■	5
DRIVERS	Coastal processes	■	■	■	■	■		5
DRIVERS	Residential development	■	■		■	■	■	5
DRIVERS	Agriculture		■	■	■			3
DRIVERS	Commerce, industry and manufacturing		■				■	2
DRIVERS	Fisheries			■			■	2
DRIVERS	Aquaculture					■		1
DRIVERS	Migration and demographic change			■				1
DRIVERS	Large scale public works							0
PRESSURES	Coastal access points	■	■	■	■	■		5
PRESSURES	Coastal population growth	■	■		■	■		4
PRESSURES	Enforcement of environmental protection			■	■	■	■	4
PRESSURES	Marine pollution		■	■		■	■	4
PRESSURES	Port and marina facilities		■	■		■	■	4
PRESSURES	Coastal squeeze	■	■		■			3
PRESSURES	Commercial fishing			■		■	■	3
PRESSURES	Terrestrial surface water pollution	■		■	■			3
PRESSURES	Roads and transport infrastructure	■		■		■		3
PRESSURES	Soil contamination		■		■			2
PRESSURES	Marine traffic		■					1
PRESSURES	Demand for social amenities/services			■				1
PRESSURES	Terrestrial traffic		■					1
PRESSURES	Demand for (fisheries) resource access						■	1
PRESSURES	Commuter belts/urban sprawl		■					1
PRESSURES	Air pollution							0
STATES	Dune systems: degraded/unstable	■	■	■	■			4
STATES	River systems: altered/channelized			■	■	■		3
STATES	Local employment: falling	■		■	■			3
STATES	Coastal population: strong/linked	■		■		■		3
STATES	Coastal population: peripheral/dispersed		■	■	■			3
STATES	Invasive species: unchecked/dominant				■		■	2
STATES	Wetlands: reduced/degraded			■	■			2
STATES	Benthic habitat: degraded			■	■			2
STATES	Harmful algal blooms: prevalent/severe			■		■		2
STATES	Local employment: rising					■	■	2
STATES	Coastal development: ad-hoc		■			■		2
STATES	Coastal development: strategic					■		1
STATES	Coastal processes: natural	■						1
STATES	Coastal processes: altered/constrained		■					1

[9] Data available from: https://data.mendeley.com/datasets/fmypymmj59/1

	Cliff systems: structurally degraded		X					1
	Sea water quality: high/improving	X				X		1
	Sea water quality: low/deteriorating						X	1
	Benthic habitat: productive/diverse						X	1
	Cliff systems: structurally sound					X		1
	Wetlands: preserved/enhanced							0
	Dune systems: healthy/protected							0
	Harmful algal blooms: decreasing/less severe							0
	River systems: natural/mobile							0
	Air quality: high/improving							0
	Air quality: low/deteriorating							0
	Invasive species: controlled/removed							0
IMPACTS	Coastal amenity: leisure/recreation	X	X	X	X	X		5
	Marine transport and navigation		X	X		X	X	4
	Cultural heritage		X	X	X	X	X	4
	Flood protection: storm surge/tidal/fluvial	X		X	X	X		4
	Food provision: terrestrial agriculture			X	X	X		3
	Habitable land: secure coastal development	X	X			X		3
	Sea level rise buffering	X	X		X			3
	Food provision: marine organisms			X	X		X	3
	Inshore marine productivity					X	X	2
	Raw material provision			X				1
	Water supply: industrial/residential			X				1
	Bioremediation: wastes						X	1
RESPONSES	Local authority planning/zoning	X	X	X	X	X		5
	Economic diversification			X	X		X	3
	Voluntary community initiatives		X	X	X			3
	Civil society lobbying: seek investment	X		X				2
	Construction of coastal/flood defences	X				X		2
	Introduction/enforcement of by-laws			X		X		2
	NGO protest			X			X	2
	Civil society lobbying						X	1
	Seek investment: EU/national/private					X		1
	Payment of EU fines				X			1
	Increased commercial exploitation	X						1
	Individual insurance cover	X						1
	Re-location away from coast					X		1
	Champions		X					1
	Increased exploitation: other species						X	1

Table 17: The concepts used by individual modellers in creating their FCM's of Tralee Bay. Those used most frequently by modellers are listed first under each of the DPSIR categories.

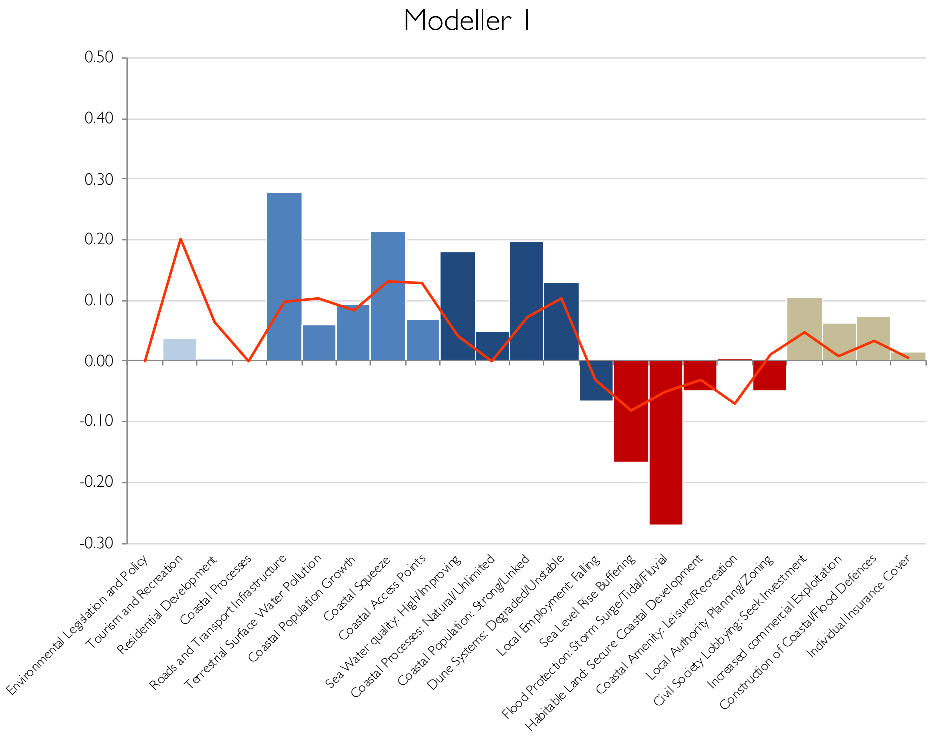

Figure 30: The baseline scenario of Modeller 1's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 1 sees increasing pressures from road and transport infrastructure and coastal squeeze enhancing community integration, but at the cost of degraded dune systems, which in turn undermine ecosystem services such as sea level rise buffering and flood protection.

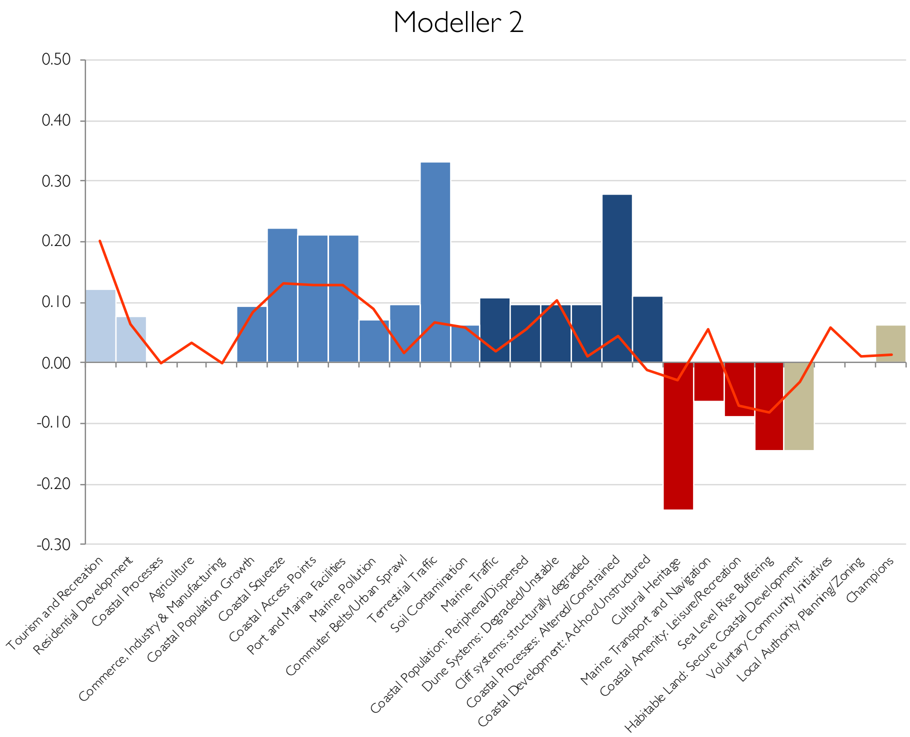

Figure 31: The baseline scenario of Modeller 2's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 2 sees increasing pressures from traffic and coastal access points altering coastal processes and degrading the cultural heritage and ecosystem services the coast provides.

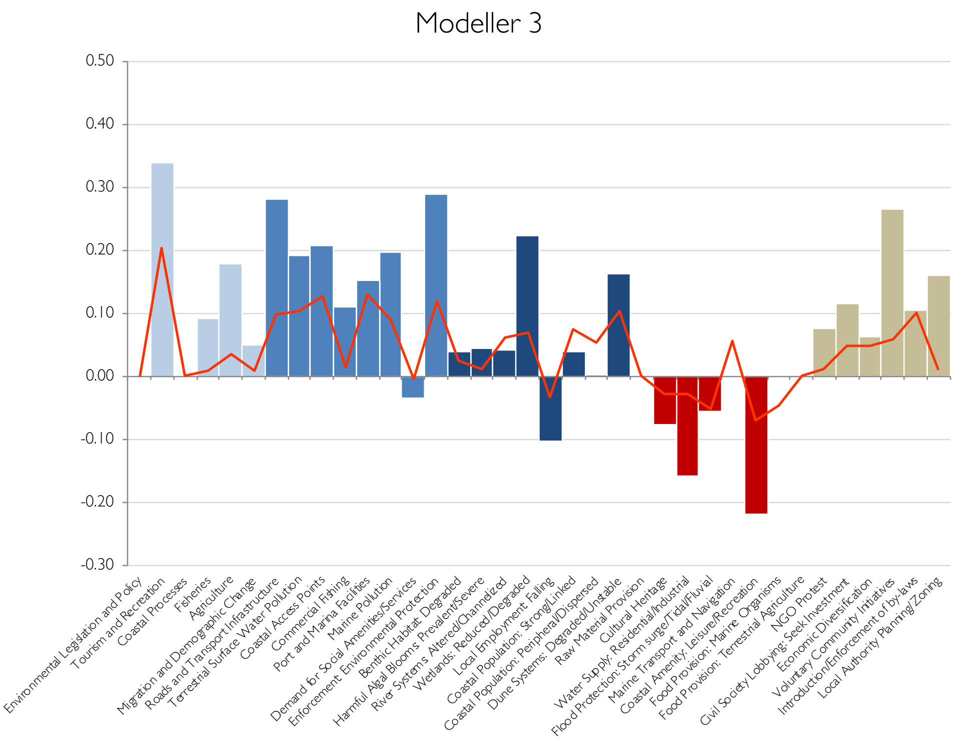

Figure 32: The baseline scenario of Modeller 3's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 3 sees increasing tourism and agriculture driving increases in road and marina facilities, which in turn degrade wetlands and dune systems (despite growing pressure to enforce environmental regulations). This sees water supplies and coastal amenity suffer, triggering a rise in voluntary community initiatives.

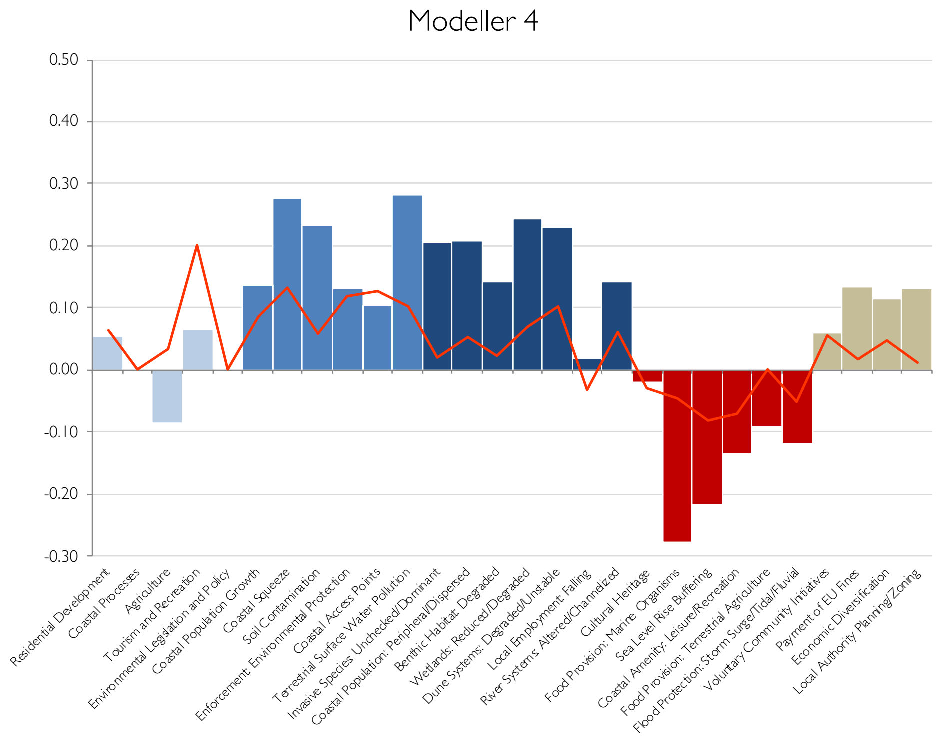

Figure 33: The baseline scenario of Modeller 4's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 4 sees increasing pressures from traffic and coastal access points altering natural coastal processes, and thus degrading the cultural heritage and ecosystem services the coast provides.

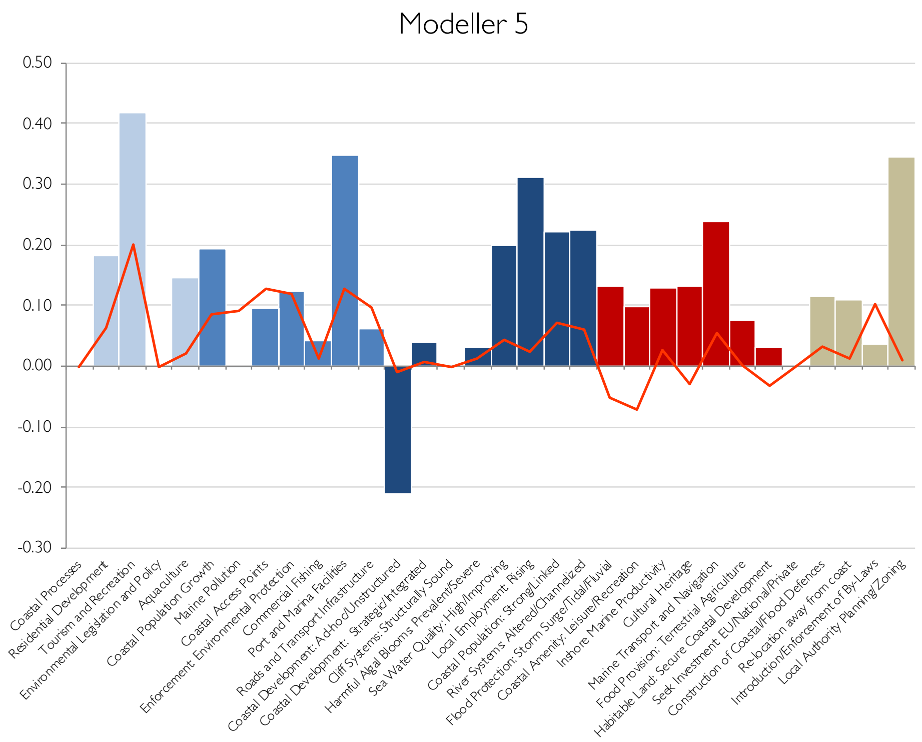

Figure 34: The baseline scenario of Modeller 5's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 5 sees residential development driving demand for an expansion of port and marina facilities. The unstructured nature of coastal growth is in turn viewed as triggering increasing efforts on the part of local authorities to impose planning and zoning regulations.

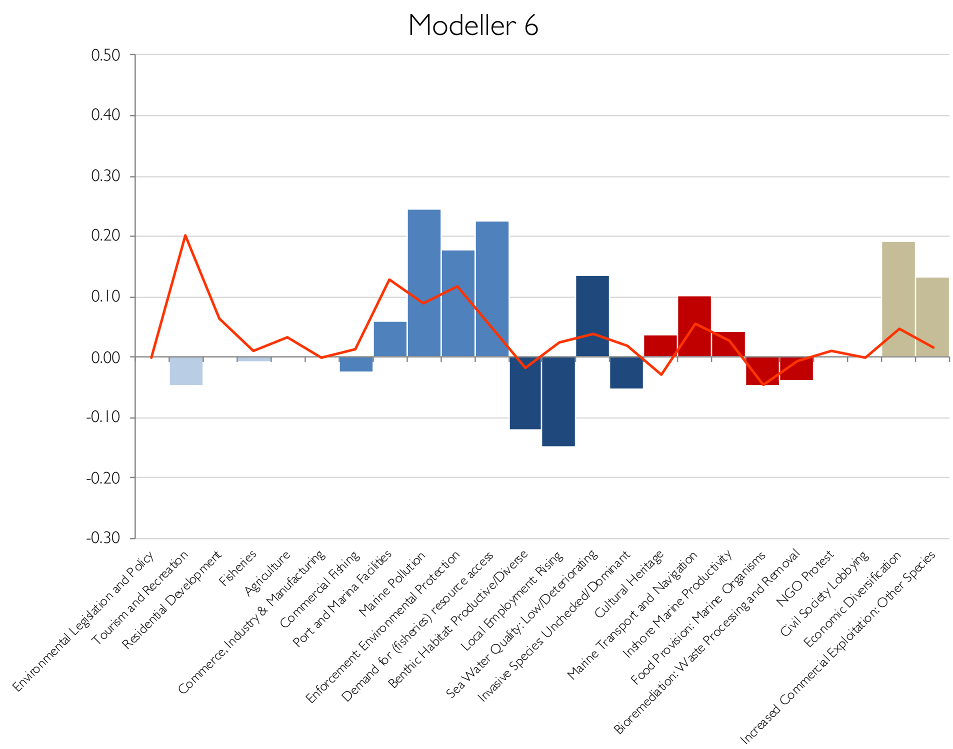

Figure 35: The baseline scenario of Modeller 6's FCM of Tralee Bay (the average of Resilience Group Member's baseline scenarios for the concepts selected are illustrated by the red line). Modeller 6 sees growing resource pressures in the fishing community leading to benthic degradation, in turn risking employment security in the sector.

4.1.2 Post-publication reflections

The method described in the preceding paper represents current best practice in participatory modelling with stakeholders using FCM. As such, it faired reasonably well in hitting the marks expected of it from a reading of its claimed strengths. What perhaps received less attention in the preceding analysis are its known weaknesses, with some reflection on those perhaps adding some additional insights for potential users of the method to consider in making their choice of how best to facilitate an adaptation process.

The first, well established, weakness of FCM is its inability to truly model system dynamics. There is no (mathematically meaningful) time step capacity in FCM. The capacity to include a temporal dimension to relationships between nodes in the map is therefore limited to what can be discerned from the phrasing of the framing question put to model builders. For instance, a modeller could be asked 'in your view, over the course of a year, what is the relationship between node X and Y', eliciting a broad-brush response illustrating a net effect, summary relationship. This type of question would mask any fluctuation in the direction or polarity of the relationship between the nodes, and can do little to shed light on processes that work at shorter or longer timescales to effect change in the model. There are rudimentary workarounds for this limitation, in that time steps can be applied through the alteration of the weighting of edge relationships after a set number of cycles of the matrix (representing for instance the end of the design life of a coastal defence measure after 10 years). However, these are very rudimentary options, and can do little to provide a meaningful facsimile of true dynamics.

A second obvious shortcoming of the approach is that it effectively locks in initial conditions, preventing any emergence of surprise. While this aspect makes FCM an unarguably useful means of holding up a mirror to the perceptions and understandings of stakeholders, it struggles to offer them insights beyond those already understood (however poorly). In making existing understandings explicit, any omissions or errors in perception become tangible and much more readily discussed and resolved. But the inability of the method to allow second or third order relationships to emerge or change makes the representation of the reality of complex adaptive social-ecological systems more problematic.

This issue also hints at a third weakness. The limitation imposed by the need to characterise relationships between nodes in the network using linear mathematical terms further compounds the rigidity and surprise-free nature of the model. Complex adaptive systems are typically characterised by their capacity to display non-linear dynamics, resulting in emergent properties and surprise. These are not characteristics that FCM can represent adequately.

These limitations and shortcomings are most relevant to considerations of how useful FCM can be as a predictive tool in determining outcomes. This is not, in my view, its primary purpose in supporting an adaptation process. No method or technique can be expected to profoundly reduce uncertainty, and giving a greater impression of doing so would likely promote unjustified confidence in its outputs. Where FCM can be said to perform more strongly is in challenging the thinking of decision makers, which is of critical importance in breaking through heuristic barriers, and in providing a means of bridging between local understanding and global environmental change – which can be applied at the boundary of the locally produced (albeit limited and static) model to illustrate change. Thus as a vehicle for communication within and beyond local coastal groups, it is very useful indeed.

4.1.3 Key conclusions and links to subsequent chapters

FCM offers considerable potential in helping to understand managers and decision makers perceptions of complex, data poor and highly uncertain systems. These properties are coming increasingly to be recognised as valuable in the characterisation and analysis of wicked environmental management problems such as climate change adaptation at the local scale. FCM's strength as a platform for communicating conceptual information among disparate stakeholder groups is also beneficial in these contexts, which are often beset by contested views and values.

The complexity and cognitive burden of the method may prevent it from serving as a panacea to the many issues which typically afflict adaptation initiatives at the local scale. Time, resource and capacity constraints may in particular prevent some coastal stakeholders from utilising FCM, given the voluntarism and short term project-based nature of many coastal management initiatives, including climate change adaptation.

There are nevertheless clear direct and ancillary benefits which flow from employing the method, some of which may result in time and cost savings in coming to a clearer understanding of what information is entering into decision makers thinking when acting under uncertainty. These benefits may create sufficient interest and value to garner the investment from regional or national scale organisations seeking to promulgate adaptation policy locally.

The following paper explores the potential of using FCM in this analytical context, attempting to determine how and to what extent climate signals factor in the decision making of coastal management stakeholders.

Part V: THE ROLE, VALUE AND LIMITATIONS OF AN FCM-BASED CLIMATE CHANGE ADAPTATION PROCESS IN PRACTICE

5.1. PAPER 4

5.1.1 ***Gray, S****., Gagnon, A., Gray, S. A., O'Dwyer, B., O'Mahony, C., Muir, D., Devoy, R. J. N., Falaleeva, M. and Gault, J. (2014) "Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping", Ocean and Coastal Management, doi.org/10.1016/j.ocecoaman.2013.11.008*

Previous papers in this thesis have highlighted how barriers to adaptation at the local scale might be overcome using decision support approaches such as scenario analysis and FCM. In the case of FCM, beyond providing an immediate means of overcoming barriers, another, perhaps equally important attribute became apparent during case study analysis research undertaken in Tralee Bay and the Outer Hebrides.

Using standard FCM indices (described in 3.1), the 'distance' between the thinking of local scale decision makers and national scale policy makers might be measured if comparable individual FCMs were to be built. This would not only allow an analysis of the scale of the signal detection barrier (as described by Moser and Ekstrom 2010), but also provide an indication of exactly what must be done to address it with respect to data gathering, capacity building and knowledge integration across scales in order for adaptation progress to be made.

The following paper begins with a description of the barriers which must be overcome, in particular at the early stages of an adaptation process where decision support tools can be invaluable in fostering momentum. It goes on to describe the methods employed at each case study location, before employing FCM indices to analyse and describe the specific differences between the models decision makers built at local and national scale, with a particular focus on difference in the detection and interpretation of signals of climate change between modellers. The implications of these differences are then discussed, with particular reference to adaptation policy in Europe.

CONTRIBUTION STATEMENT

Declaration of own contribution to the published (or intended for publication) scientific papers within my dissertation.

DISSERTATION TITLE: Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping

PAPER–4: **Gray, S.**, Gagnon, A., Gray, S. A., O'Dwyer, B., O'Mahony, C., Muir, D., Devoy, R. J. N., Falaleeva, M. and Gault, J. (**2014**) "Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping", Ocean and Coastal Management, doi.org/10.1016/j.ocecoaman.2013.11.008

OWN CONTRIBUTION IN THIS WORK: Concept development (fully), Literature search (fully), Methods development (fully), Research design (fully), Data collection (mainly), Data analysis (fully), Construction of the manuscript (fully), Argumentation (fully), Critical revision of the article (mainly).

Stefan Gray, MSC

July 11, 2019

Are coastal managers detecting the problem? Assessing stakeholder perception of climate vulnerability using Fuzzy Cognitive Mapping

S. R. J. Gray, A. S. Gagnon, S. A. Gray, B. O'Dwyer, C. O'Mahony, D. Muir, R. J. N. Devoy, M. Falaleeva, J. Gault

Abstract Critical barriers to adaptation to climate change include the timely detection and agreed definition of problems requiring adaptive action. In the context of local scale coastal management in north-western Europe, challenges to problem detection and identification are exacerbated by the diffuse nature of administrative, sectoral, and legal rights and other professional governance obligations. Yet, if adaptation is to progress in a manner that is both locally legitimate and in accord with national policies, climate signals must be detected and climate impact problems framed in similar ways by two key groups; local scale 'bottom-up' experts and decision makers, and national scale 'top-down' scientists and policy makers. With reference to case study sites in Ireland and Scotland, we employ participatory modelling with coastal stakeholders using Fuzzy Cognitive Mapping (FCM) to trial its potential in measuring and assessing stakeholder perceptions of climate vulnerability both individually and collectively. We found that FCM not only offers insight into the existing detection and framing of climate signals in coastal decision making but also provides a structured communication platform from which climate problems might be coherently integrated into future coastal management deliberations as the adaptation process matures.

1. Introduction

1.1. Identifying barriers to adaptation at the local scale

As the literature on climate adaptation policy and practice has expanded, barriers to the adaptation process have become more clearly understood (Burch, 2010; Ekstrom et al., 2011; Lorenzoni et al., 2007; Moser and Ekstrom, 2010; Pahl-Wostl, 2009; Tribbia and Moser, 2008; Vogel et al., 2007). Scholars have identified the three broad categories of such barriers as 'understanding', 'planning' and 'management' (Moser and Ekstrom, 2010;Wilby and Dessai, 2010), differentiated via the phase of the adaptation process at which they are typically encountered (Fig. 36). Overcoming these barriers at the local scale is of critical importance given that adaptation action must principally occur locally if climate vulnerabilities are to be addressed in a timely, efficient, and legitimate manner (Adger et al., 2005; Falaleeva et al., 2011; Tribbia and Moser, 2008).

1.2. Analysing barriers to adaptation at the local scale using Fuzzy Cognitive Mapping

To date, research on overcoming the barriers to adaptation has centred on the evolution of adaptive measures (e.g. Gurran et al. (in press) and Kopke and O'Mahony (2011)) and the roles played by individuals and institutions in facilitating adaptation (Falaleeva et al., 2011; Storbjörk and Hedrén, 2011; Tompkins, 2005). What has received less attention, however, is the understanding held by individual decision-makers – the so called 'mental models' of key stakeholders – and how these models are related to adaptation outcomes. Mental models are cognitive representations of external reality that are held by individuals and used to structure their reasoning with respect to decision-making (Jones et al., 2011). Individuals use these cognitive representations as heuristic devices to support the acquisition of knowledge incrementally and thus overcome the limitations of human cognition under conditions of complexity and uncertainty (Gray et al., 2014). Although adaptation research has recently highlighted the importance of mental models in potentially 'filtering out' the key signals of climate change (Moser and Ekstrom, 2010), and as key determining factors that limit or facilitate coastal adaptation (Schmidt et al., 2013; Tribbia and Moser, 2008), there is currently little empirical evidence that evaluates the relationship between mental models and their influence on adaptation action.

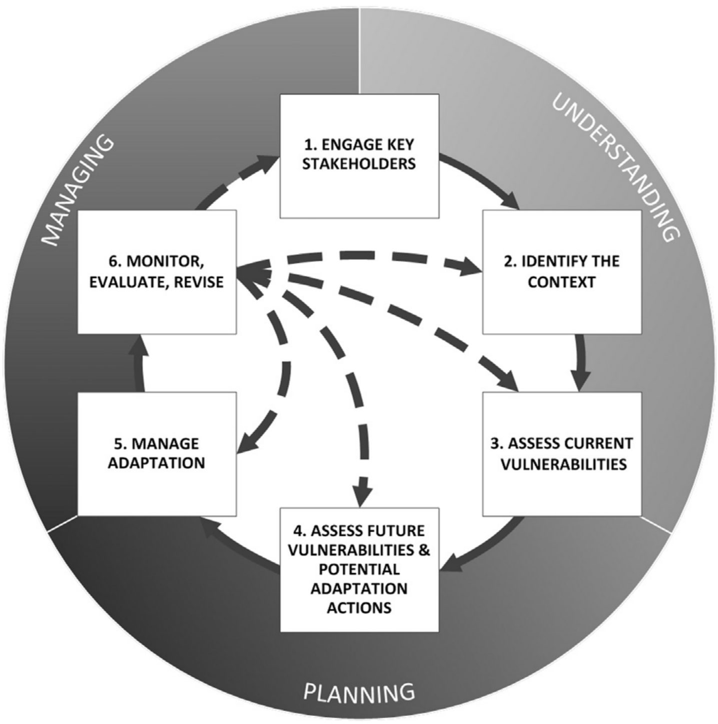

Figure 36: An idealised adaptation process comprised of six steps over three phases. (Adapted from Moser and Ekstrom, 2010; Wilby and Dessai, 2010).

In this paper, we propose that explicitly representing the knowledge held by individual decision-makers thought to underpin stakeholder decision-making is key to understanding how climate vulnerabilities are identified conceptually and organised in a broader context of information. Further, employing a technique called Fuzzy Cognitive Mapping (FCM) may offer considerable potential in understanding how the many barriers described above act to inhibit adaptive responses in a given context. FCM is a method of 'mental modelling' (Gray et al., 2014) that creates a 'map of cognition', which represents an individual's thought processes in relation to a given problem space (Axelrod, 1976). FCM has been employed extensively across diverse fields in the analysis and facilitation of decision-making where circumstances are characterised by complexity and uncertainty, including medical science (Papageorgiou et al., 2012), product design (Cheah et al., 2011), and complex industrial process assessment (Asadzadeh et al., in press). Capturing an FCM representation of an individual's reasoning regarding climate adaptation offers insight into not only whether climate problems have been detected, but also clearly illustrates how climate problems are defined by individuals in making decisions regarding adaptive responses. Gaining this insight is vital in determining which information has (or crucially, has not) entered into stakeholder deliberation on climate change. Further, we contend that FCM is underutilized as a way to broker a shared conception of how adaptation should proceed, thereby enhancing capacity to facilitate explicit and collaborative knowledge generation.

Participatory models created using FCM provide an external representation of an individual's internal perceptions of the structure and function of a given system or problem domain (Gray et al., 2014; Özesmi and Özesmi, 2004). Using simple mathematical relationships, internal qualitative beliefs are semi-quantitatively encoded to create fuzzy dynamic models comprised of concepts and weighted edge relationships that describe the causal linkages between concepts (Wei et al., 2008). Using graph theory, inferences may then be drawn regarding the role of each belief in a networked structure of the system (i.e., domain), and what the influence of changes in its expression may indicate relative to other beliefs through a series of model iterations (Kosko, 1986). Although not previously used in an adaptation context, FCM have been employed as a way to understand the cumulative reasoning in environmental planning (see Kosko (1986) and Özesmi and Özesmi (2004)).

1.3. Applying FCM analysis to climate problem detection and framing

Adaptation to reduce vulnerability to climate change can refer to technological responses (e.g. building sea defences), or to changes in behaviour, management, and policy (e.g. planning regulations) (IPCC, 2007a). Globally, adaptive responses to climate change are at a relatively early stage of development. In a European context, this is particularly the case in the peripheral coastal regions (Biesbroek et al., 2010; Dannevig et al., 2012; Ford et al., 2011). Accordingly, the barriers to adaptation of most immediate concern in the region are those relating to stakeholder understanding of climate change and the problems it poses to coastal systems at the local scale.

The characteristics of coastal governance significantly complicate the challenge of overcoming these barriers. Rights, responsibilities, obligations, and ownership with respect to the coast are in many cases complex, even opaque, leaving the number of stakeholders to consult with and seek consensus among often numbering in the tens or even hundreds for any given coastal management decision. While this in many respects represents a positive and welcome development, reflecting advancements in 'bottom-up' environmental decision making in line with the Aarhus Convention (UNECE, 1998), it carries a number of implications for the flexibility, ambition, and agility of coastal management decision making (McKenna and Cooper, 2006). Under these circumstances, the legitimate progression of coastal climate adaptation is reliant upon all interested parties across various marine and terrestrial, administrative, commercial, and societal entities not only detecting but also defining climate problems at the same time and in the same way. This issue has been encountered and documented in other environmental management contexts requiring adaptive interventions to be enacted (Gray et al., 2012).

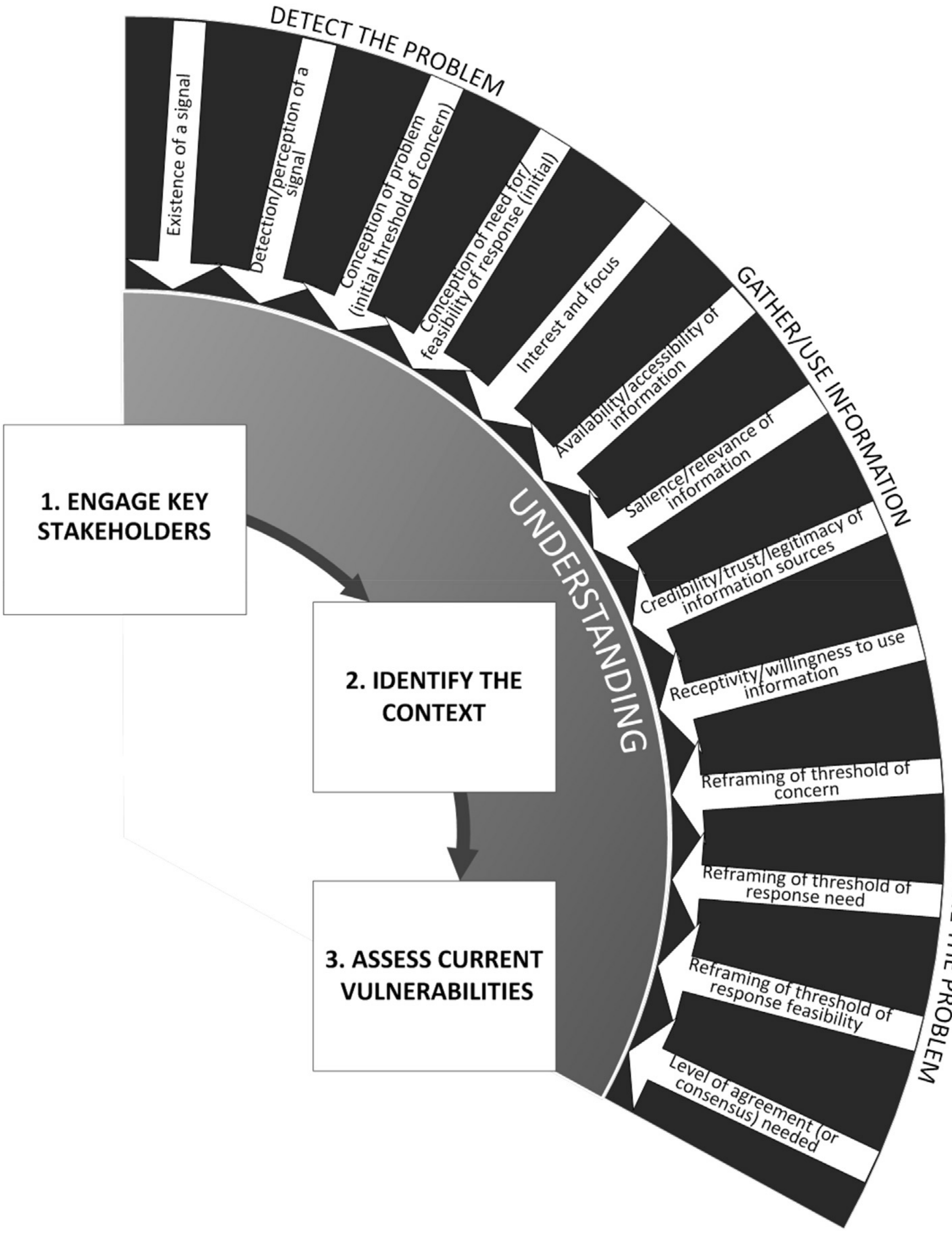

Figure 37: Common barriers (arrows in the black arc) encountered during the understanding phase of a climate adaptation process (Moser and Ekstrom, 2010).

1.4. Detecting the problem

The first and perhaps most fundamental barrier for local coastal management stakeholders to overcome in adapting to climate change is the detection of a signal that requires an adaptation response (Moser and Ekstrom, 2010) (Fig. 37). Evidence of climate change in coastal and marine environments is extensive and growing (Nicholls et al., 2007). However, many of the specific signals of change, such as rising sea levels (Devoy, 2008) or the biogeographical migration of marine species (Hays et al., 2005), are very gradual and therefore subtly expressed, and thus do not necessarily match the scales of human understanding or decision making. Additionally, climate change may be experienced as a number of abrupt, discrete events rather than continuous transformation, such as the incidence of extreme coastal storms and surges (Lozano et al., 2004). In both cases the accurate detection and attribution of these impacts to climate change on the part of local coastal stakeholders may be problematic.

Where climate signals are gradual and subtle, and no higher level policy imperative exists to spur adaptation, adequate longitudinal data and/or mechanisms of organisational memory to coherently interpret a trend of change would be required to instigate a locally appropriate adaptive response. However, the financial wherewithal to sustain the collection and interpretation of long term data is often difficult to come by at the local scale (O'Hagan and Ballinger, 2010), and staff turn-over in paid coastal management positions is typically high (McKenna and Cooper, 2006). The capacity to identify a 'direction of travel' attributable to climate change impacts before they are expressed in a way that precludes most if not all adaptation options is therefore very limited. Similarly, where signals are composed of discontinuous events such as intense storms or surges, coherently ascribing each event within a continuum of extended change requires continuity in management methodologies and comprehensive frameworks of coastal planning often not afforded to local authorities.

Under these circumstances, coastal stakeholders at the local scale are typically forced to rely on the outputs of climate monitoring, modelling, and impact analysis at higher (global, national, and regional) scales to detect a signal of change, and an over-arching adaptation policy lead that provides the impetus (and obligation) to secure this information (Falaleeva et al., 2011). However, downscaled climate information presented in a format meeting the specific planning requirements of local scale coastal management practitioners is extremely scarce, and also subject to the cascading effect of errors in projections and modelling, which are compounded the further down the modelling chain the analysis travels (Ranger et al., 2010). Further, higher-level policy imperatives to seek out and utilise adaptation information are by no means uniformly present across the northern periphery of Europe (Falaleeva et al., 2011). Even where policy imperatives are present, much is typically left for actors at the local scale to discern for themselves with respect to precisely which climate impacts must be adapted to – and over what timescales (Department of Environment Communities and Local Government, 2012). It is therefore essential to understand and document to what extent stakeholders in coastal management processes are detecting signals of change, and to what degree the informational outputs provided at higher scales are entering the deliberations of stakeholders regarding climate impact and adaptation response.

1.5. Defining the problem

Even where signals of climate change are detected, reaching agreement among diverse coastal stakeholders on the potential impact and their timescale (threshold of concern) to which adaptation responses are required can be problematic. By way of illustration, consider coastal stakeholders whose properties or livelihoods may be vulnerable to accelerating rates of coastal erosion as a result of rising seas and increasingly severe storm activity. These vulnerable stakeholders are likely to call for some form of (typically engineering-oriented) preventive action to be taken in advance of these impacts of climate change being fully realised. However, coastal conservation groups, recreational beach-goers, and taxpayers unaffected by the threat of erosion are less likely to view the projected impacts as problematic in isolation (Cooper and McKenna, 2008). Allowing coastal erosion to take place unhindered allows critical coastal habitats and recreational spaces to migrate landwards, whereas taking steps to intervene may result in the loss of valued coastal landforms in pursuit of a static coastline (McKenna et al., 2000). Though an extreme case, this situation illustrates the type of difficulties encountered in negotiating agreed thresholds of concern and adaptation response where multiple interests intersect.

Even where 'low-regret' options such as dune protection and regeneration schemes are available, they nevertheless represent a significant opportunity cost which require the achievement of full stakeholder buy-in (Wilby and Dessai, 2010), particularly under the prevailing consensus-driven voluntarism of Integrated Coastal Zone Management (ICZM) as practiced on the northern periphery of Europe (McKenna and Cooper, 2006). Facilitating a clear and coherent debate among stakeholders regarding how interested parties frame the cause and effect relationships at the heart of a problem, and the specific mechanisms by which any proposed solutions may achieve their intended aims, is therefore crucial if progress is to be made on coastal climate adaptation (Tompkins et al., 2008). To this end, gaining an understanding of how different coastal stakeholders define the problems of climate change that they detect provides insight into not only the likely steps required to negotiate an acceptable compromise between them (Voinov and Bousquet, 2010), but also the type and scale of climate information each requires to make informed adaptation decisions (Gaddis et al., 2010).

1.6. Analysing the detection and framing of climate issues among key coastal management decision makers and the wider stakeholder community

To investigate the role the barriers of climate signal detection and framing play in hampering the initiation of coastal climate adaptation, we present mental model data collected from coastal decision-makers in two case study sites located in Ireland and Scotland. At each of the sites, FCM was used as a tool to determine how key coastal decision-makers are currently detecting and framing climate change issues. Further, these data from the two study sites were compared to a scientific "expert" reference model, along with the views of the wider coastal management stakeholder community (elicited via questionnaires/surveys). This analysis determined the extent to which climate signal detection and problem framing among coastal decision-makers in Ireland and Scotland is aligned with both 'top-down' science and the 'bottom-up' concerns of coastal stakeholders. Under the prevailing institutional arrangements of coastal management in Europe, the perspectives of these groups must align as closely as possible for adaptation to progress in a legitimate and scientifically robust manner.

2. Material and methods

2.1. Overview

The research approach described below has been positioned within a wider framework aiming to facilitate coastal adaptation. Thus, the methods of analysis employed are specifically tailored toward the provision of outputs which are aligned with subsequent planning and management phases of the adaptation process modified from Moser and Ekstrom (2010) and Wilby and Dessai (2010) (cf. Fig. 36). At each case study site, a two-stage approach to data collection was undertaken to support an analysis of the detection and framing of climate change issues among key coastal management decision-makers and the wider community of coastal management stakeholders, which included a stakeholder survey and collection of mental models through FCM.

A. Purposive stakeholder survey:

- Participants: In order to gain a full understanding of decision making at the two study sites, a broad range of coastal management stakeholders perceptions were examined (*n* = 32 in Tralee Bay, *n* = 16 in the Outer Hebrides). For the purposes of this research, 'coastal management stakeholders' were defined as those with responsibility for, or long-standing expertise and local influence in, coastal planning and development, emergency preparedness, pier and harbour management, inshore fisheries, aquaculture, tourism, coastal agriculture, environmental protection, and other coastal sectors of activity relevant to the geographical setting.
- Rationale: These stakeholders form the core constituency whose support is crucial to the successful conduct of an adaptation initiative. Identifying how these stakeholders perceive climate change within their local coastal system, and which (if any) specific climate issues they perceive to require adaptive responses, is essential in order to analyse the barriers to overcome in facilitating adaptation at this scale.
- Content: Questions included the issues of core concern, the timeframe at which adaptation should be undertaken, and which sources of information had been utilised in reaching a conclusion regarding the hazard posed by climate change.

B. Fuzzy Cognitive Mapping:

- Those most likely to be involved in coastal adaptation decision making at the local scale were identified. These tightly focussed groups of high-level stakeholders (*n* = 6 in Tralee Bay, *n* = 7 in the Outer Hebrides) were invited to join in what were informally termed local 'coastal resilience groups'. Each member of the group was then asked to create a cognitive map of their local coastal social-ecological system. An expert derived cognitive map of the system was also created at each site to act as a reference point against which the alignment of local concerns with those of 'top-down' science could be gauged.

- Using methods described by Kosko (1986) and expanded by Özesmi and Özesmi (2004), in-depth analysis of the detection and framing of coastal climate adaptation issues was possible, in turn allowing inferences to be drawn regarding the degree of divergence in perception of climate issues among group members, between the group and the expert reference model, and between the group and the wider body of coastal stakeholders surveyed during the opening stage of the research (Figure 38).

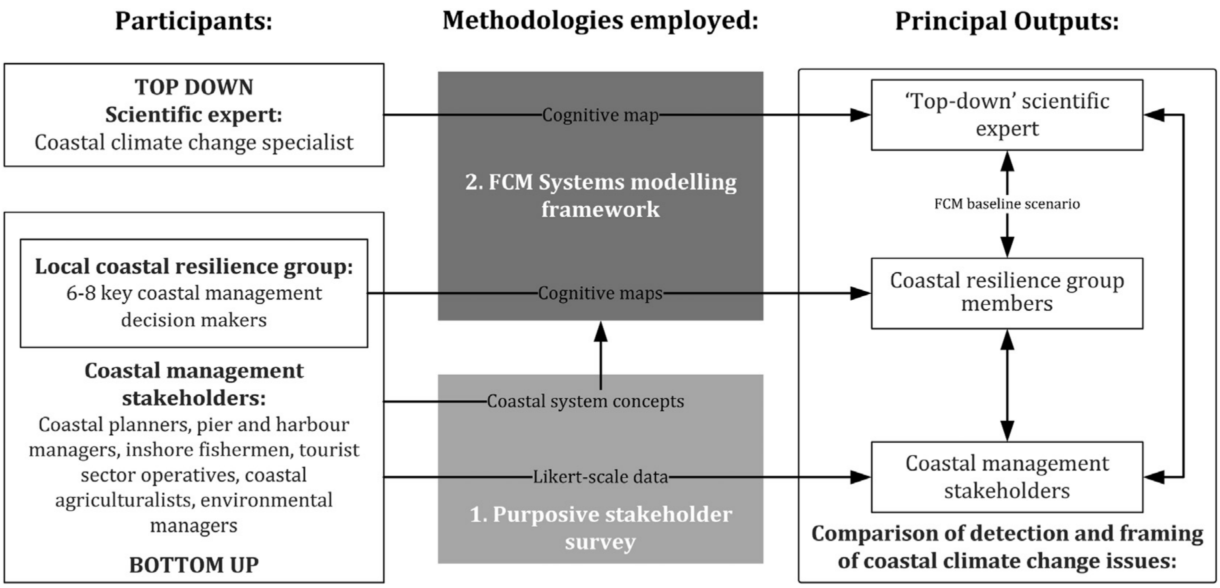

Figure 38: Schematic of the role and relationships of research participants, methodologies, and outputs

2.2. Case study sites

The case study material supporting this research was collected at two sites: Tralee Bay in the Republic of Ireland (Figure 39), and the Outer Hebrides, an island chain to the west of Scotland (Figure 40).

2.2.1. Tralee Bay

Tralee Bay forms the northern side of the Dingle Peninsula in southwest Ireland. The coast of Tralee Bay is comprised of sandgravel beaches backed by low cliffs or dune barriers, sand-cobble barriers with flanking mudflats and Cord Grass dominated salt marsh, and eroding low cliff coast with narrow cobble sediment. Cliff erosion rates are commonly 0.5e1.0 m per year (Devoy, 2008). The Bay is a shallow embayment Ramsar site, acting as a winter reserve, which supports important numbers of Pale Bellied Brent Goose (*Branta bernicla hrota*), and was declared a Special Protection Area in 1989 for its geomorphological and botanical interest.

Tralee town is the main settlement in the area, with 20,000 inhabitants. Economic activity has grown over the last decade focussing on retail, commerce, residential development and tourism. Rural villages such as Castlegregory or Fahamore attract visitors for surfing, diving, and fishing. Fenit supports the most westerly commercial port of Ireland, a multi-use harbour for commercial shipping activity and fishing and a 130 berth marina.

Tralee Bay's principal climate threats are flooding and erosion. For the southwest of Ireland, climate projections indicate an increase in winter precipitation, resulting in increased levels of runoff and flooding (McGrath et al., 2009; Sweeney et al., 2008). This is particularly problematic for Tralee town where increased levels of development over the recent past have resulted in a decrease in the capacity of the area to absorb flood waters from low-lying areas. Climate projections also indicate a sea level rise of 0.48 m (IPCC, 2007b), which will result in inundation of low-lying coastal areas. Importantly, when increases in sea levels are combined with projected increases in Atlantic wave heights and storm surges (McGrath et al., 2009), increased levels of coastal inundation and erosion can be expected. This is particularly the case when storm surges combine with high astronomical tides to overtop coastal defences. Increased sea level rise will also result in increased tidal penetration of estuaries, which will exacerbate problems of seasonal flooding. Summer average temperatures are projected to rise by 1.4-1.8^{o}C by the 2050s, which in concert with fewer precipitation days in summer (McGrath et al., 2009; Sweeney et al., 2008) may result in enhanced potential to attract tourism.

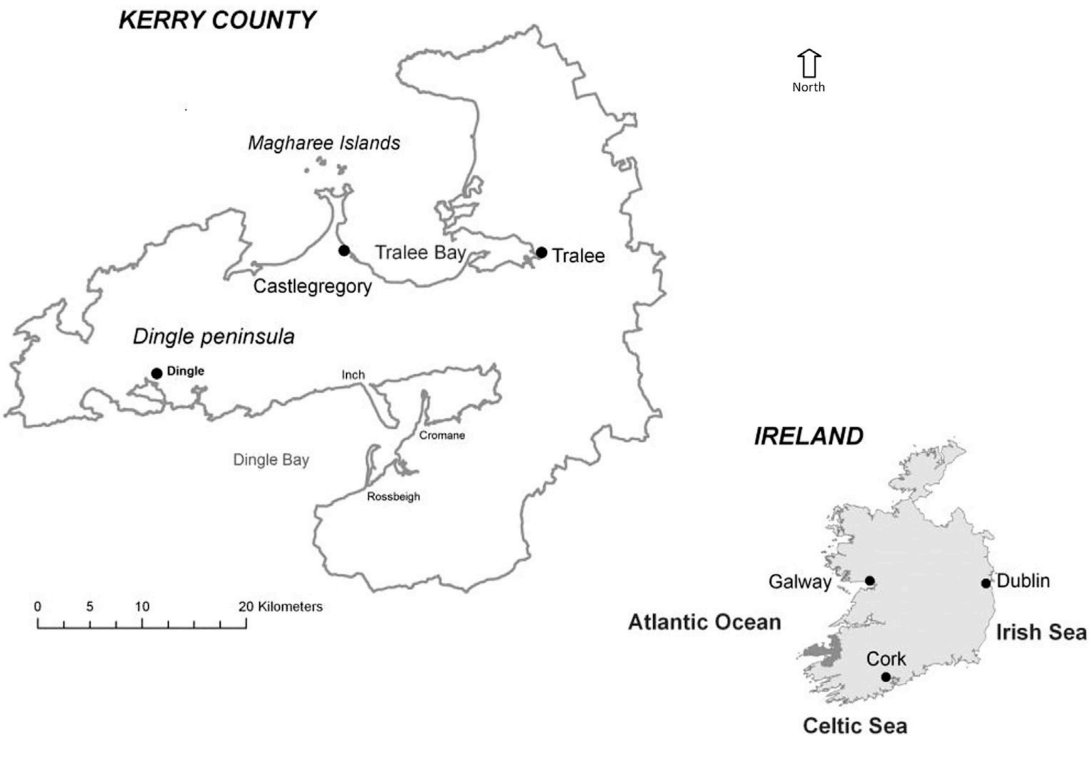

Figure 39: The Tralee Bay case study site (CoastAdapt).

2.2.2. The Outer Hebrides

The Outer Hebrides is a chain of islands 210 km long, situated to the northwest of mainland Scotland, from which they are separated by the Minch and the Sea of the Hebrides. Over seventy islands compose the archipelago with a combined coastline of

2,500 km. A population of 26,500 is distributed among 15 islands, which are linked by a network of causeways, ferries, and air routes. Ports and harbours and larger settlements are concentrated on the east coast. Stornoway with a population of nearly 7 000 is the main town and where the main offices of Comhairle nan Eilean Siar, the local authority for the Outer Hebrides, are located (Outer Hebrides Community Planning Partnership, 2009).

Given its remote and rural location, the population of the Outer Hebrides is mostly engaged in non-industrial activities, with the economy relying on tourism, aquaculture, and public sector employment (Muir et al., 2013). Traditional activities such as fishing (now concentrated on shellfish) and crofting agriculture, which historically underpinned the economy, have declined (Comhairle nan Eilean Siar, 2003) and now represents one component of the mixed income profile of many islanders. The main public sector employers are Comhairle nan Eilean Siar and the Ministry of Defence, with a missile defence training-testing installation in South Uist (Thomson, 2008).

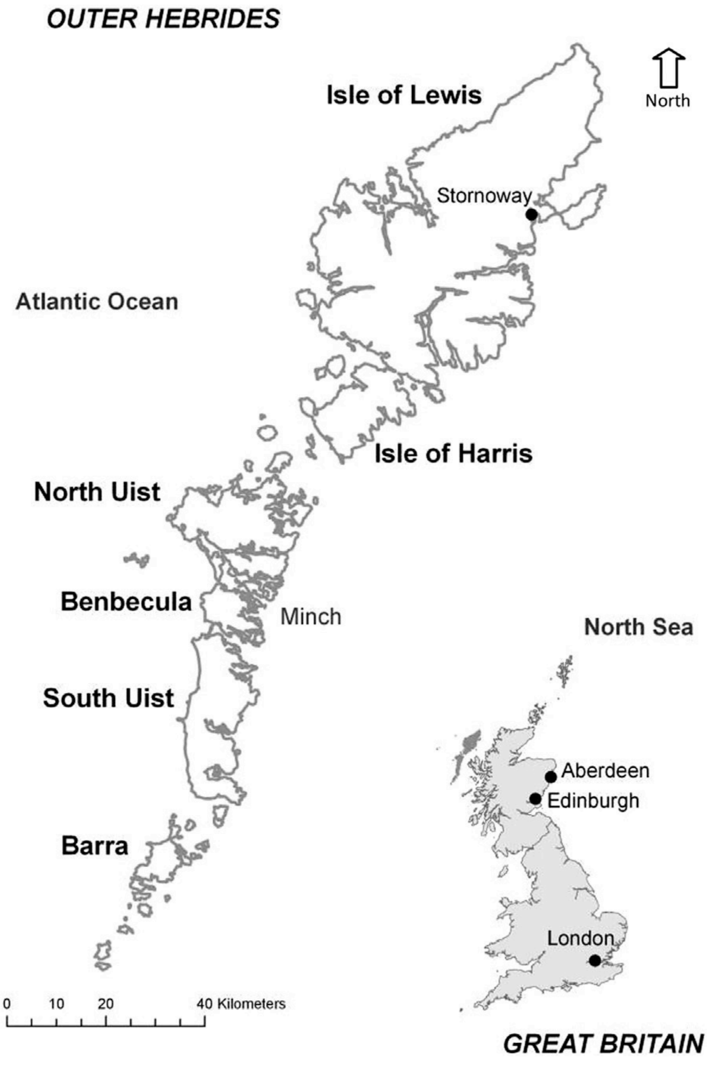

Figure 40: The Outer Hebrides case study site (CoastAdapt).

The landscape of the west coast of the Outer Hebrides is dominated by sand deposits in beaches, and low-lying areas of machair protected by a coastline of dunes. Machair is an Aeolian (wind-blown) shell rich sand deposit, extending in places over a mile from the coast. See Ritchie (1966), Love (2003) and Redpath (2012) for a full overview of the ecological value and extent of Hebridean machair.

Many of the machair systems in the Outer Hebrides are protected by a dune ridge, although there are sections of coastline where, due to erosion, this has been degraded or lost. Thus the machair landscapes and ecology are fragile and large areas, particularly where the hinterland is below high water level, are vulnerable to sea-water inundation and resulting loss of land. Therefore, the two climate change elements that are the most threatening to the Outer Hebrides are the frequency and intensity of Atlantic storms and sea-level rise due to their potential to cause erosion of the dune systems, dune overtopping, and inundation of low-lying coastal areas. In addition, an increase in sea level would make it more difficult for the water to recede back to sea from the flooded machair in the spring through the drainage system, especially in view of the topographic gradient being already minimal under current conditions (Professor William Ritchie, Personal communication). Projected increases in sea level in combination with an increase in the severity of wave climate is thus of concern; the former is an issue as unlike most of Scotland the Outer Hebrides are not rising isostatically (Bird, 2008). Damage or destruction of machair systems would have devastating economic and cultural effects. In addition, the latest climate change projections from the United Kingdom Climate Impacts Programme (UKCIP), i.e., UKCP09, project winters in northern Scotland to become warmer and wetter with a slight increase in the intensity of precipitation. As for the Irish case study, summers are projected to become warmer and drier, which may be beneficial to tourism (Sweeney et al., 2008).

The islands were affected by a severe storm in January 2005 causing significant damage to the coastal infrastructure and loss of lives, thereby further increasing community awareness of their vulnerability to severe storms, climate change, and sea-level rise (Muir et al., 2013). This is noted in the Single Outcome Agreement (SOA) of the Outer Hebrides, which under the heading of climate change recognises the vulnerability of exposed coastlines to coastal flooding and that the impacts of storms are of increasing concern to community residents.[10]

2.3. Stakeholder surveys

The survey methodology employed in Ireland was broadly similar to that employed by Tribbia and Moser (2008), in that stakeholders were presented with (predominantly Likert scale based) questionnaires which sought to uncover their awareness of climate

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[10] SOAs are agreements between the Scottish Government and community planning partnerships (the latter are led by local authorities), identifying objectives and reporting on progress in achieving them with respect to national outcomes.

change issues, views on the need for (and appropriate temporal/spatial scale of) climate adaptation responses, and the frequency of their use of scientific data/information in making coastal management and climate related decisions. Following completion of the questionnaire, each survey respondent took part in a semi-structured interview lasting from 30 to 120 min (Falaleeva et al., 2013). Any concepts which could be identified from the interview data which conformed to the "cause concept/linkage/effect concept" pattern described by Özesmi and Özesmi (2004) were employed in formulating the modelling methodology described in Section 2.4.

The survey methodology employed in Scotland differed in some respects from that used in Ireland. As part of the 'bottom-up' vulnerability assessment methodology of the CoastAdapt project, community workshops were organised to engage with stakeholders to assess current vulnerabilities and introduce the concept of adaptation. At these workshops, a survey was distributed to coastal management stakeholders in attendance. This Likert-scale based survey, which also allowed for further comments to be entered, aimed at determining stakeholders' understanding of local climate change impacts, knowledge of adaptation options regarding those impacts, and their use of scientific information and climate change scenarios for planning ahead.

Despite the minor differences in approach of the surveys conducted at each site, both fulfilled the role required of them in order to support the analysis undertaken here, as the principal aim of each survey was to establish the views and concerns of the broad group of coastal management stakeholders among whom adaptation initiatives must gain support in order to become securely established. Data derived from each survey were also readily utilisable in subsequent participatory modelling stages of the research process.

2.4. Social-ecological systems modelling using FCM

In order to analyse further the extent to which signals of climate change have entered the deliberations of local level coastal adaptation decision-makers, and how such signals are subsequently framed with respect to the definition of problems to resolve via adaptation, we employed FCM-based participatory modelling.

2.4.1. Selecting key local decision makers to form coastal resilience groups

At each case study site, a number of key local coastal decision makers interviewed during the conduct of the baseline survey were invited to join what were informally termed local 'coastal resilience groups'. The group's purpose was to bring together these key decision makers on climate adaptation at a local level to 1) investigate their perceptions regarding the need to adapt to climate change, 2) integrate their expertise and extensive local knowledge to create a shared conception of how the coastal system is structured and functions, and 3) formulate adaptive management responses to coastal climate change impacts, predicated on the shared conception of the system derived. Stakeholders were thus selected to participate in the group on the strength of their knowledge of the local coastal system, and capacity to represent the different local authorities, state agencies, NGOs, and community groups whose collaboration is critical to the progress of coastal management decision making (Voinov and Bousquet, 2010). Crucially, each candidate was identified as highly influential in determining whether adaptation is a factor in the conduct of coastal management. Participation in the process required stakeholders to meet initially on a one-to-one basis with the research team to build an individual FCM of the coastal system, and then attend plenary workshops. Seven of 11 stakeholders invited were able to participate in the Outer Hebrides coastal resilience group, and six of 10 invitees agreed to participate in the Tralee Bay coastal resilience group.

2.4.2. Defining 'top-down' scientists and policy makers and 'bottom-up' resilience groups

For the purposes of this research, we have categorised two key groups as crucial to facilitating, the planning and implementation of robust adaptation measures. The first group are the 'Top-down' scientists and policy makers who identify and characterise the likely impacts of climate change and formulate policy responses accordingly. This work typically occurs at a national/regional scale, and sets a benchmark against which sectoral and local scale adaptation efforts can be measured. A second group of interest is the key decision makers at a local level who must formulate and implement adaptive responses to climate change. This group, though bound by higher-level policy with respect to how they undertake adaptation, has considerable autonomy in determining what they will adapt to and when. As stated previously, the views of these groups must align as closely as possible if adaptation is to progress in a legitimate and scientifically robust manner. A key first step in helping to negotiate the emergence of this more unified perspective is to determine the degree of disparity between the bottom-up and top-down perspectives.

2.4.3. Constraints and trade-offs in modelling with key local level decision-makers

There are four methods commonly employed to create cognitive maps: 1) from questionnaires; 2) from written text; 3) from quantitative data describing causal relationships; and, 4) by allowing interview subjects to draw them directly (Özesmi and Özesmi, 2004). The latter option is generally considered preferable, in that it offers greatest flexibility and allows the interviewee to explore and interrogate their own cognitive structuring of the problem in the process of building a map, thereby allowing these representations to be used as proxy measures of individual mental models (Jones et al., 2011). This method also demands a high cognitive burden of the interviewee and thus can be time consuming – introducing a difficult trade-off in the formulation of a participatory modelling initiative. Targeting local high-level decision-makers (Davis and Wagner, 2003) such as those enlisted to participate in this study enhances the degree to which research outputs will be respected and accepted in subsequent decision contexts (Voinov and Bousquet, 2010; Voinov and Gaddis, 2008). However, the demands of these stakeholders' respective roles constrain the time each is typically willing or able to contribute to the research, with many agreeing to participate on condition that time dedicated to interviews and workshops is minimised. With this constraint in mind, a hybrid individual modelling methodology was designed, drawing on questionnaire and interview data to initiate the modelling process while allowing interviewees the freedom to customise modelling elements as desired. To further streamline facilitation and optimise the potential for the introduction of adaptive interventions at later stages of the adaptation process, models were structured using the Driver-Pressure-State-Impact-Response (DPSIR) analytical framework (Atkins et al., 2011).

2.4.4. Modelling methodology

Questionnaire and survey data were reviewed to identify concepts that stakeholders had employed in describing cause-linkage-effect relationships within the system, giving a total of 54 concepts which were allocated to groups as drivers (11), pressures (14), state changes (14), impacts (3) or responses (13) (Tscherning et al., 2012). In addition, a review of the coastal ecosystem services literature (Atkins et al., 2011; Crowder and Norse, 2008; Dennison, 2008; Elliott et al., 2007; Fisher et al., 2009; Granek et al., 2010; Luisetti et al., 2011) identified nine concepts to further populate the impacts group (see Table 18). These modelling elements were printed to colour coded magnetised tiles to be employed during model facilitation.

Figure 41: Building an individual FCM with magnetised tiles on a whiteboard.

Each interview began with an illustration of how FCMs are built using a neutral example (in this case a hypothetical African biodiversity conservation management issue) (Özesmi and Özesmi, 2004). The interviewee was then asked to define an appropriate spatial boundary for the coastal social-ecological system to be modelled (via reference to a Google map of the study site). A series of open-ended questions were then asked to the interviewee to facilitate the model building process (Özesmi and Özesmi, 2004), beginning with the question ‘Referring to the boundaries defined by the Google map, what do you consider to be the key drivers of activity within the coastal social-ecological system?’ The interviewee was offered the range of pre-defined tiles to select from, and also a number of blank tiles on which concepts could be written if those provided were not considered appropriate. The interviewee then placed the tiles they had selected on a magnetised whiteboard (Fig. 41), defining causal edge relationships between concepts with marker pens as strongly, moderately or weakly positive or negative, and progressing sequentially through DPSIR categories to complete their model.

DPSIR category	Modelling concept
Drivers	Agriculture; Aquaculture; Commerce, Industry & manufacturing; Tourism & recreation; Residential development; Environmental legislation & policy; Migration & demographic change; Fisheries; Coastal processes
Pressures	Demand for social amenities/services; Enforcement of environmental protection; Coastal squeeze; Air pollution; Terrestrial surface water pollution; Marine pollution; Coastal access points; Terrestrial traffic; Marine traffic; Roads & transport infrastructure; Port & marina facilities; Coastal population growth; Soil contamination; Commercial fishing
State (changes in)	Wetlands; Coastal process dynamics; Dune systems; Cliff systems; River systems; Air quality; Benthos; Ocean chemistry; Sea water quality; Invasive species; HABs; Community cohesion; Coastal employment; Integration of coastal development
Impacts (to)	Cultural heritage; Coastal amenity; Water supplies; Inshore marine productivity*; Bioremediation of wastes*; Flood protection*; Marine transport & navigation*; Raw material provision*; Marine food provision*; Terrestrial food provision*
Responses	Re-location away from coast; Construction of coastal/flood defences; Local authority zoning; Local authority planning; Introduction/enforcement of by-laws;

	Economic diversification; Civil society lobbying; NGO protest; Individual insurance cover; Seeking investment; Payment of EU fines; Voluntary community action; Increased commercial exploitation

*Concepts derived from literature review.

Table 18: Base modelling concepts employed at the Tralee Bay case study site.

2.4.5. Model analysis

All group member FCMs and the two top-down scientists models were transcribed into adjacency matrices (Kosko,1986) and analysed using the FCMapper analytical tool (Wildenberg et al., 2010). This simple to use tool is freely available for download in spreadsheet form, and offers the facility to automatically calculate the metrics described below, as well as run simple scenario analyses on the modelled system. Alongside a simple tallying of climate related concepts used by each modeller, three key FCM metrics were calculated to provide insight into the detection and framing of climate issues among the bottom-up decision makers and top-down scientists participating in this study:

i. Density: The measure model 'density' expresses the number of connections between concepts within an FCM as a proportion of the total number of connections possible (Özesmi and Özesmi, 2004). FCMs with higher density scores display a greater degree of complexity in their characterisation of the relationships between modelled concepts, and thus offer a greater number of options for intervention (adaptation) within the model (Gray et al., 2014).

ii. Centrality: The measure 'degree centrality' ($C_D(V)$) indicates the relative importance of a concept within the structure of an FCM by providing a summation of its absolute incoming (indegree) and outgoing (outdegree) connection weights:

$$C_D(V) = \sum((\mathrm{id}(V) + \mathrm{od}(V)) \quad (1)$$

where indegree id(V) is the summation of all weighted edge relationships entering concept (V) and outdegree od(V) is the summation of all edge relationships exiting concept (V) (Obiedat et al., 2011). Measures of 'indegree' and 'outdegree' indicate, respectively, the degree to which a given concept is affected by and affects other concepts within the FCM.

iii. Baseline scenario: Through calculating the output of an FCM's adjacency matrix over a series of iterations, a baseline scenario may be derived representing the steady state of the system – essentially providing a snapshot of how the concepts and linkages of the system would resolve themselves in the absence of change or intervention, with all feedback loops played out:

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j \equiv i}}^{N} A_j^{(k)} w_{ji}\right) \qquad (2)$$

where $A_i^{(k+1)}$ is the value of factor V_i at iteration step k+1, $A_i^{(k)}$ is the value of factor V_i at iteration step k, $A_j^{(k)}$ is the value of factor V_j at iteration step k, and w_{ji} is the weight of the edge relationship between V_i and V_j. Threshold function f (a logistic function) is used to normalise the values at each step. Inferences may be drawn regarding the dynamic attributes of the system as modelled by analysing the scenario output of an FCM (Özesmi and Özesmi, 2004). The FCMapper tool (Bachofer and Wildenberg, 2011) was used to calculate the baseline scenario of each of the FCMs referred to in this study.

3. Results

3.1. Survey data

In Tralee Bay, survey respondents were relatively confident in their knowledge of climate impacts, with 55% describing themselves as 'very aware' of the projected impacts of climate change for their region, and a further 29% 'somewhat aware' (Table 19). Fewer respondents declared a knowledge of adaptive responses to these impacts, however, with only 42% claiming to be 'very familiar' with the term adaptation when used in a climate context. Fewer still reported using scientific data/reports in their decision making on climate change or coastal issues, with only 29% doing so 'very often'.

	Are you aware of the projected impacts of climate change in your region?		Are you aware of adaptation options available to you in the context of climate change?		Do you often use scientific data/reports in your decision making on climate/coastal issues?	
	Tralee Bay	Outer Heb.	Tralee Bay	Outer Heb.	Tralee Bay	Outer Heb.
Very	55%	36%	42%	7%	29%	n/a
Somewhat	29%	57%	23%	71%	26%	n/a
Not very	16%	0%	35%	7%	45%	n/a

No resp.	0%	7%	0%	14%	0%	n/a

Table 19: Stakeholder views on climate impacts, adaptation options, and use of scientific outputs in decision making.

Similarly, in the Outer Hebrides stakeholders were broadly aware of the basics of climate change impacts. However, their knowledge of adaptation options to manage those impacts scored on average lower, with the overwhelming majority recording a 'somewhat' aware response to this question. None of the respondents have used climate change projections to plan ahead or they were not aware of their use. Flooding risk is assessed using maps from the Scottish Environmental Protection Agency (SEPA), which are constructed from historical data, supplemented more recently by the outcomes of a LiDAR survey for the identification of the most vulnerable areas to coastal flooding. These maps, however, refer to current conditions and do not account for longer term climatic changes and associated sea-level rising.

With respect to the issues that adaptation action should be directed toward, stakeholders in Tralee Bay considered each of the six potential climate change impacts presented to them to require action. Of these, precipitation/flooding was the climate change issue of greatest concern. The issues of sea level rise, coastal erosion, storms/surges, and invasive species were also felt to be important factors in triggering adaptation, with only the potential for sea surface temperature (SST) increase registering greater uncertainty among stakeholders as to whether adaptive actions are required (Table 20). In the Outer Hebrides sea level rise and storm/ surges were ranked as the two climate change issues of greatest concern and these were followed by coastal erosion and degradation of the dune systems and precipitation/flooding. In contrast to Tralee Bay, invasive species and changes in SST were not a concern, even for the fish farming sector, who considered very unlikely the SST vulnerability threshold requiring adaptive action to be reached in the foreseeable future.

A clear majority of respondents in Tralee Bay considered adaptation action in advance of scientific certainty regarding projected climate impacts to be very appropriate (61%). The timescale at which stakeholders believe adaptation action to be necessary corroborates this sense of relative urgency, with 45% of respondents favouring action within the coming decade. In the Outer Hebrides, stakeholders took a mixed view of the time-frame at which adaptation should be undertaken. Some respondents mentioned the next 4-5 years (e.g. fish farming sector, emergency preparedness officer, and other local authority officers), due to the nature of their business, and the fact that the community risks register are based on foreseeable events within that timeframe. It was also noted that councils are run on a political cycle with an election taking place every 4-5 years, although the fact that the majority of councillors of Comhairle nan Eilean Siar are independent and therefore not split along political lines, resulted in council members also looking ahead within the time-frame of the next generation (i.e., 25-30 years) to ensure the sustainability of the islands. Such medium term thinking was also suggested by the planning department officer in view of recent changes in the horizon of strategic planning moving from five years to 20-25 years. Nonetheless, none of the respondents had gathered or used any information regarding the hazard posed by climate change.

3.2. Modelling data

3.2.1. Inclusion of climate-related concepts in group member FCMs

The FCMs built by Tralee Bay coastal resilience group members included a number of concepts directly related to climate impact issues (Table 4), including 'sea level rise buffering', 'flood protection', 'dune/cliff system degradation' and 'habitable land for secure coastal development'. Similarly, group members from the Outer Hebrides modelled a number of climate-related concepts. A number of discrepancies were nevertheless evident between the climate issues included in resilience group member models and the baseline survey data (cf. Table 3).

Ranking of issue:	Tralee Bay (Stakeholders)	Outer Hebrides (Stakeholders)
1	Precipitation/flooding	Sea level rise
2	Sea level rise	Storms/surges
3	Accelerating coastal erosion	Accelerating coastal erosion
4	Storms/surges	Precipitation/flooding
5	Invasive species	
6	Sea surface temperature	

Table 20: Climate change issues of concern.

3.3. Density of group member FCMs

The density scores returned by an analysis of the adjacency matrix of each of the FCMs are presented in Figures 20 and 21. In Tralee Bay the top-down reference modeller records the highest density score of 0.11, with the average density of resilience group member FCMs 0.07. In the Outer Hebrides, the average score of the seven resilience group members (RGM) is nearly 0.09, higher than in Tralee Bay, and also the 'top-down' scientist. Density measures illustrate the number of potential entry points of management intervention within a system perceived by the model builder. In the context of adaptation, higher density scores thus illustrate that a broader range of adaptation measures may be perceived as feasible to the modeller in question.

Interestingly, these measures appear to broadly reflect initial stakeholder views at each site elicited via informal discussion with the research team prior to the interview and workshop process. In Tralee Bay, stakeholders saw relatively few adaptive responses to climate change available to them, while in the Outer Hebrides stakeholders viewed many adaptive options to be feasible which scientists and policy makers may have perceived as impractical or politically unpalatable.

Ranking of issue:	Tralee Bay (Decision makers)	Outer Hebrides (Decision makers)
1	Accelerating coastal erosion (84%)	Storms/surges (57%)
2	Storms/surges (67%)	Accelerating coastal erosion (43%)
3	Precipitation/flooding	Sea level rise (43%)
4	Sea level rise (50%)	
5	Invasive species (33%)	
6	Sea surface temperature (17%)	

Table 21: Ranking of climate-related concepts in terms of their frequency of inclusion in the models of coastal decision makers in Tralee Bay and the Outer Hebrides (% of group members including the concept in their model in brackets).

3.3.1. Centrality of climate-related concepts

The relative importance of climate related concepts identified within the analysed FCMs varied significantly among resilience group members, and between resilience group members and the top-down models (Figures 42 and 43). Averaged across all group members, the top-down scientific expert recorded much greater centrality of issues related to flooding, surges, and coastal erosion than did members of the decision making group in Tralee Bay, with the top-down modeller making no reference to SST or invasive species. A similar pattern was observed for the Outer Hebrides where concepts related to sea-level rise, coastal erosion, and flooding are more central in the expert model than the average of the group models.

As stated, ‘indegree’ and ‘outdegree’ indicate respectively the degree to which a given concept is affected by and affects other concepts within the FCM. It is noteworthy that with respect to key climate-related concepts such as precipitation/flooding, storms/surges, and sea level rise, Tralee Bay group members record substantially lower indegree scores than the top-down reference modeller (Fig. 44). Likewise, both the ‘indegree’ and ‘outdegree’ scores of the climate-related concepts in the Outer Hebrides are higher for the expert FCM than the average of the seven coastal stakeholders FCMs (Fig. 45). This in turn diminishes the options present within resilience group member FCMs to alter the role these concepts play within the model.

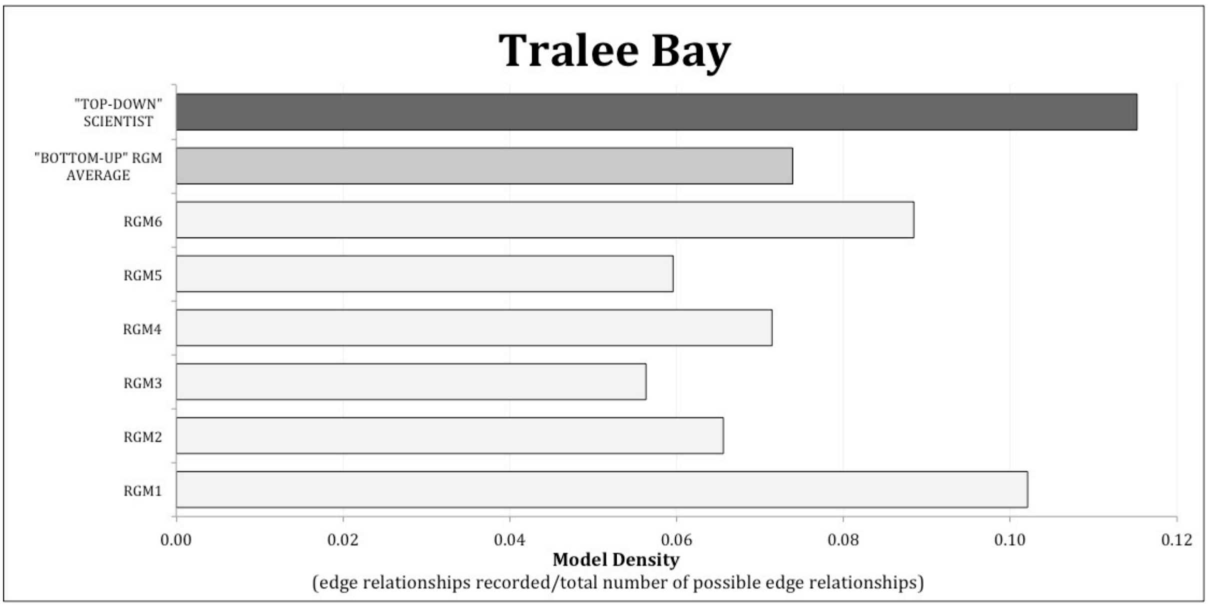

Figure 42: Density metrics for Tralee Bay.

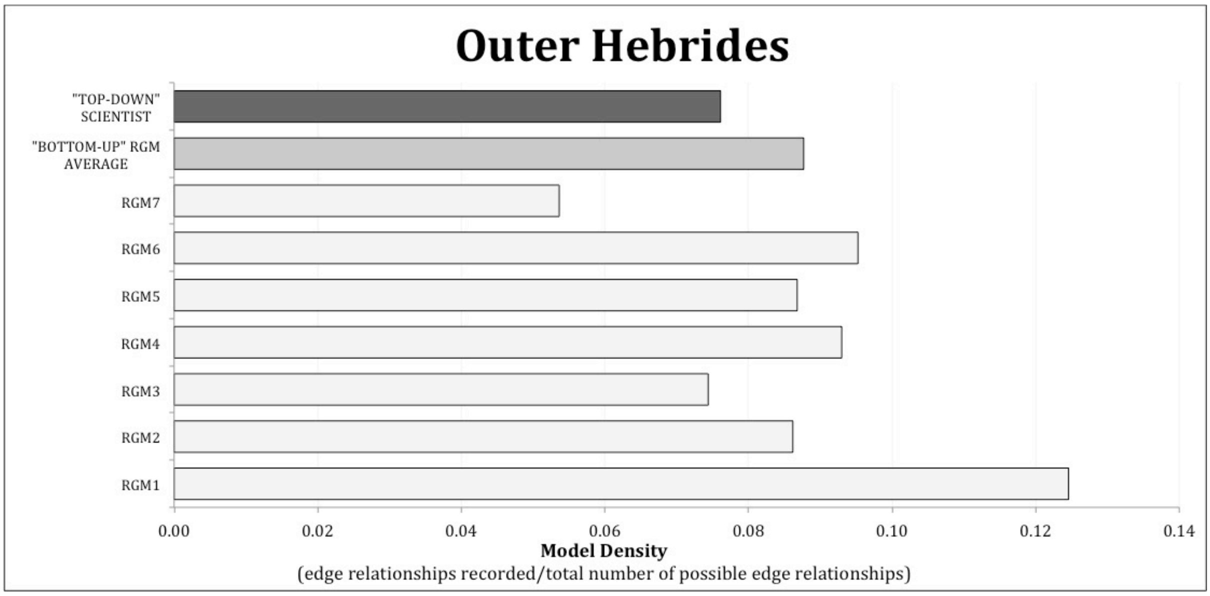

Figure 43: Density metrics for the Outer Hebrides.

3.3.2. Climate related concepts in the baseline scenario output

Figures 46 and 47 illustrate climate-related concepts from the baseline scenario output of the top-down reference model and the (averaged) RGM models. Notable disparities are evident between top-down and bottom-up perceptions of sea level rise buffering and dune/cliff system degradation in Tralee Bay. A less-marked disparity is also evident between top-down and bottom-up perspectives regarding fluvial and surge/storm related flood protection. In the Outer Hebrides, disparities are even stronger for sea level rise and flood defences and storm surge related flood impacts with a smaller disparity observed with regard to dune system degradation.

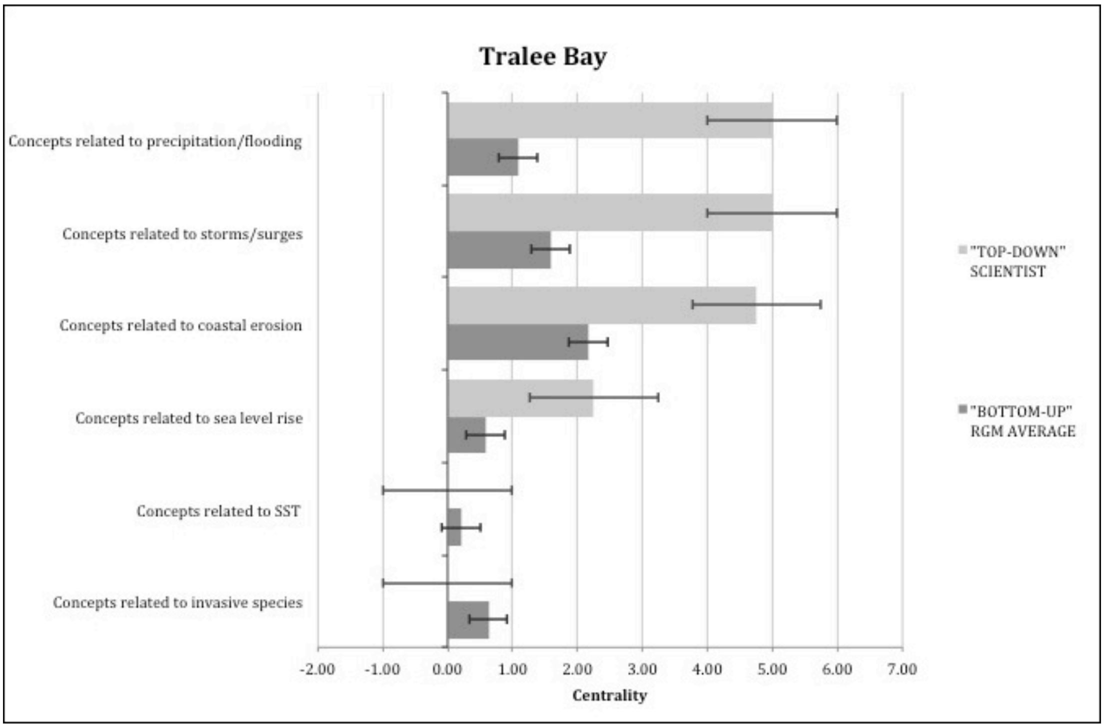

Figure 44: Centrality of climate related issues within RGM and Top-down reference models in Tralee Bay.

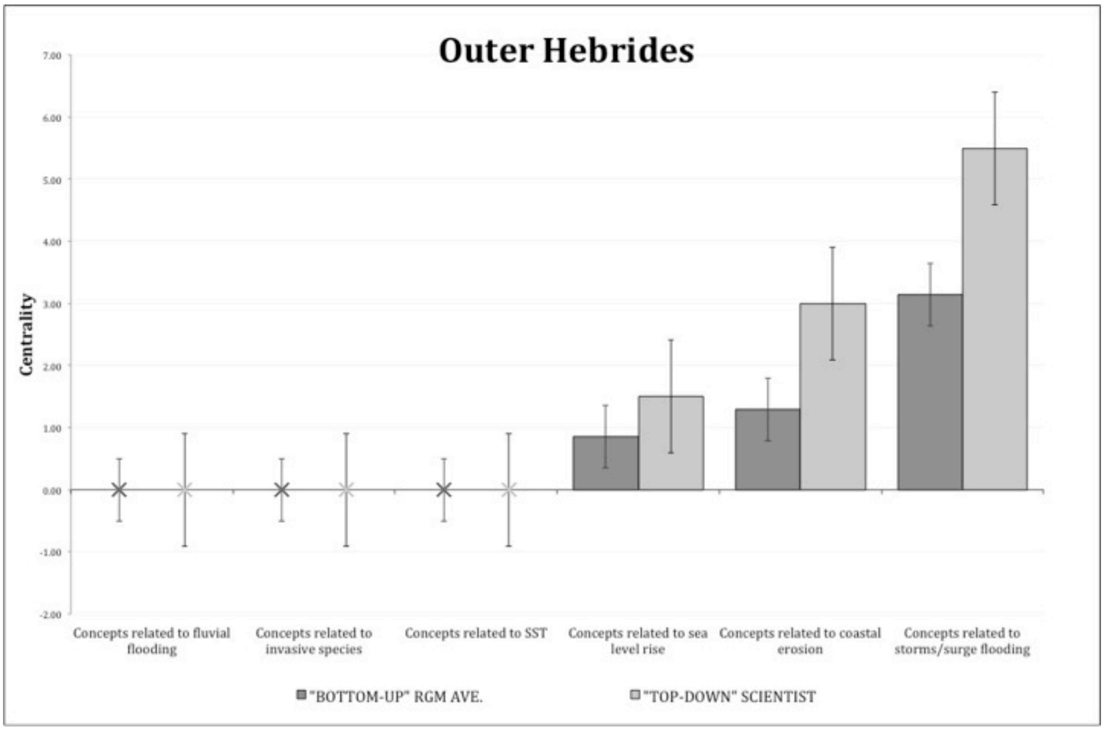

Figure 45: Centrality of climate related issues within RGM and Top-down reference models in the Outer Hebrides.

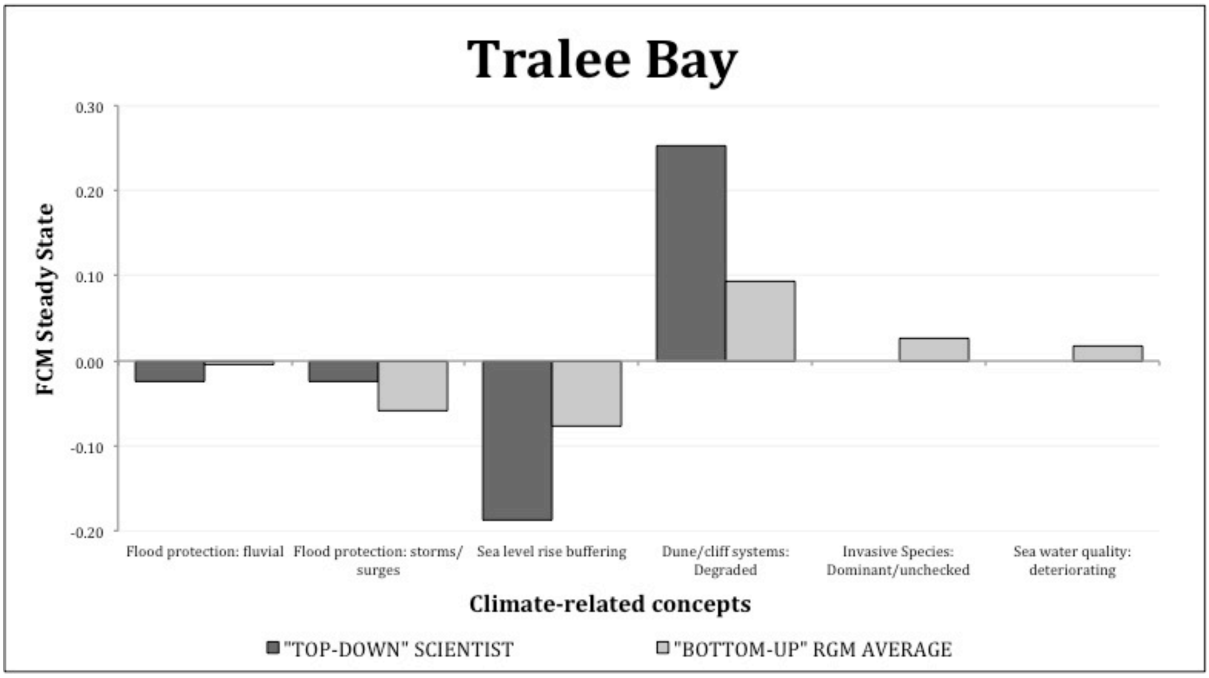

Figure 46: Climate related concept baseline scenario output in Tralee Bay

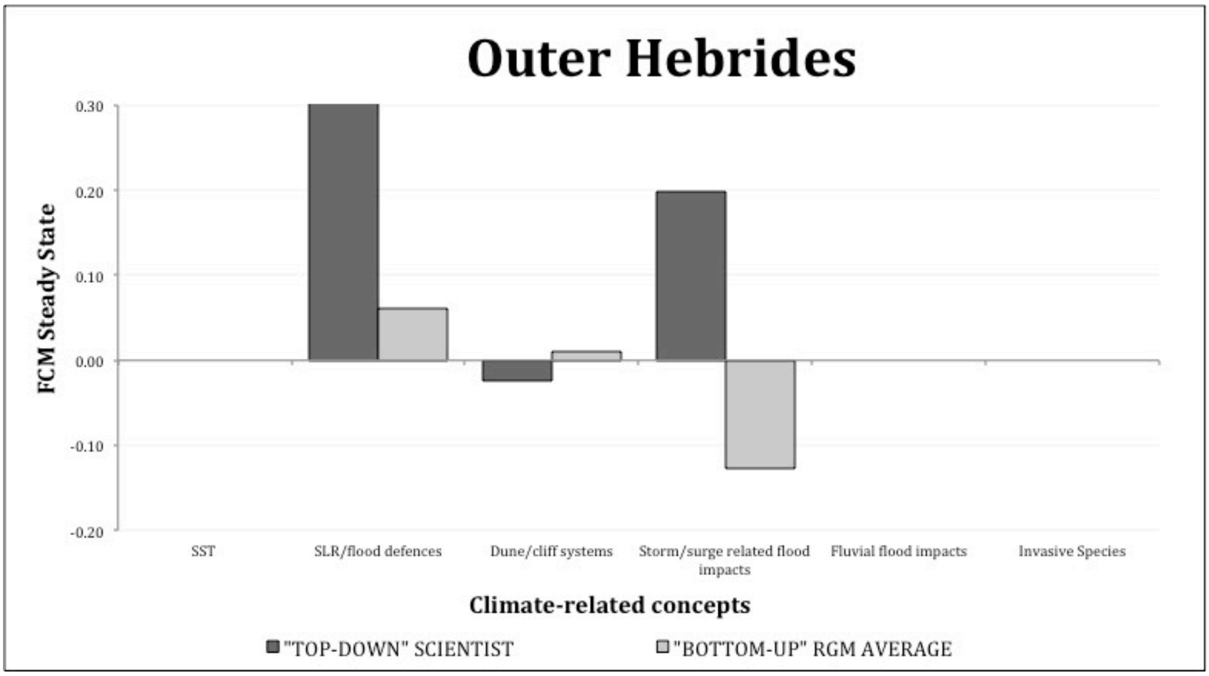

Figure 47: Climate related concept baseline scenario output in the Outer Hebrides

4. Discussion

Adaptation must be undertaken predominantly at the local level as the impacts of climate change will be differentiated spatially, with vulnerability to climate risk and available adaptive capacity varying markedly between areas (Agrawal et al., 2009). In response to this spatial differentiation, policy at the national (e.g. Ireland's National Adaptation Framework, Scotland's Climate Change Adaptation Framework) and international level (e.g. the EU White Paper on Adaptation) has begun to explicitly call for participative, 'bottom-up' approaches to adaptation. We therefore contend that the detection of climate signals and framing of climate impact problems by 'top-down' scientists and policy makers, and 'bottom-up' local decision makers and coastal management stakeholders is of utmost import and must be as closely aligned as possible in order for coastal climate adaptation to progress in a scientifically rigorous and locally legitimate manner. While offering a degree of cautious optimism in this regard, our findings in Tralee and the Outer Hebrides nevertheless identify disjunctures in perspectives across roles and scales that must be addressed.

Figure 48: Measures of indegree (all inbound edge relationships) and outdegree (all outbound edge relationships) for climate-related concepts included by resilience group members and the reference modellers.

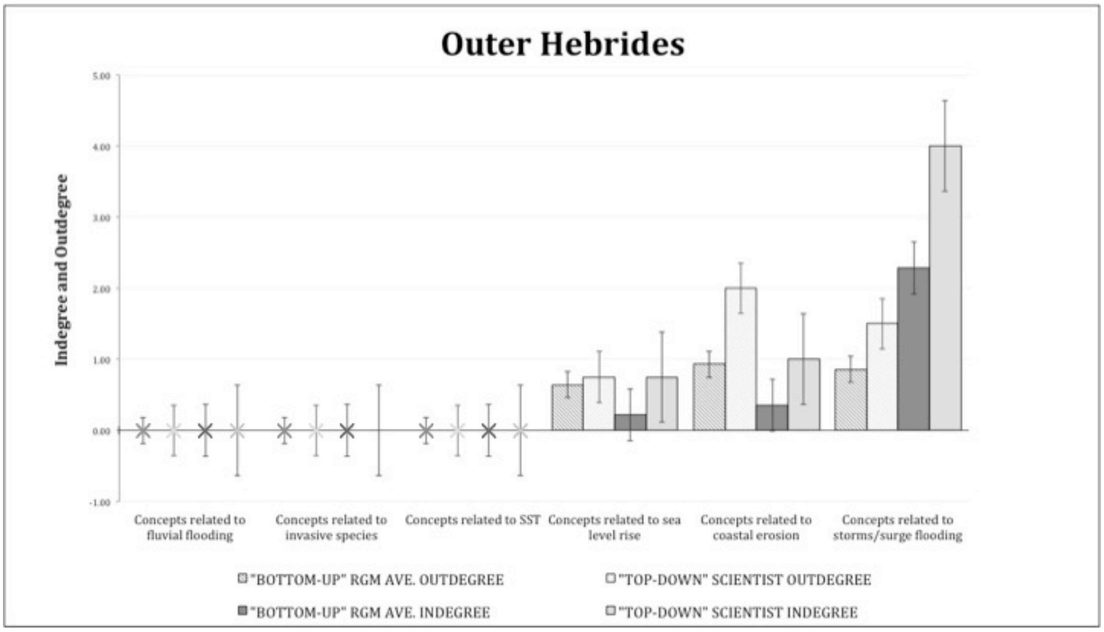

Figure 49: Measures of indegree (all inbound edge relationships) and outdegree (all outbound edge relationships) for climate-related concepts included by resilience group members and the reference modellers.

4.1. Climate signal detection and framing of climate problems

Taken at face value, the survey data collected in Ireland and Scotland appear to support a contention that stakeholders perceive climate change to be a pressing concern, and understand relatively well how climate impacts are likely to be expressed locally. This view is in line with much of the literature supporting a greater emphasis on 'bottom-up' approaches to adaptation and natural resources management in order to foster local-level sustainability (Fisher et al., 2009; Granek et al., 2010; Luisetti et al., 2011). However, the sources of information that coastal management stakeholders reported utilising in coming to decisions about the nature and scale of threat posed by climate change challenge the validity of this position. Scientifically robust sources of information were referred to by less than a third of respondents in Ireland. During subsequent interviews, Media sources were identified as providing the majority of climate-related information underpinning the responses offered to survey questions put to stakeholders. These findings are in line with a recent European-wide survey on the coastal and marine impacts of climate change wherein 29% of respondents reported employing scientifically robust sources of information, with television and the internet cited as the predominant information providers with respect to climate change (Buckley and Pinnegar, 2011). Where stakeholder perception of the climate signals which require adaptation responses is principally informed by the Media, problematic disjunctures between the signal detection of stakeholders and local decision makers/top-down scientists are likely.

However, there is evidence to suggest that non-scientific sources need not dominate stakeholder perspectives on adaptation. Survey data collected both by Tribbia and Moser (2008) and during the course of this research highlight that coastal stakeholders are willing (and able) to engage with climate change impact projection and monitoring data tailored to the needs and decision environments of stakeholders at the local scale. For instance, survey data from Tralee suggests that the use of scientific outputs by stakeholders shows a relatively high correlation with both stakeholder perception of climate change as an important issue (Spearman R statistic: 0.484; *p*-value: 0.006) and awareness of the projected climate impacts in the local area (Spearman R statistic: 0.507; *p*-value: 0.004). A critical component of on-going efforts to implement adaptation through a local lens must therefore be a means of translating not only adaptation policy to the local level, but also the top-down science which underpins it.

The urgency of this need was further highlighted by a comparison of the bottom-up mental models of resilience group members with those of the top-down scientific reference modeller. The members of the group identified substantially fewer concepts affecting the impacts of precipitation/flooding and storms/surges within the coastal system than did the top-down modeller. Tralee Bay group members regarded these key climate-related concepts to carry far fewer consequences for the structure and functioning of the system than did the top-down modeller. Instead, socioeconomic drivers such as tourism, agriculture, and residential development were cited by group members as significantly affecting the provision of key coastal ecosystem services which are vulnerable to climate hazards.

Similarly, when Outer Hebrides stakeholders were asked about the main issues related to coastal management in the case study region, only one interviewee explicitly mentioned climate change, although all but one of the other respondents raised issues related to climate change impacts, i.e., perception of an increase in the frequency of severe storms, coastal erosion and the associated flood risks in low-lying areas, construction of sea defences, and an increase in water table (as a result of sea-level rising) and its impact on crofting on the machair. The only exception was a representative of the fish farming business sector, who mentioned environmental legislation and policy as the main issue.

The main consequences of climate change that the interviewees discussed are similar to those identified in the above baseline survey, i.e., loss of land due to sea-level rise, sea level rise and erosion affecting coastal roads and infrastructure, severe storms and changes in wind patterns affecting fish farming activities, and other risks associated with severe storms such as impacts on infrastructure and livelihoods.

This perspective on the structure and dynamics of the system is by no means less valid, and is invaluable to communicate to national scale policy makers. However, augmenting this understanding with locally appropriate information regarding on-going processes of physical change would clearly be beneficial from an adaptation perspective. Bridging this gap would also likely see the difference in FCM density reported substantially diminish, providing a greater number and quality of adaptation options to decision makers at the local scale.

Bridging the evident divide between top-down and bottom-up perspectives on the framing of adaptation issues will require an authentic process of knowledge exchange. Insights from the resilience and adaptive management literature illustrate the utility of cross-scalar, bi-directional flows of both information and resources where collaborative natural resources governance akin to the subsidiarity required of climate adaptation is pursued (Berkes, 2009; Olsson et al., 2007; Plummer and Armitage, 2007). These mechanisms allow issues to be resolved by the local agents who are typically best placed to not only detect them but also, through integrating tacit knowledge and formal scientific information, understand them (Lebel et al., 2006; Olsson et al., 2004). Feedback loops between the detection of an issue and the initiation of action are thus shortened while maintaining the scientific rigour and local legitimacy of how such interventions are framed (Hahn et al., 2006).

Achieving the type of bi-directional information and resource flows required to overcome these barriers in climate signal detection and framing will likely require the intervention of some form of bridging organisation (Tribbia and Moser, 2008). Numerous examples of the translational role such an organisation may play between actors at various scales are reported in the Adaptive Co-management literature (Berkes, 2009; Hahn et al., 2006; Pinkerton, 2007; Schultz, 2009). At a time of ongoing global financial crises and austerity measures it is unlikely that the resources necessary to sustain the existence of a dedicated adaptation bridging organisation could be secured. However, instead electing to foster more fluid, ad-hoc institutions – described by Cundill et al. (2005) as more akin to a boat than a bridge – might provide a 'cheap and transitory', time-bound and project or strategy specific alternative. Navigating the divide between the top-down and bottom-up detection and framing of climate impacts and adaptation, in this way is also in line with the approach advocated by McKenna and Cooper (2006) in response to the issues of sustainability encountered by ICZM effort in Europe.

4.2. Employing FCM in support of an adaptation process

A number of different approaches to progressing coastal adaptation have been put forward in the literature (Cundill et al., 2005; Hahn et al., 2006; Pinkerton, 2007; Schultz, 2009), typically involving some form of stakeholder engagement, consultation or deliberation process that seeks to harness and/or harmonise stakeholder views on the nature and scale of the adaptation challenge present. The benefit of employing FCM as a facilitation tool within this type of process is that it provides a clear and direct 'map of cognition', via which specific errors or omissions in the integration of knowledge across scales and domains on the part of stakeholders can be readily identified. Further, FCM's measures of indegree, outdegree and centrality illustrate the specific role a concept plays in characterising a stakeholder's view of a given decision context. This allows targeted climate change impact or adaptation information to be provided to stakeholders in an appropriate and timely manner, providing the scope to resolve conflicts and reach consensus (Metcalf et al., 2010), and optimising the potential for informed and robust adaptation decision-making to occur.

This is a critical issue to address as greater effort and resources are coming to be invested in the kind of informational platforms as the UKCIP. UKCIP is a clear global leader in the provision of scaled and tailored climate impact and adaptation information. Yet our findings from the Outer Hebrides modelling work suggest that even the UKCIP cannot sufficiently assist local level stakeholders and the key decision makers serving them in coming to adaptation decisions aligned with upper level policy guidance without active intervention. With Ireland currently making steps to develop a similar climate information platform, ensuring sufficient attention is also paid to the institutional support required by stakeholders and decision makers is paramount if adaptation progress is to be made.

5. Conclusions

A note of caution should be sounded regarding the distribution of rights and obligations surrounding the implementation of adaptation in what are still very much the early stages of our understanding of how responses to climate change can best be supported. There is apparent agreement between top-down and bottom-up perspectives that highly localised actions in the near term are desirable and appropriate. However, the translation of conceptual adaptation policy into pragmatic action at the local scale will require flexible and responsive bridging organisations. These organisations must be fluid and capable of evolving quickly, to not only support the integration of constantly changing information and knowledge between scales, but also to play a critical role in informing adaptation policy through its requisite iterations as our understanding of the field matures.

A key tool that can be employed to facilitate these aims is FCM. In order to allow bridging organisations to swiftly get to the crux of the disparities and/or deficits of information across and between scales of adaptation decision making and implementation, it is essential to analyse the mental models employed in the detection of climate impact signals and framing of adaptation issues to resolve, both for the purposes of communication and conflict resolution, and to respond within the limited shelf life of a given phase of an adaptation process to the specific data and information needs of decision-makers.

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5.1.2 Post-publication reflections

The value of FCM as a tool to provide insight into the thinking of expert stakeholders engaged in adaptation decision making was made clear during the course of the field research underpinning this paper. In particular, the method allowed a meaningful comparison to be made between stakeholders in different locations with different adaptive capacities, facing similar challenges, and ultimately responding to them in surprisingly similar ways.

Interestingly, local expert stakeholders in both Tralee Bay and the Outer Hebrides viewed their vulnerability to critical climate change impacts such as sea level rise and storm surge with much less concern than did experts involved in setting adaptation policy at national level. Digging into the rationale underpinning these assumptions during the modelling process highlighted key gaps in the sources and types of information employed during stakeholders' deliberation of climate vulnerability. But arguably of equal relevance, it illustrated the relative importance to stakeholders at the local level of what national scale experts might consider to be trivial, parochial concerns which might crowd out that evidence in immediate decision making.

These were issues such as customary uses of dune systems, the role local amenities played in fuelling the incomes generated by tourism, and the inertia brought on by decades of history to try to overturn in viewing the coast as suddenly more dynamic and impermanent than it had been. The weight of those realisations is difficult to quantify in terms of the role they played in conditioning local stakeholder perceptions of climate risk, and in many respects must remain conjecture (thus it is largely absent from the published article). But the conversations, interactions and relationships witnessed by the research team in spending time at each site made it clear that local community expectations bore heavily on decision makers, and facing up to the toughest of adaptation decisions, which would inevitably carry significant costs and disruptions with them, was no easy task. While national scale experts can deal with such issues in the abstract, at the local scale, dune systems have names, as do those whose lives and livelihoods rely on them. Envisioning these as time-bound and vulnerable involves tough choices that it would be much easier to view as a long term future concern than one with roots in the here and now. It is therefore possible that the absence of insight into vulnerability was to some extent wilful.

This is perhaps an important consideration for those developing adaptation resources in support of local scale decision makers. In the Scottish case, decision makers had access to one of the most well-funded and sophisticated climate services suites in Europe – the UK Climate Impact Programme (UKCIP), which has been in operation since 1997. In the Irish case, no such adaptation services resource was at that stage available, with the Irish Climate Information Platform then in development. Yet there was little to differentiate between the deliberations of stakeholders in Scotland and Ireland. Some means of bridging between national scale climate service resources and local scale decision makers is likely essential in order to maximise the impact of platforms such as UKCIP. FCM could play a useful role in helping to bridge that gap.

Another issue of interest to the wider adaptation community may be the extent to which the key benefits that were realised in conducting an analysis via FCM might be argued as difficult to achieve with stakeholder numbers greater than those participating in this study. The number of FCMs which can be collected and analysed could likely not extend beyond those illustrated here (*n*=6 in Tralee Bay, *n*=7 in the Outer Hebrides) without the support of a large and well-funded research team, or perhaps an automated back end computational processing facility – a solution which would likely diminish the benefits realised in conducting the analysis. The time consuming task of analysing and creating a group model from the individual inputs of stakeholders is perhaps the most useful element of the method, offering an opportunity to get to grips with the perceptions of decision makers in planning adaptation. Scaling this process up will likely not only be technically demanding but also of lesser value.

However, this may not necessarily be seen as problematic. Firstly, there are typically fewer than 15-20 key players in adaptation decision context who will ultimately determine outcomes (certainly in a coastal adaptation context this is the case). Identifying and securing their participation is key to the value of the exercise. Secondly, adopting the approach described by Olsson et al. (2006)[11] in working with smaller groups who are the key forces in providing momentum for change is the most effective way of facilitating a transition toward social-ecological system resilience. For these reasons, the scale limitations of an overhead-heavy method such as FCM should not necessarily be considered a barrier to its implementation as an adaptation bridging tool.

5.1.3 Key conclusions and linkages to subsequent papers

This paper has illustrated the benefits of employing FCM as a facilitation tool in coastal adaptation planning. FCM provides a clear and direct 'map of cognition', via which the exact nature of errors or omissions in the integration of knowledge across scales and domains on the part of stakeholders can be readily identified.

Using FCM indices of indegree, outdegree and centrality to illustrate the specific role a concept plays in characterising a stakeholder's view of a given decision context can in turn facilitate the cost effective targeting of climate change impact or adaptation information. These benefits can offset the overhead capacity costs of undertaking a participatory modelling initiative such as FCM. This is particularly so where regional or central government organisations invest time and resources into the construction of a framework FCM, from which subsidiary FCM projects can be rolled out at the local scale.

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[11] Olsson, P., L. H. Gunderson, S. R. Carpenter, P. Ryan, L. Lebel, C. Folke, and C. S. Holling. 2006. Shooting the rapids: navigating transitions to adaptive governance of social-ecological systems. *Ecology and Society* **11**(1): 18. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art18/

Where, as in the case of the Outer Hebrides, evidence suggests that even high-quality knowledge integration initiatives such as the UKCIP adaptation resources have not been taken up by local scale decision makers, this is of crucial importance.

The following paper illustrates another analytical facet of FCM which may be beneficial in supporting and sustaining an adaptation process: that of measuring the transformative capacity of adaptation measures in responding to climate change impacts.

6.1. CHAPTER 5

6.1.1. ***Gray, S.,*** *Gray, S. A., De Kok, J. L. Helfgott, A. E. R. O'Dwyer, B. Jordan, R. and Nyaki. A. "Using fuzzy cognitive mapping as a participatory approach to analyse change, preferred states, and perceived resilience of social-ecological systems".*

The final chapter in this thesis explores a challenging and openly speculative component of social-ecological systems (SES) analysis – the extent to which an alternate system steady state can be identified, navigated toward and measurably attained. This is in many respects the ultimate aim of adaptation: effecting transition from a persistently vulnerable system state toward one in which persistent resilience in the face of increased exposure to climate risk is possible.

The chapter begins with a review of current thinking in regard to the resilience framework and its role in analysing SES states, in particular those involving bottom-up initiatives to determine desired steady-state conditions. The chapter then goes on to describe FCM, and in particular, its attributes which might support resilience assessment, mapping these against a framework of resilience analysis introduced by Walker et al. (2002).

Having illustrated an FCM-based methodology by which resilience analysis might be attempted, the remainder of the chapter is given over to an analysis of the method's utility in practice.

This chapter initially appear in Ecology and Society in a different form. The opening sections of the chapter (6.1.2. to 6.1.9.) are as they appeared in the published paper. However, from section 6.2 through to the conclusion, the chapter has been re-drafted for inclusion in this thesis, referring to Irish coastal climate change adaptation case study material rather than the African bushmeat case study appearing in the published article.

CONTRIBUTION STATEMENT

Declaration of own contribution to the published (or intended for publication) scientific papers within my dissertation.

DISSERTATION TITLE: Making sense of changing coastal systems: overcoming barriers to climate change adaptation using fuzzy cognitive mapping

PAPER–5: **Gray, S.,** Gray, S. A., De Kok, J. L. Helfgott, A. E. R. O'Dwyer, B. Jordan, R. and Nyaki. A. (Unpublished) "Using fuzzy cognitive mapping as a participatory approach to analyse change, preferred states, and perceived resilience of social-ecological systems", derived from: Gray, S. A., **Gray, S.** De Kok, J. L. Helfgott, A. E. R. O'Dwyer, B. Jordan, R. and Nyaki. A. (**2015**). "Using fuzzy cognitive mapping as a participatory approach to analyse change, preferred states, and perceived resilience of social-ecological systems". Ecology and Society **20**(2): 11. dx.doi.org/10.5751/ES-07396-200211

OWN CONTRIBUTION IN THIS WORK: Concept development (mainly), Literature search (fully), Methods development (fully), Research design (mainly), Data collection (mainly), Data analysis (fully), Construction of the manuscript (mainly), Argumentation (mainly), Critical revision of the article (mainly).

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July 11, 2019

Using Fuzzy Cognitive Mapping as a participatory approach to measure resilience, change, and preferred states of social-ecological systems

S. R. J. Gray, S. A. Gray, J-L. De Kok, B. O'Dwyer, R. Jordan, A. Helfgott, and A. Nyaki

Abstract: There is a growing interest in the use of Fuzzy Cognitive Mapping (FCM) as a participatory method for understanding social-ecological systems. In recent years, FCM has been employed in a diverse set of contexts ranging from fisheries management to agricultural development, in an effort to generate models of complex systems which are useful for decision-making, illuminate the core presumptions of environmental stakeholders and structure environmental problems for scenario development. This increase in popularity is due to FCM's bottom-up approach and capacity to incorporate a range of individual, community-level and expert knowledge into an accessible and standardized format. Although there has been an increase in the use of FCM as an environmental planning and learning tool, limited progress has been made in linking FCM to existing resilience frameworks, in particular the assessment of transitions between alternate basins of attraction, or in comparing its use explicitly to other participatory modelling approaches available. Using case study data developed from coastal climate adaptation in Ireland, we provide an overview of the methodology and examine the usefulness of FCM for promoting resilience analysis among stakeholders in terms of identifying key state variables, evaluating the equilibrium points and defining desirable or undesirable state outcomes through collaborative scenario analysis.

6.1.2. Introduction

The last several years have seen considerable research effort dedicated to understanding the drivers of change within social-ecological systems (SES), in particular those which alter system function to the point where human well-being, conservation, or other environmental management goals are compromised. These research efforts have focused primarily on analysing and understanding the ecological attributes that govern the system's dynamics and the propensity that different system configurations have to limit or facilitate a shift into a different 'stability landscape' (Walker et al. 2004). Understanding the structure, defined dynamic relationships, and movement toward or away from alternate regimes has been suggested as a starting point to understand resilience and change across a range of SESs (see Brooks and Adger 2005, Carpenter et al. 2001, Folke 2006, Füssel and Klein 2006, Gallopín 2006, Walker et al. 2002). Although there are some variations in the literature with regard to the definition of the term resilience (Brand and Jax 2007) which can vary slightly based on its application in either ecological (Holling 1973; Gunderson and Holling 2002) or social (Adger 2000) system contexts, it is considered the capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity (Walker 2006).

The popularity of the resilience framework has seen new questions emerge regarding how the resilience paradigm might make a transition from theory to praxis within environmental management circles. A key unresolved issue in this respect is to what extent the analytical methods which have been commonly used to characterize and communicate SES change to social agents engaged in environmental management are successful in supporting resilience analysis (Bennett et al., 2005,Gunderson 1999, Walters 1997). There are a number of natural resource management examples (see Holling and Meffe 1996) demonstrating how linear, rigid and deterministic assumptions about natural resource systems have proven incommensurate with observed system outcomes. These surprises emerge due to such reductionist approaches being derived from the once prevalent view that ecosystems exist in a single, dominant equilibrium state (Folke 2006), with natural variation in these systems often played down or ignored. It is now widely accepted that the core characteristics of SES as dynamic, complex, adaptive, and uncertain make them incongruent with reductionist command and control models (Holling and Meffe 1996), which has in turn led to the development of new modelling and analytical approaches that explicitly incorporate surprises and multiple system states in SES resilience analysis (Carpenter et al., 2002).

In addition, top-down and exclusionary approaches to understanding the environment also run counter to recommendations for resilience assessments (Walker 2004). When institutions engaged in environmental assessments are highly connected, self-reinforcing and inflexible, they may be susceptible to rigidity traps (Carpenter and Brock 2008). Further, researchers have also pointed out failures in communication between stakeholders involved in decision-making, which are attributed to a lack of terms, indicators, and measures that communicate the social impacts of ecological change. These issues are exacerbated by the inability to easily incorporate relevant social values (Norton 1998) or diverse knowledge systems (Gray et al 2012) into environmental assessments. As many resource decision-making contexts are also characterized by low controllability, unclear causal linkages, high social and ecological stakes, data poverty, and heterogeneity of social agents, it is becoming increasingly clear that new modelling methods that support resilience thinking must include the ability to represent complexity in an adaptive and practical manner (Holling 1978; Walters 1986). Such modelling approaches must allow understanding to be revised adaptively as new information becomes available through stakeholder feedback (Gray et al. 2014b), and provide iterative opportunities to incorporate social values, diverse sets of beliefs and preferences alongside ecological dynamics.

The growth of qualitative (or semi-quantitative) participatory modelling in the context of SES resilience assessment has come in response to these emerging demands to incorporate complexity when understanding SES behaviour, and for greater inclusivity in the modelling process (Bennett et al. 2005, Cumming et al. 2005, Fletcher et al. 2006, Fuentes 2012, Kearney et al. 2007, Kok 2009, UNECE 1998). Currently a wide range of stakeholder-centred modelling programs, practices, and guidelines exist, which all essentially aim to provide decision support and facilitation in participatory planning and governance contexts (Gray et al. 2016). Voinov and Bousquet (2010) outline two major objectives that drive participatory modelling: 1) to increase and share knowledge and understanding of a system and its dynamics under various conditions, and 2) to identify and clarify the impacts of solutions to a given problem. Although the tools and software available to environmental managers have increased in number in recent times, some have nevertheless cautioned that diversity of modelling practices does not necessarily indicate diversity in function, as new stakeholder modelling programs are often prone to duplication of efforts (Jones et al. 2008).

Over the last decade, though norms for understanding the characteristics of SES have emerged and there has been an increase in the development of participatory modelling approaches, the analytical trade-offs between domain general and flexible modelling tools in support of resilience assessments remain relatively poorly explored. Although scholars in the field have recently begun to review and typify the strengths and weaknesses of different participatory approaches to incorporating stakeholder knowledge and values into environmental decision-making (Lynam et al. 2007; Sandker et al. 2010; Voinov and Bousquet 2010); however, these reviews are rarely explicitly linked to concepts related to resilience assessment, despite some notable recent efforts (see Ross and Berkes 2014). Therefore, to further the conversation on emerging participatory approaches to the modelling and analysis of change in SES at scales dominated by human agency, we discuss how the resilience framework can be aligned with Fuzzy Cognitive Mapping (Kosko, 1986), and compare this approach to some of the other participatory modelling approaches available. Fuzzy Cognitive Mapping (FCM) is a relatively simple-to-use form of semi-quantitative modelling that can be used to visualize the behaviour of systems with feedback under different adaptive behavioural patterns. We use a case study of coastal climate adaptation in Ireland to demonstrate the added value of FCM in collecting and standardizing stakeholder knowledge to generate an understanding of key state variables. Further, by using FCM's capacity to conduct semi-quantitative scenario analyses, we illustrate the relationship between the current and projected equilibrium states of a SES and their relationships to desired or undesired states under a range of potential shocks to the systems and in light of management actions.

This paper is designed to contribute to the existing understanding of how to measure and communicate resilience, specifically by 1) harnessing the current and collective knowledge of social agents within a SES to share knowledge about the state space and dynamics which comprise these systems, and 2) analysing how different SES configurations may limit or facilitate system trajectory toward stakeholder-defined desirable or undesirable equilibrium within a stability landscape. We begin by reviewing the historical and contemporary applications of FCM, and then place the method within the context of emerging participatory frameworks of resilience assessment, followed by a discussion of the usefulness and shortcomings of the approach using an illustrative case study example.

6.1.3. Fuzzy Cognitive Mapping

Originally developed by Kosko (1986) as a semi-quantitative and dynamic method to structure expert knowledge, FCM has its historical roots in cognitive mapping. FCM, like all cognitive maps, are graphical representations of organized knowledge that visually illustrate the relationships between elements within a knowledge domain. By connecting concepts (nodes) with semantic or otherwise meaningful directed linkages, the relationships between concepts in a hierarchical structure are logically defined (Novak and Cañas 2008). The argument for representing cognition with structural maps is derived from constructivist psychology, which suggests that individuals actively construct knowledge by creating mental systems which serve to catalogue, interpret and assign meaning to environmental stimuli and experiences (Raskin 2002). Knowledge "constructed" in this manner can externally represent the foundation of an individual's organized understanding of the workings of the world around them, and therefore cognitive maps are external representations of internal 'mental models' (Jones et al 2011). Individuals' assimilate external events and accommodate information into these mental model structures to facilitate reasoning and understanding (Craik, 1943,Flavell 1996, Piaget 1983). Using this theoretical framework, cognitive maps can be elicited to represent an organized understanding of a general context or domain, thereby providing an illustrative example of a person's internal conceptual structure of the issue in question (Novak and Cañas 2008).

FCM build on these notions and are highly structured and parameterized versions of cognitive maps that represent direct and indirect causality, combining aspects of fuzzy-logic, neural networks, semantic networks and nonlinear dynamic systems (Glykas 2010) in a stock-and-flow representation based upon individual or group beliefs (Gray et al. 2014a). Because FCMs are based on cognitive mapping and are semi-quantitative they are often considered to be representations of mathematical pair-wise associations, using qualitatively (e.g. low, medium, high) or quantitatively assigned weighted edges (between -1 and 1) between components that collectively comprise a representation of a particular domain (Wei et al. 2007). Using these pairwise relationships the structure between the elements of a particular domain can be used to compute the cumulative strength of connections between elements with weighted edges, highlighting any domain as a system (see Figure 50).

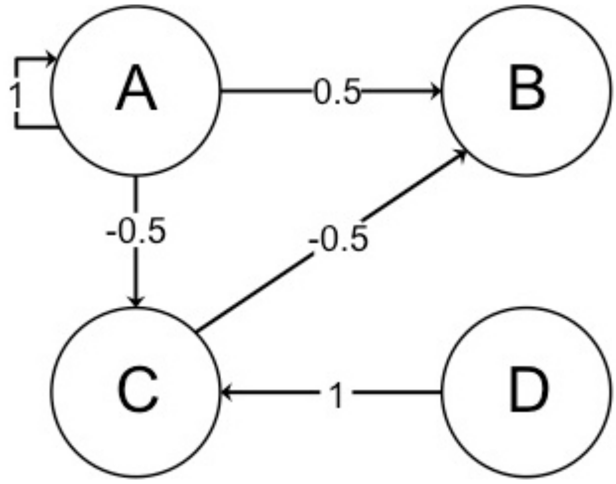

Figure 50: An example of a simple fuzzy cognitive map (FCM), illustrating weighted edge relationships (-1, 1) between system elements A, B, C, and D.

FCMs have been used in a number of disciplines to indicate relationships among variables as well as to understand system dynamics. The application of FCM can be categorized in terms of the type of knowledge being represented in the cognitive map (Gray et al 2014a). Broad categories include traditional experts known to the scientific literature, such as scientists (Celik et al. 2005, Hobbs et al. 2002), engineers (Amer et al. 2011) and physicians (Benbenishty 1992), and local experts that include pastoralists (Ortolani et al. 2010; Papageorgiou et al. 2012, Halbrendt et al. 2014), fishermen (Mackinson 2000, Wise et al. 2012), environmental managers (Gray et al. 2013, Gray et al. 2014) or bringing together several environmental stakeholders as a way to facilitate decision-making (Celik et al. 2005; Gray et al. 2012; Kafetzis et al. 2010; Meliadou et al. 2012; Özesmi and Özesmi 2004; Papageorgiou et al. 2012).

Because of the simplicity and flexibility of the method which accommodates the modelling of any domain, FCM research encompasses a wide range of applications, including: risk assessment (Hurtado 2010, Medina and Moreno 2007), work efficiency and performance optimization (Jose 2010, Xirogiannis et al. 2010), strategic deterrence and crisis management (Kosko 1993; Perusich 1996), scenario/policy assessment (Amer et al. 2011, Kok 2009), spatial suitability and prediction mapping (Amici et al. 2010, Metternicht 2001), and environmental modelling and management (Adriaenssens et al. 2004, Hobbs et al. 2002, Jarre et al. 2008, Mackinson 2000, Prato 2009). All of these efforts are unified in attempting to:

i. Make tacit expertise explicit,
ii. Formally structure complexity, and
iii. Characterize a system's dynamics, which provide an understanding of system structure that would otherwise not be well understood.

By systematically collecting and integrating a range of expertise, FCM provides an easily elicited method to represent internal knowledge that would otherwise be loosely linked, highly complex, or unavailable to enhance the understanding of a system domain.

We focus here on the use of FCM as a means of encoding and aggregating stakeholder and/or expert knowledge into a standardized format, thus allowing a broad range of knowledge types to be integrated and communicated in pursuit of SES resilience assessment at a scale commensurate with human planning and management activity. This avoids a common pitfall of over simplifying complex understandings of the system into predetermined 'bins' such as simply local knowledge, traditional knowledge or scientific knowledge, with the biases such classifications typically entail (Gray et al. 2012). Eliciting representations of knowledge in the structured and simplified language of FCM allows tacit knowledge to be made explicit, and scientific knowledge to be made more tractable and tangible for non-scientific audiences to engage with. This in turn facilitates the construction, revision, and debate of knowledge claims regarding the structural and functional identity of the system subjected to management (Amici et al. 2010; Özesmi and Özesmi, 2004; Wildenberg et al. 2010). Further, although somewhat novel as a method for environmental planning, the application of FCM in a participatory modelling context has provided an adaptable method to support existing resilience assessment frameworks previously recommended, specifically with regard to procedural steps for resilience assessment and understanding change and transition in SES including; 1) sharing knowledge to define the state space of a given SES, 2) analysing the structure of an SES, 3) analysing SES function based on defining stability landscapes through scenarios, and 4) evaluating how changes to structural configurations may relate to movement toward or away from desirable or undesirable future trajectories (Figure 51).

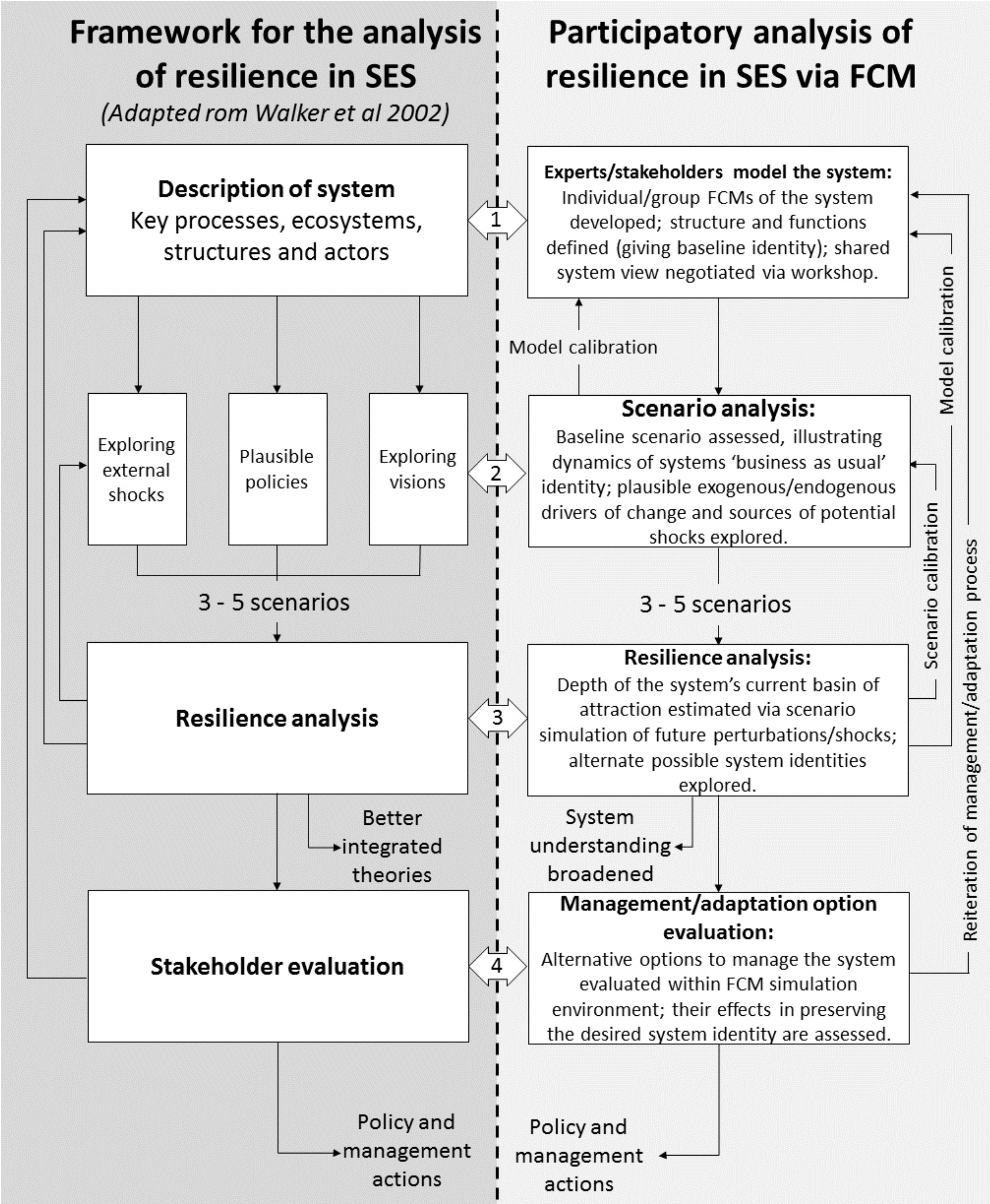

Figure 51: Mapping the proposed participatory FCM approach to SES resilience assessment to the framework put forward by Walker et al. (2002).

6.1.4. Constructing FCM based on shared community knowledge or distributed expertise to define the state space

As FCMs can serve as semi-quantitative, detailed representations of individual and/or group knowledge structures, either through aggregation of individual models or through group FCM building exercises (e.g. stakeholder workshops), they can be used to define the perceived configuration of a SES. Using the imprecise nature of common language, FCM permits individuals or groups of individuals to interpret and express the complexity of their environment and experiences by combining their knowledge, preferences and social values with quantitative estimations of the perceived relationships between components within a particular context (Jose 2010, Jones et al. 2011, Lynam et al. 2007, Özesmi and Özesmi 2004). FCMs have been proposed as a unique tool for aggregating diverse sources of knowledge to represent a "scaled-up" version of individuals' knowledge and beliefs (Özesmi and Özesmi 2004). The product of the aggregation of individual's FCMs is sometimes referred to as a 'social cognitive map' and is often considered a representation of shared knowledge (Gray et al, 2012; Özesmi and Özesmi 2004). The concept of shared knowledge in the form of social cognitive maps has been used in a variety of distinct applications, including: to gain a more comprehensive understanding of complex systems; to describe consensus in knowledge among individuals; and to define differences in individual and group belief or knowledge structures. In applying FCM to understand change within SES, the work described here has primarily focused on engaging in community-generated modelling activities via workshops with a range of stakeholders to generate a working model of the salient social and ecological components that comprise a resource system. Such definitions of the variables that are contained within the perceived boundaries of a system lend themselves to the idea of defining the state space (Walker et al. 2004) or the multi-dimensional state that all combinations of the defined variables can exist within. These definitions of what constitutes the state space of an SES are the components/variables that exist within a given space, e.g., a protected area, or are required for a system to have a given function, e.g., the international timber trade. Additionally, the relationships between state space variables that are defined in terms of degrees, e.g., low, medium, or high, of positive or negative influence together represent the networked structure of a system.

6.1.5. Analysing FCM structure

Because FCM are derived from graph theory and are semi-quantitative, the static structure between state space variables can be represented in mathematical terms. These structural measures are determined by translating the cognitive map into an adjacency matrix (Table 22). Allowing the structural relationships of these concepts to be represented in a matrix allows each variable included in a model to be categorized in one of three ways; as a driving variable (forcing component), receiving variable (impacted component), or ordinary variable (intermediate component) (Nyaki et al. 2014). Additionally, the variable's relative importance to the system can be analysed via reference to the strength of its incoming and outgoing edge relationships relative to those of other variables via centrality measurements common to network analyses (see Özesmi and Özesmi 2004). FCM are also subject to a range of other quantitative measurements that allow for comparison of one model to another, including measuring model complexity and model density (see Gray et al. 2014 for a review of structural measures).

	A	B	C	D
A	1	0.5	-0.5	0
B	0	0	0	0
C	0	-0.5	0	0
D	0	0	1	0

Table 22: Adjacency matrix derived from the fuzzy cognitive map of Figure 1.

6.1.6. Analysing FCM dynamics

In addition to defining the state space and the structured relationship between variables, the results of dynamic interactions between structured components within a domain can be determined using matrix calculation to develop FCM scenarios. The output of an FCM's adjacency matrix can be calculated using matrix algebra over a series of iterations to illustrate its baseline scenario – a representation of the steady state of the system (Kosko 1986) which is complementary to the resilience concept of a basin of attraction. This provides a snapshot of how the variables and linkages of the system given the current SES configuration would resolve themselves in the absence of change or intervention, with all feedback loops played out:

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j \equiv i}}^{N} A_j^{(k)} w_{ji} \right) \tag{1}$$

where $A_i^{(k+1)}$ is the value of factor V_i at iteration step k+1, $A_i^{(k)}$ is the value of factor V_i at iteration step k, $A_j^{(k)}$ is the value of factor V_j at iteration step k, and w_{ji} is the weight of the edge relationship between V_i and V_j. Threshold function f (e.g. a logistic or sigmoidal function) is used to normalise the values at each step to keep the dynamic analysis bounded. This initial state of the system, calculated based on the network structure and defined influences between variables, indicate the region in state space in which the system tends to remain (Walker et al. 2004) without significant changes to any state space variable.

6.1.7. Analysing FCM dynamics: alternative stable states

Inferences may be drawn regarding the dynamic attributes of the system as modelled by analysing the scenario output of an FCM (Özesmi and Özesmi 2004). Analysis of the scenarios can either focus on the equilibrium end states, if present or transient behaviour during the iteration steps. "What if" scenarios help explore how the system might shift into another set of equilibrium points within the same basin of attraction, or slip into an alternative regime under a range of possible conditions as variables included in the state space are artificially changed. This is accomplished by increasing or decreasing (referred to as "clamping") key variables as continually high or low (Kosko 1986, 1994), resulting in a new system state that can be compared with the steady state.

The persistence of a system's identity in the face of disturbance has been suggested as a useful measure of resilience (Cumming et al. 2005). Therefore, by comparing current basins and alternative equilibrium states, it is possible to characterize a system's current identity and determine the scale of disturbance it can endure while maintaining a certain output (Kok 2009). Such assessments draw on the concept of "stability landscapes" described by Walker et al. (2004) to describe the transition between alternative equilibrium states within a basin.

6.1.8. Reviewing equilibrium points and defining desirable and undesirable identities of SES under different scenarios

In addition to understanding the structure and function of SESs, the modelling process itself, i.e., developing an FCM with stakeholders, has also helped policy makers frame regulations in a manner responsive to the needs and terms of stakeholders and maximize stakeholder buy-in of experimental policy measures (Özesmi and Özesmi 2004). Murungweni et al. (2011) further emphasize the potential of the FCM modeling process to form strong links of communication and trust between stakeholders, researchers, and policy makers.

To date, however, significantly less attention has been paid in the literature to defining desired and undesired states of an SES using FCM based on stakeholders' perceived system components included in a model. Kok (2009) outlined the considerable potential of FCM in this regard with a hypothetical Brazilian deforestation example, providing a strong steer regarding the role and value of FCM in fulfilling a resilience assessment brief that remarkably few have taken up using stakeholder-generated data. To add to the discussion, we suggest that all components stakeholders include in an FCM which are thought to be important to the composition of a domain or 'state space' (Walker et al. 2004) can be designated as existing in one of 3 states and be subjectively preferred as: increasing, decreasing or showing no preference. Defining preferred states establishes system desirability in the face of external or internal pressures within an SES. Further, such an explicit approach establishes a qualitative basis for analysing the system's identity given its current basin of attraction and whether scenario results are considered to be a change in equilibrium state within the current basin of attraction or whether scenario results are significant enough to constitute movement toward another basin of attraction, or shift into a new stability landscape (Walker et al. 2004).

6.1.9. An FCM-based approach to resilience analysis

Methods which support the coupling of participatory modelling with the management of a system toward more resilient states have not yet been explicitly identified. We demonstrate how a participatory FCM process can be used to fulfil the objectives of previously proposed resilience analyses using a case study example. Specifically we link the FCM methodology with four steps of participatory resilience assessments proposed previously by Walker et al. (2002) (Figure 51).

- **Step 1: Resilience of what?** With the help of stakeholders, develop a conceptual model of the problem to be managed, exploring key drivers of change in the system, its historical profile, what can be controlled within it, how institutions interact in the governance of the system, and what key process at lower and higher scales contribute to the system's integrity and identity.
- **Step 2: Resilience to what?** Identify the external disturbances and endogenous processes to which the desired configurations are expected to be resilient. Scenarios are developed exploring how these key drivers might plausibly interact in future, with particular emphasis on the potential for shocks.
- **Step 3: Analysing resilience:** Assess the interaction of known uncertainties regarding changes in the system's identity (emerging from step 2) with key system structures and functions (emerging from step 1, mainly ecosystem goods and services) that stakeholder's value, principally via determining possible driving variables and processes that govern the dynamics affecting these structures and functions. Threshold effects and information regarding non-linearities in system behaviour are particularly relevant.
- **Step 4: Implications for decision-making:** A reflexive stakeholder evaluation of the resilience assessment process, culminating in the proposal of policy and management actions in line with the emerging understanding of the system's current identity, and maximising the capacity for the system to self-organise toward other acceptable identities. A shared view of the system and the processes of change that it faces will greatly enhance the potential for such actions and policies to be enacted.

6.2. Case study: climate change adaptation in Tralee Bay, Ireland

Tralee Bay is located on the northern side of the Dingle Peninsula in County Kerry, southwest Ireland. The coastal margin is primarily comprised of sand-gravel beaches backed by low cliffs or dune barriers, sand-cobble barriers with flanking mudflats and Cord Grass dominated salt marsh, and eroding low cliff coast with narrow cobble sediment. Cliff erosion rates are relatively high in some places, commonly in the region of 0.5-1.0 m per year (Devoy, 2008). Tralee Bay supports important numbers of over-wintering Pale Bellied Brent Goose (Branta bernicla hrota), and is a shallow embayment Ramsar site. The Bay was also declared a Special Protection Area in 1989 for its geomorphological and botanical interest.

The main settlement in the Bay area is Tralee town, with ~20,000 inhabitants. Economic activity has grown over the last decade focusing on tourism, retail, commerce, and residential development. Rural villages such as Castlegregory or Fahamore attract visitors for surfing, diving, and fishing. Fenit supports the most westerly commercial port of Ireland, a multi-use harbour for commercial shipping activity and fishing and a 130-berth marina.

Tralee Bay's principal threats from climate change are fluvial and tidal flooding and coastal erosion. Although carrying substantial uncertainties, climate projections for the southwest of Ireland presently indicate an increase in winter precipitation, resulting in increased levels of runoff and flooding (McGrath et al., 2009; Sweeney et al., 2008). This is particularly problematic for Tralee town where increased levels of development over the recent past have resulted in a decrease in the capacity of the area to absorb flood waters from low-lying areas. Climate projections also indicate a sea level rise of ~0.48 m (IPCC, 2007b), which will result in inundation of low-lying coastal areas. Importantly, when increases in sea levels are combined with projected increases in Atlantic wave heights and storm surges (McGrath et al., 2009), increased levels of coastal inundation and erosion can be expected. This is particularly the case when storm surges combine with high astronomical tides to overtop coastal defences. Increased sea level rise will also result in increased tidal penetration of estuaries, which will exacerbate problems of seasonal flooding. Summer average temperatures are projected to rise by 1.4-1.8°C by the 2050s, which in concert with fewer precipitation days in summer (McGrath et al., 2009; Sweeney et al., 2008) may result in enhanced potential to attract tourism.

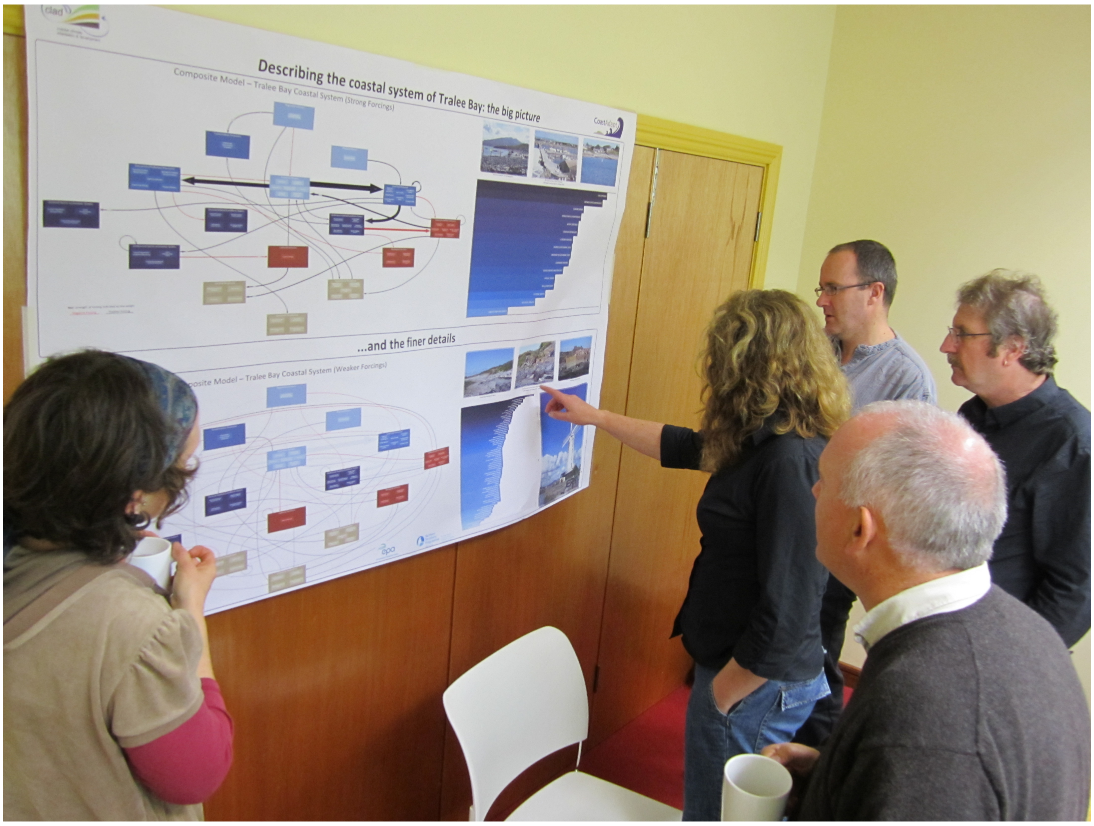

Figure 52: Modelling the Tralee Bay social-ecological system using FCM

To define the perceived state space of the system, the current basin of attraction, and anticipated changes to system states, data collected from a series of participatory modelling workshops conducted over a 7 month period with 6 key coastal management stakeholders who had been invited to participate in an informal coastal resilience group in Tralee Bay (Figure 52). The group had been selected as key actors in coastal resilience from a wider survey of coastal management stakeholders – defined for the purposes of this research as those with responsibility for, or long-standing expertise and local influence in, coastal planning and development, emergency preparedness, pier and harbour management, inshore fisheries, aquaculture, tourism, coastal agriculture, environmental protection, and other coastal sectors of activity relevant to the geographical setting. Over the course of a series of one to one meetings and facilitated workshops, the group defined the structure and core functional relationships of the coastal SES. They described the defining elements of a preferred state identity, and analysed shifts toward or away from this identity under scenarios of future change in climatic and socioeconomic boundary conditions, to better understand how adaptive capacity can best be enhanced in the face of uncertainty.

6.2.1. Experts/stakeholders model the system

- Group members first met with a researcher to build an individual FCM of the coastal SES. Concepts gathered during an earlier survey phase of the research were categorised as drivers, pressures, states, impacts or responses, and provided to each modeller for the purposes of building an FCM of the system. Modellers were also given the option to create new concepts in order to construct their FCM if desired. Modellers were provided with an unrelated FCM example to help facilitate the model building process.
- The six individual FCMs were translated into adjacency matrices and aggregated to form a draft group model.

6.2.2. Scenario analysis: identifying the current basin of attraction

- In its draft form the model consisted of 70 concepts with 272 connections. A process of model revision conducted during a facilitated group workshop saw connecting edge relationships expand to 310.
- The system steady state of this amended group model was calculated by entering the new adjacency matrix into the FCMapper tool (Wildenberg et al. 2010), providing a baseline scenario output (See supplementary material, Figure 5).
- The signature of the baseline scenario was discussed with the group via reference to which concepts were indicated to be increasing in prevalence relative to others.

6.2.3. Resilience analysis: identifying drivers of SES change

- During the course of the individual modelling and facilitated workshop phases of the study, participants identified changes in the social-ecological system 'state' and 'impacts' sections of the model as characterising the social and ecological integrity of the coast. These were key indicators of whether a given system state configuration was felt to be desirable or undesirable (i.e. if the 'coastal amenity: leisure/recreation' concept fell into decline livelihoods would be threatened).

- The trajectory of these concepts within the model was also broadly indicative of SES's resilience to climate change, as they play key roles in defining the breadth and depth of the current basin of attraction. For instance, if the concepts 'dune systems' or 'flood protection: storm surge/tidal/fluvial' are sufficiently robust as to maintain a positive trajectory in the face of climatic change, the stability landscape could be described as desirably resilient.
- As modelled by the group, a significant number of state and impact concepts (i.e. 'dune systems', 'wetlands', and 'sea level rise buffering') were found to be in decline. This was due in the main to the influence of drivers of tourism and residential expansion increasing pressures such as 'coastal squeeze' and 'coastal access points'.

6.2.4. Management/adaptation option evaluation

- Additional concepts were introduced to the model in order to simulate the behaviour of the SES under plausible future scenarios of climatic, economic and institutional change.
- The model's baseline outputs under two alternate future scenarios were calculated:
    1. a scenario of low-end climate impacts, low economic growth, and strong environmental institutions, and
    2. a scenario of high-end climate impacts, high economic growth, and weak environmental institutions.
- These baseline outputs were then compared to those of the current day SES, characterising changes in state space variables under alternate future conditions, and thereby illustrating the basin of attraction each scenario would likely trigger the SES to move toward (See supplementary material, Figure 6).
- At a second facilitated workshop, study participants were presented with the alternate basins of attraction illustrated by scenarios 1 and 2 and asked to discuss their implications, defining aspects of each that were perceived to be illustrative of undesirable SES states that participants would prefer to mitigate or avoid.
- Participants then devised new system concepts that could serve as adaptive interventions under each scenario, attempting to shift the SES into an alternate, shallower basin of attraction that would provide greater scope in future to respond with flexibility and agility to climatic, economic and institutional change (See supplementary material, Figures 55 - 58).
- This was achieved via targeting interventions toward the enhancement of ecosystem service concepts which had been identified as critical to SES

resilience. For instance, adaptation options implemented under scenario 1 sought to enhance natural capital by altering patterns of tourism, agriculture and energy generation to preserve and enhance coastal wetlands, dune systems and the ecological niches of native species. These environmental gains could in turn be harnessed in support of local commercial ventures, providing not only ecological but social and economic resilience in the face of change. In the deeper, more extreme basin of attraction represented by scenario 2, adaptation was configured around a policy of coastal retreat, building a greater capacity to absorb shocks while maintaining key SES structures and functions. This was to be achieved via alleviating pressure on dune systems and coastal wetlands through landward relocation of businesses and dwellings, effectively aiming to preserve the buffering capacity of the coast in its present form despite increasing exposure to adverse climatic impacts.

- The adaptive intervention concepts were added to the group model under their respective scenarios, with the baseline output of each then recalculated to gauge the efficacy of adaptation in shifting the SES toward a preferable equilibrium state.

6.2.5. Results

Study participants had earlier indicated the trajectory of 'state' and 'impact' sections of the model to be indicative of whether a given system configuration represented a desirable or undesirable outcome with respect to social-ecological system resilience. Assessing these particular regions of the model, adaptation interventions resulted in shifts in 20 of 23 state and impact concepts under both scenarios 1 and 2 (see Supplementary Material, table 23).

Under the more benign scenario 1, 12 state and impact concepts exhibited a strong post-adaptation improvement (52%), 5 exhibited a moderate improvement (22%), 1 a weak improvement (4%), 3 exhibited no change (13%), and 2 exhibited a weak deterioration (9%).

Under the more challenging scenario 2, 12 state and impact concepts exhibited a strong post-adaptation improvement (52%), 1 exhibited a moderate improvement (4%), 1 a weak improvement (4%), 3 exhibited no change (13%), 3 exhibited a weak deterioration (13%), and 3 exhibited a moderate deterioration (13%).

A rudimentary assessment of the trajectory of change triggered under each adaptation scenario would therefore suggest that the respective interventions performed broadly comparably, nudging a number of the key state and impact concepts indicative of social-ecological system resilience in a direction that study participants favoured. However, determining the extent to which these changes represent an alternate basin of attraction requires further examination, with the extent of shifts in concept values offer greater insight into the nature of any alteration in pre and post adaptation basins of attraction.

Prior to adaptation, the concepts 'dune systems', 'wetlands', 'river systems', 'ecological niches: native species', 'flood protection: storm surge/tidal/fluvial', 'sea level rise buffering', 'habitable land: secure coastal development', and 'integrated coastal development' all exhibit a strongly deteriorating trend under scenario 1 (Figure 53). The picture painted is one of steadily eroding ecological integrity resulting in reduced ecosystem service provision, in turn undermining the resilience of the Tralee Bay SES to absorb the shocks and pressures of climate change whilst maintaining its original structure and functions.

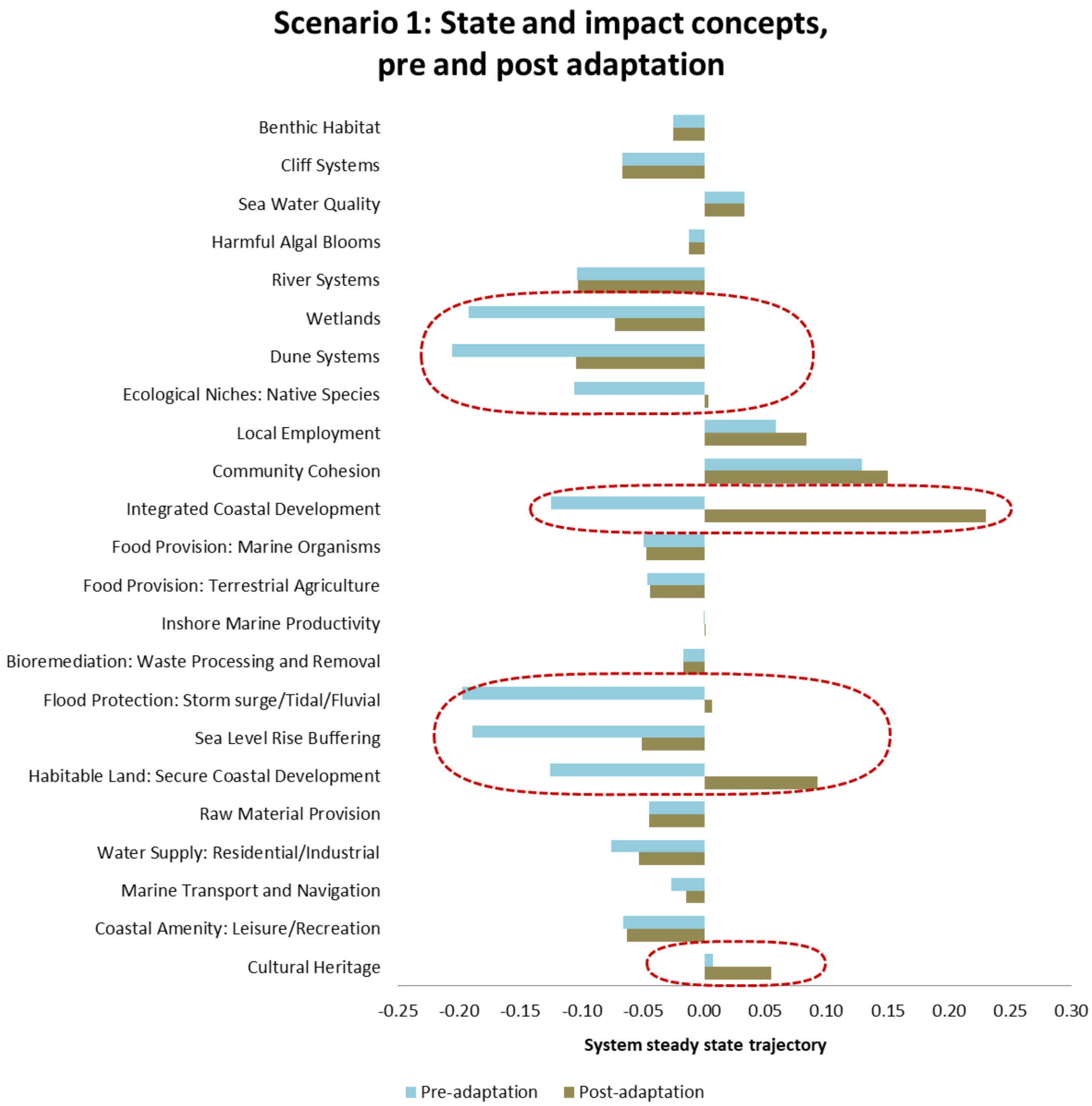

Figure 53: Pre and post adaptation state and impact concept expression under scenario 1. The four regions of the graph circled in red represent appreciable state-space change, although whether they should be seen as signalling a shift to an alternate basin of attraction is difficult to objectively determine.

Post-adaptation, an appreciably different picture emerges. Four key regions of the graph exhibit shifts in trajectory: the deterioration in wetlands, dune systems ecological niches has been arrested, and a reversal in trend is evident with respect to integrated coastal management, flood protection and habitable land.

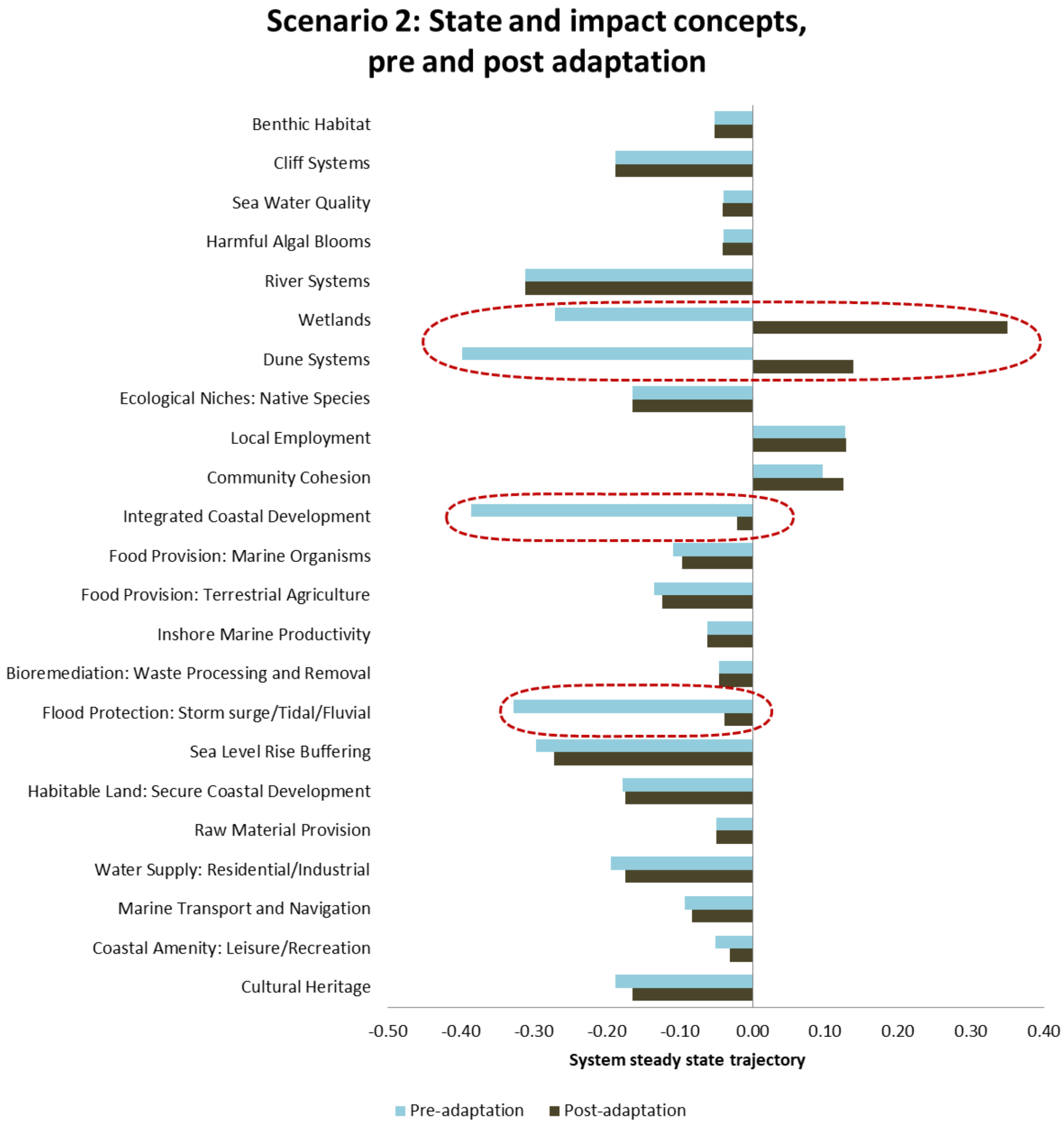

Figure 54: Pre and post adaptation state and impact concept expression under scenario 2. The three regions of the graph circled in red represent appreciable state-space change, which may be interpreted to signal a shallowing of the pre-adaptation basin of attraction.

As with scenario 1, scenario 2 exhibits a similar (though more severe) pattern of state and impact concept deterioration prior to adaptation (Figure 54). With adaptation in place, three areas of appreciable change in the system steady state graph are 'wetlands' and 'dune systems', 'integrated coastal development', and 'flood protection: storm surge/tidal/fluvial'.

6.2.6. Discussion

Despite having explored both the direction and scale of change each post-adaptation scenario represents, reaching a firm conclusion regarding whether or not either objectively represents a shift to an alternate basin of attraction remains problematic.

Under scenario 1 the argument may be somewhat stronger, given that the 'shape' of the state space indicated is unambiguously different, with flood protection, habitable land, and integrated coastal development all illustrating a step change in the equilibrium of the system. But given the continued (if albeit markedly reduced) decline in dune systems and wetlands, and other ecological aspects of the SES which remain on their pre-adaptation trajectory, any claim that the system would settle into an alternate basin of attraction and remain there is questionable.

Despite (or perhaps because of) making a less vigorous case for an equilibrium shift into a new basin of attraction, the post-adaptation system steady state exhibited under scenario 2 may be argued to provide a clearer picture of adaptation efficacy. The shifts evident in wetland and dune system health, integrated coastal development and flood protection could indicate positive steps on a longer journey of necessary change, perhaps akin to a shallowing of an undesirable basin of attraction, making escape from it at some point in the future a more attainable objective.

The interpretation of analyses of this nature is clearly highly subjective, leaving much to the views, experience and SES knowledge of those engaged in the exercise. As such, claims as to whether a system has made or is likely to make a transition to another, more desirable basin of attraction must remain unsubstantiated. While this presents obvious analytical barriers, in that reproducibility of results becomes at best problematic where subjective perception of systemic properties informs the analysis, it is also a useful property to employ in local-scale resilience assessment. The thought provoking challenges to status-quo conceptions of systemic behaviour involved, both in the present and under future scenarios of change, brings much greater depth and meaning to deliberations over the wisdom or otherwise of engaging in adaptive intervention.

It is also important to highlight that although there has been a dramatic increase in the use of FCM across multiple scientific fields (Papageorgiou and Salmeron 2013), even proponents of the method have begun to identify some analytical weaknesses in the approach. In fact, several of the methodological shortcomings that have recently been identified may present significant issues when attempting to model and analyse the complexity found in many SESs. For example, in their review Papageorgiou and Salmeron (2013) indicate that FCMs are limited in their ability to model time delays with regard to the interactions between nodes and are limited to defining linear relationships within a system. Additionally, they point out that FCM dynamics are of the first order; that is, the next system state depends on the previous one, and therefore the approach does not deal well with the randomness associated with many complex domains. Because SESs often, if not always, include nonlinear relationships, thresholds at which system states can change significantly are prone to surprises that are at times dramatic and, by definition, unexpected (Carpenter et al. 2002, Schwartz et al. 2011, Davidson et al. 2013) it is clear that FCMs are a useful "quick and dirty" and indeed "fuzzy" participatory approach that is most appropriate as a way to promote social learning and deliberation among diverse stakeholders and not as a formal assessment tool. The method would benefit from further development, including new analytical techniques, novel scenario algorithms that attempt to account for complexity, and additional empirical assessments that identify the social or ecological conditions that are more or less well suited for the use of FCM.

6.2.7. Future directions

A number of directions regarding FCM should be explored in the future. Given the extent to which FCM allows for different kinds of information to be integrated into the same model, the process described here can be used to gather multiple forms of evidence to validate perceived understanding through adaptive management. In the model-building process, not only do participants develop structural understanding of a complex system subjected to management, but through deliberation, they also discuss uncertainty. Such conversations can be used to suggest points for which further evidence is needed and can allow participants to determine what and how data can be collected to validate perceived dynamics empirically (Gray et al. 2014a). Shedding light on 'unknown unknowns' to shift them into the category of 'known unknowns' is also a key contribution here.

It is important to note that in participatory settings, FCMs are constructed based on perceived dynamics of a system; therefore, scenario analyses provide an understanding of perceived resilience measurements rather than empirical resilience measurements. However, individuals may use specific data collection protocols to validate not only the structural aspects of the model but also the model's predictions. Such interplay between the conjectured and the actual outcomes will allow for informed model refinement as well as provide a platform by which individuals can systematically test steps in the adaption process. In other words, as individuals ground-truth elements of their models, either by local measures or through available measures of greater spatial/temporal scope, they can test the underlying causal links between elements by running subsequent scenarios after new data/evidence forms are integrated.

Lastly, although comparisons between the preferred state, current steady state, and different scenario states provide useful benchmarks for discussion with stakeholders, determining conditions under which the system slips from one basin of attraction into another is by no means straightforward. Given the highly subjective nature of how the state space and preferred state are identified, whether the qualitative identity of a SES is maintained under scenarios is largely unclear and represents an area of research that would benefit from additional study. Based on the case study presented here, when the steady-state condition was compared with the climate impact scenarios, state and impact variables of greatest concern to participants with fell into relatively marked states of decline. This is an indication that the SES, given its current configuration, has a very limited capacity to absorb the impacts of climatic (and socioeconomic) change while maintaining the structure and functions preferred by participants. Yet to determine from this analysis at which point those structures and functions can be deemed to have failed to an extent sufficient to alter the system's identity is not yet possible. Similarly, the shifts in system steady state triggered by adaptive interventions were perhaps predictably effective, shoring up the areas of the model they specifically targeted, while leaving others relatively unaffected. Conclusions regarding whether change of this nature constitutes an alternate basin of attraction cannot be supported by this data alone. Accordingly, researchers engaged in participatory modelling, resilience analysis, and FCM might contribute further by beginning to develop new ways of measuring system identity. This may be accomplished by combining aspects of more qualitative approaches, i.e., narrative scenarios, with semi-quantitative approaches iteratively, drawing on unique aspects of each in the participatory process.

6.2.8. Conclusion

The FCM approach described here has facilitated a much greater degree of multi-stakeholder participation in coastal adaptation decision making than would otherwise have been feasible, and significantly broadened the range of factors which entered into stakeholder deliberation of climate impact and adaptation response. This highlights the potential of FCM to provide a participatory 'neutral space' where stakeholders can model the system of interest on an equal footing, and in so doing co-produce new knowledge and also serves to define the nature of further information required to resolve adaptation uncertainty.

It is perhaps this aspect of FCM processes that is of greatest value, given their relatively limited value as predictive artefacts capable of demonstrating a transition between notional basins of attraction. The case study demonstrated here has offered an indicative measure of how far a coastal system might shift from its current state given the effect of climate change and subsequent adaptation intervention. However, due to the subjectivity of the FCM process, and limitations on the extent to which non-linear dynamics and surprise might be accounted for, these indicative results highlight the scale of what remains unknown. Given these 'unknowns' are embedded within the mental models of key coastal adaptation decision makers, FCM's capacity to illustrate the limits of current understandings presents an invaluable opportunity to trigger further knowledge gathering. This contribution to resilience assessment may become increasingly valuable as sound coastal adaptation decision making becomes an ever more urgent priority.

6.2.9. References

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Supplementary material – Chapter 5

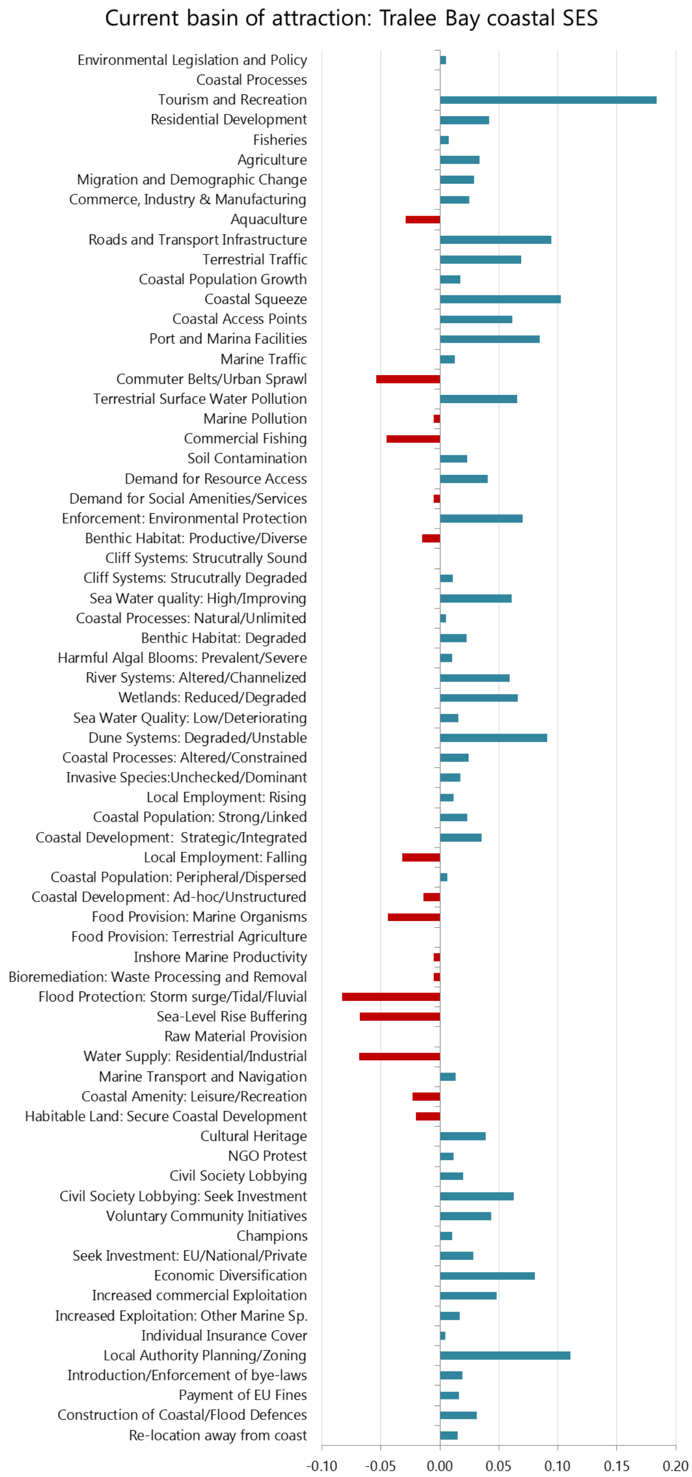

Figure 55: The basin of attraction of the Tralee Bay SES. Concepts in red are decreasing in prevalence relative to those in blue

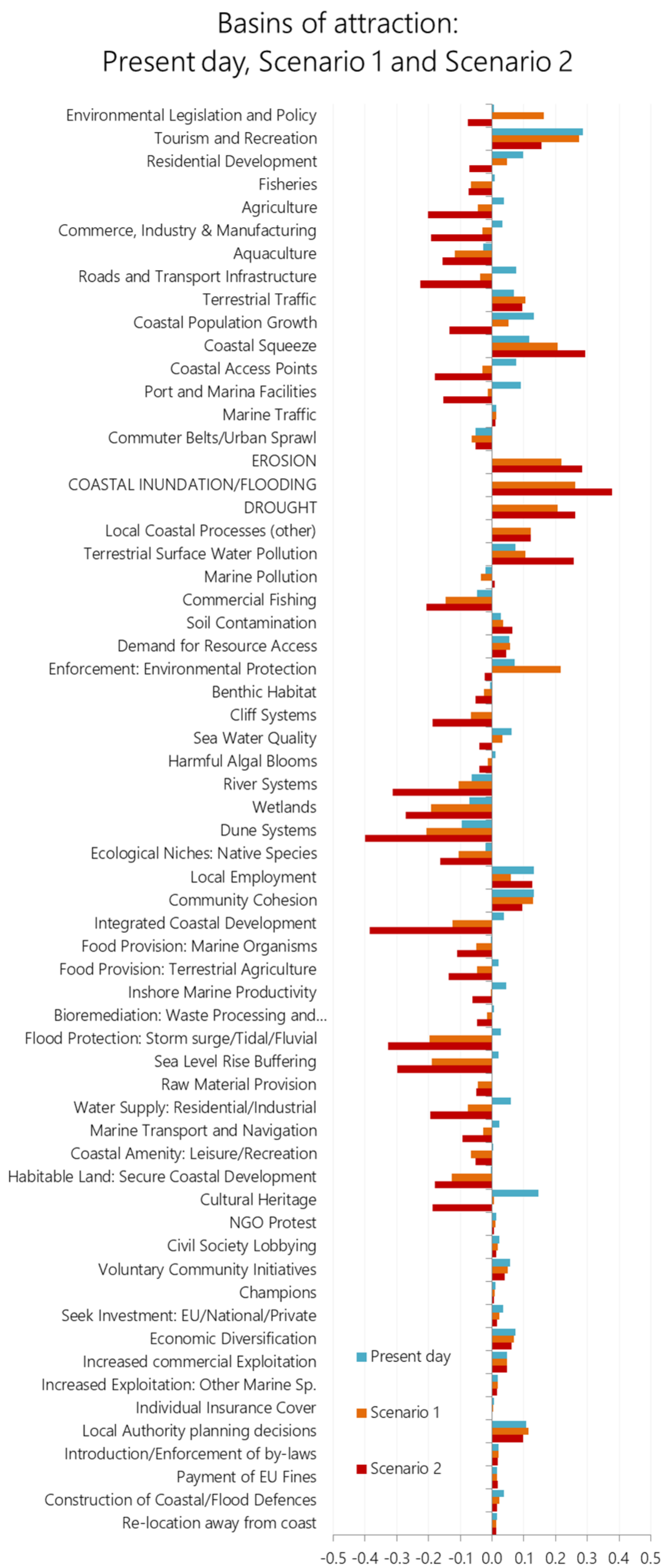

Figure 56: Different basins of attraction illustrating the implications of different system configurations

Adaptive Measures: Scenario 1

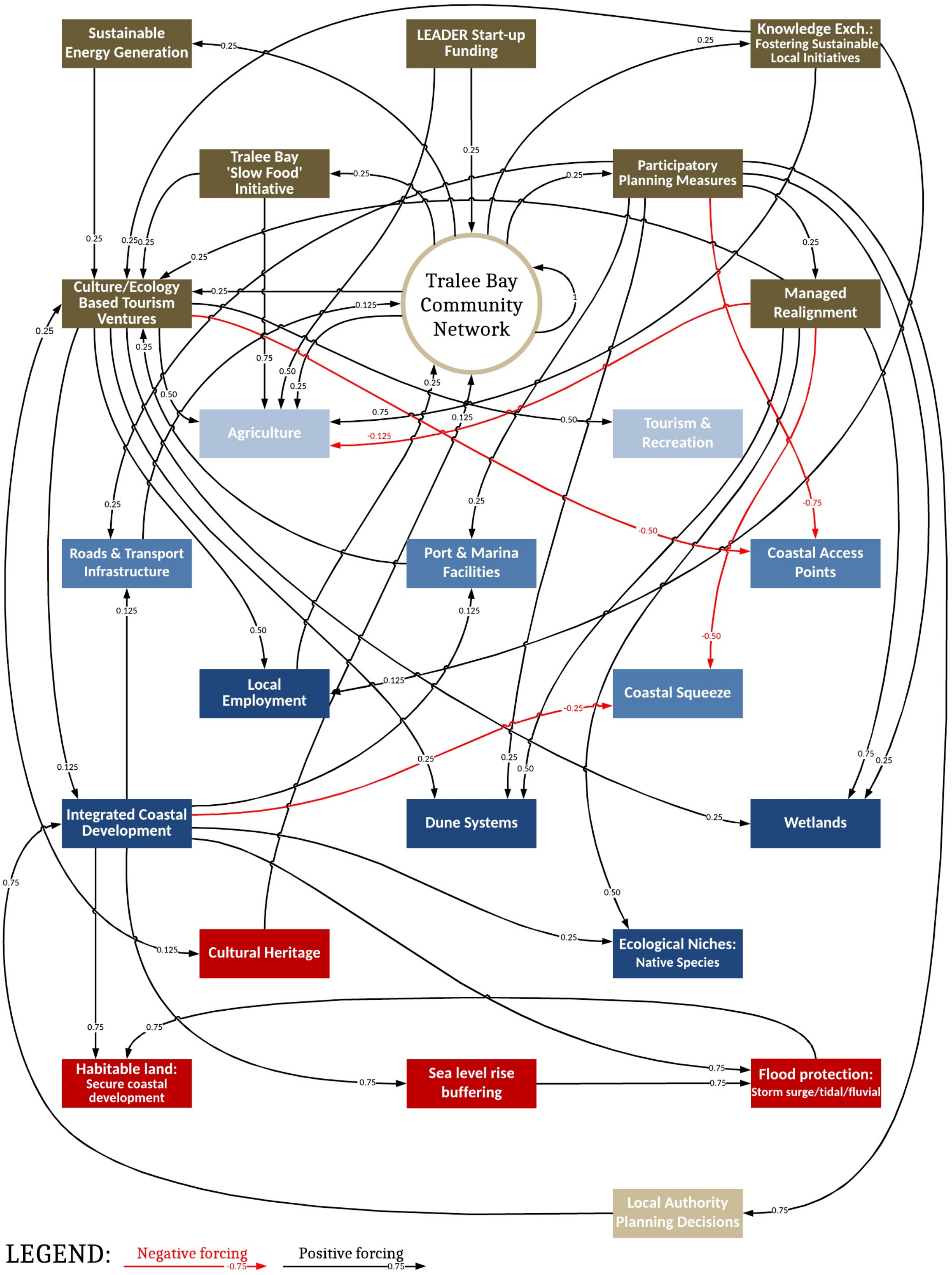

Figure 57: Adaptation options selected under scenario 1

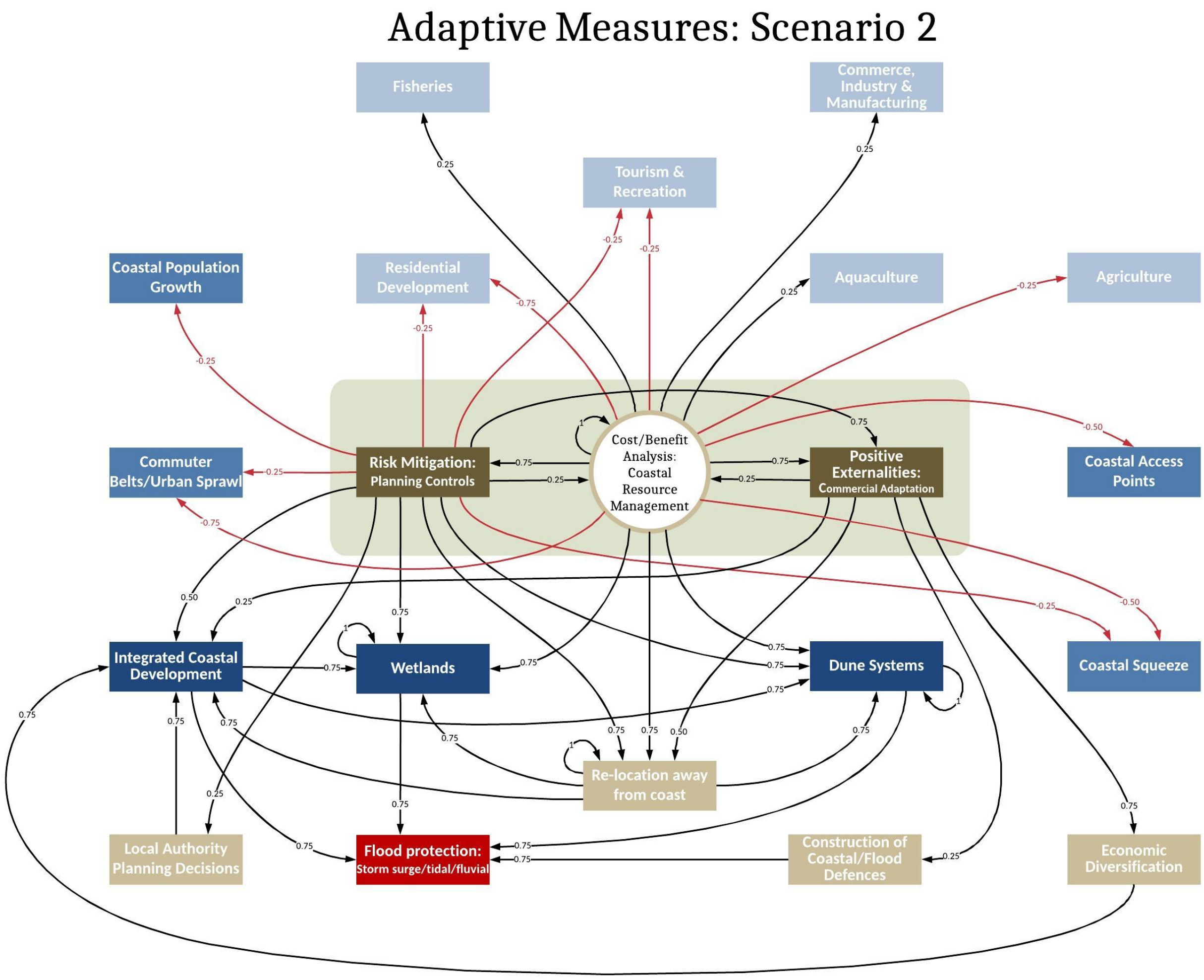

Figure 58: Adaptation options selected under scenario 2

	Scenario 1		Scenario 2		
	Pre-adaptation	Post-adaptation	Pre-adaptation	Post-adaptation	
LEADER start-up funding	0.00000	0.00000			
Sustainable energy generation	0.00000	0.04542			
Tralee Bay slow-food initiative	0.00000	0.04542			
Culture/ecology based tourism	0.00000	0.23109			
Participatory planning measures	0.00000	0.04542			
Managed realignment	0.00000	0.03404	0.00000	0.23872	Positive externalities: commercial adaptation
Knowledge exchange: local initiatives	0.00000	0.04542	0.00000	0.13684	Risk mitigation: planning controls
Tralee Bay community network	0.00000	0.22878	0.00000	0.24891	Cost/benefit analysis: coastal resource management
Environmental Legislation and Policy	0.16381	0.16382	-0.07650	-0.07650	Environmental Legislation and Policy
Tourism and Recreation	0.27316	0.28448	0.15615	0.11805	Tourism and Recreation
Residential Development	0.04763	0.07170	-0.07229	-0.18374	Residential Development
Fisheries	-0.06722	-0.06173	-0.07314	-0.02509	Fisheries
Agriculture	-0.04359	0.23590	-0.20206	-0.23835	Agriculture
Commerce, Industry & Manufacturing	-0.03111	0.00224	-0.19192	-0.15178	Commerce, Industry & Manufacturing
Aquaculture	-0.11592	-0.11381	-0.15531	-0.11183	Aquaculture
Roads and Transport Infrastructure	-0.03824	0.02270	-0.22672	-0.22553	Roads and Transport Infrastructure
Terrestrial Traffic	0.10520	0.10925	0.09572	0.08718	Terrestrial Traffic
Coastal Population Growth	0.05158	0.06957	-0.13326	-0.12661	Coastal Population Growth
Coastal Squeeze	0.20622	0.11835	0.29315	0.21796	Coastal Squeeze
Coastal Access Points	-0.02949	-0.12662	-0.18041	-0.18704	Coastal Access Points
Port and Marina Facilities	-0.01436	0.04679	-0.15304	-0.15369	Port and Marina Facilities
Marine Traffic	0.01294	0.01340	0.01004	0.01006	Marine Traffic
Commuter Belts/Urban Sprawl	-0.06411	-0.06799	-0.05266	-0.18700	Commuter Belts/Urban Sprawl
EROSION	0.21892	0.21892	0.28466	0.28466	EROSION
COASTAL INUNDATION/FLOODING	0.26161	0.26161	0.37815	0.37815	COASTAL INUNDATION/FLOODING
DROUGHT	0.20760	0.20760	0.26311	0.26311	DROUGHT
Local Coastal Processes (other)	0.12112	0.12112	0.12112	0.12112	Local Coastal Processes (other)
Terrestrial Surface Water Pollution	0.10514	0.12401	0.25862	0.25048	Terrestrial Surface Water Pollution
Marine Pollution	-0.03507	-0.03659	0.00797	0.00167	Marine Pollution
Commercial Fishing	-0.14518	-0.14500	-0.20763	-0.20317	Commercial Fishing
Soil Contamination	0.03423	0.04965	0.06319	0.05713	Soil Contamination
Demand for Resource Access	0.05589	0.02261	0.04395	0.04472	Demand for Resource Access
Enforcement: Environmental Protection	0.21561	0.21592	-0.02222	-0.02244	Enforcement: Environmental Protection
Benthic Habitat	-0.02555	-0.02521	-0.05195	-0.05200	Benthic Habitat
Cliff Systems	-0.06655	-0.06655	-0.18823	-0.18823	Cliff Systems
Sea Water Quality	0.03268	0.03261	-0.04009	-0.04040	Sea Water Quality
Harmful Algal Blooms	-0.01233	-0.01236	-0.04017	-0.04030	Harmful Algal Blooms
River Systems	-0.10389	-0.10284	-0.31196	-0.31200	River Systems
Wetlands	-0.19240	-0.07261	-0.27085	0.35030	Wetlands
Dune Systems	-0.20607	-0.10492	-0.39871	0.13884	Dune Systems
Ecological Niches: Native Species	-0.10591	0.00340	-0.16416	-0.16446	Ecological Niches: Native Species
Local Employment	0.05828	0.08351	0.12735	0.12824	Local Employment
Community Cohesion	0.12883	0.15013	0.09665	0.12476	Community Cohesion
Integrated Coastal Development	-0.12478	0.23032	-0.38578	-0.02114	Integrated Coastal Development
Food Provision: Marine Organisms	-0.04952	-0.04750	-0.10906	-0.09642	Food Provision: Marine Organisms
Food Provision: Terrestrial Agriculture	-0.04648	-0.04400	-0.13524	-0.12317	Food Provision: Terrestrial Agriculture
Inshore Marine Productivity	-0.00075	0.00040	-0.06220	-0.06222	Inshore Marine Productivity
Bioremediation: Waste Processing and Removal	-0.01669	-0.01669	-0.04611	-0.04611	Bioremediation: Waste Processing and Removal
Flood Protection: Storm surge/Tidal/Fluvial	-0.19790	0.00612	-0.32778	-0.03889	Flood Protection: Storm surge/Tidal/Fluvial
Sea Level Rise Buffering	-0.18914	-0.05101	-0.29723	-0.27189	Sea Level Rise Buffering
Raw Material Provision	-0.04481	-0.04481	-0.04888	-0.04888	Raw Material Provision
Water Supply: Residential/Industrial	-0.07577	-0.05350	-0.19401	-0.17382	Water Supply: Residential/Industrial
Marine Transport and Navigation	-0.02688	-0.01459	-0.09260	-0.08239	Marine Transport and Navigation
Coastal Amenity: Leisure/Recreation	-0.06626	-0.06289	-0.05110	-0.03085	Coastal Amenity: Leisure/Recreation
Habitable Land: Secure Coastal Development	-0.12562	0.09276	-0.17872	-0.17442	Habitable Land: Secure Coastal Development
Cultural Heritage	0.00722	0.05466	-0.18831	-0.16459	Cultural Heritage
NGO Protest	0.01009	0.01122	0.00609	0.00635	NGO Protest
Civil Society Lobbying	0.01863	0.01962	0.01429	0.01517	Civil Society Lobbying
Voluntary Community Initiatives	0.05003	0.05269	0.03942	0.04153	Voluntary Community Initiatives
Champions	0.00918	0.01195	0.00659	0.00688	Champions
Seek Investment: EU/National/Private	0.02364	0.03076	0.01649	0.02616	Seek Investment: EU/National/Private
Economic Diversification	0.06968	0.07589	0.06214	0.06628	Economic Diversification
Increased commercial Exploitation	0.04726	0.05386	0.04659	0.05041	Increased commercial Exploitation
Increased Exploitation: Other Marine Sp.	0.01736	0.01633	0.01699	0.01702	Increased Exploitation: Other Marine Sp.
Individual Insurance Cover	0.00315	0.00527	0.00179	0.00480	Individual Insurance Cover
Local Authority planning decisions	0.11389	0.21939	0.09799	0.15299	Local Authority planning decisions
Introduction/Enforcement of by-laws	0.02061	0.02088	0.01834	0.01776	Introduction/Enforcement of by-laws
Payment of EU Fines	0.01669	0.01717	0.01759	0.01740	Payment of EU Fines
Construction of Coastal/Flood Defences	0.02338	0.03612	0.01544	0.22257	Construction of Coastal/Flood Defences
Re-location away from coast	0.01355	0.01366	0.01402	0.41551	Re-location away from coast

Outcome of adaptive interventions for state and impact concepts:

Improvement		Deterioration	
Strong			Strong
Moderate			Moderate
Weak			Weak
No change			No change

Table 23: Results of adaptive interventions modelled under scenarios 1 and 2. State concepts are highlighted in blue, impact concepts in red.

Modelling Approach/ Tool	Ease of use with s/holders	Model input collected from s/holders	Model outputs presented to s/holders	Spatial or Temporal	Strengths in participatory SES resilience analysis?	Weaknesses in participatory SES resilience analysis?
Narrative scenario analysis	High	Focus group discussions; envisioning future states under parameterized conditions; system components defined	Alternative system states, usually qualitatively defined	Temporal	Stakeholder driven, less constrained and highly flexible given stakeholder priorities	Scenario outputs are often constrained to the contexts where data are collected. Qualitative output often must be translated into quantitative or semi-quantitative format for additionally model coupling
Qualitative Concept-mapping	High	Concepts/system components and associations/relationships between components defined	System structure, static qualities and characteristics of the system	Neither	Provides representation of a problem space and the associations and characteristics of the problem space	Static and therefore not suitable for scenario analysis or evaluation of dynamic or emergent properties
Fuzzy cognitive maps	Medium to High	Concepts/system components, structural relationships between concepts or components; sign and strength of causal influence between concepts	System structure and system states, sensitivity for changes in system structure	Neither	Allows for feedbacks; system components and relationships easily added or removed. Often intuitive since based on concept mapping; problem-structuring with stakeholders	Model outputs not linked to discrete values; nonlinear relationships difficult include; determining consensus on components and relationships takes time
Bayesian belief networks	Medium to High	System components; unidirectional relationships between components defined based on probability estimates	Probabilistic or conditional system states	Neither	Often intuitive since based on concept mapping. Real-world probabilities can be assessed for model validity; deals with uncertainty	No feedbacks included; determining consensus on components and probabilities may take time

Agent-based models	Low	Types of agents, rules of behaviours for agents; initial state conditions, validation of the model	Aggregate-level system behaviour, system states	Both	Allows for feedbacks; model parameters easily changed. Discrete units that reflect real-world values can be modelled; handles non-linearity	Agent types not easily changed; not flexible in participatory setting since models are usually constructed before stakeholder workshops

Table 24: Comparison of participatory modelling methods and their utility in participatory resilience assessment

Part VI: SYNTHESIS AND CONCLUSIONS

7.1. SYNTHESIS

Recap: the overarching coastal adaptation problem

Climate change threatens the viability of life on the coast, yet identifiable instances of pre-emptive adaptation remain relatively rare. The reasons why this is the case include the predominance of what are now well-known obstacles to adaptation, including:

- Coastal decision making is complex and frequently dysfunctional
- Challenges of scale lead to a cascade of uncertainty
- Embarking on a journey of transformational change is unpalatable to coastal stakeholders

To resolve this problematic impass, supranational and national scale policymakers have called for action–research to fill knowledge gaps, specifically:

1. How to support good decision making at the local scale?
2. How to tailor information for adaptation decision contexts?
3. How to move beyond reactive, incrementalism into a more meaningful phase of transformational adaptation?

Prior to this research programme getting underway, a nascent orthodoxy had begun to emerge with regard to how these problems should be tackled. Adaptation barriers were beginning to be described and studied in more depth, and participatory modelling methods were growing in number and range of applications, drawing predominantly on the resilience literature of complex adaptive systems in describing the nature of adaptation problems. A central component of this nascent orthodoxy was the role of scenario analysis in fostering strategic responses to climate adaptation problems.

7.1.1. Objectives of Paper 1

The primary aim of the first paper of the thesis was to assess a scenario analysis-based approach to coastal adaptation for its potential to overcome the barriers to adaptation which prevent progress being made in enhancing the resilience of coastal communities. This aim was achieved through:

- Setting out (via reference to the literature) scenario analysis' credentials in respect to facilitating decision making in data scarce/uncertain contexts
- Describing a scenario analysis-based method of facilitating coastal climate adaptation
- Describing the use of the method via reference to a case study in Cork Harbour, Ireland
- Using a framework of adaptation barriers derived from the literature to determine how well the claimed strengths of scenario analysis perform in supporting a stakeholder driven coastal adaptation process
- Identifying where scenario analysis specifically works well and/or falls short as a decision support tool

- Gaining greater insight into the specific characteristics a futures/uncertainty oriented decision support method will require to in order to succeed

7.1.2. Findings of Paper 1

The main findings of the paper were that scenario analysis performs reasonably well in overcoming early stage barriers. However, many of its claimed strengths proved difficult to capitalise on in real-world stakeholder settings. A key issue that scenario analysis could do little to resolve occurs when an adaptation process moves into phases of identifying and assessing adaptation options. Casual stakeholder buy-in (such as that engendered by most intuitive-logic scenario processes) will not suffice, and suspension of disbelief in the futures the scenarios describe can collapse. Where this occurs, there is typically no second chance: the approach to adaptation cycle stages 1 – 3 is therefore critical to the success of the adaptation process as a whole.

This realisation led to the conclusion that the difficulty in connecting an intuitive logic scenario with stakeholders' internal mental models of how coastal systems work and what the future may look like can result in stakeholders disengaging before any substantive adaptation commitments are made. It is therefore crucially important to find alternate options for connecting local decision makers with broad scale, uncertain drivers like climate change if adaptation is to advance locally and coastal resilience is to be meaningfully enhanced in the face of increasing climatic risk.

Having undertaken a significant review of the options available to undertake such a task (see Gray, Paolisso, Jordan and Gray (2017) for a wide ranging review of approaches to environmental modelling with stakeholders), FCM was selected as the most appropriate candidate for connecting with coastal stakeholders in a more profound and long lasting way, particularly in the kind of data-poor, resource constrained contexts within which coastal adaptation must typically be carried out.

7.1.3. Objectives of Paper 2

Paper 2 of the thesis presented an overview of the strengths and weaknesses of FCM in stakeholder driven decision contexts such as those attending coastal adaptation. The paper sought to review the FCM literature and establish a baseline understanding of:

- How FCM can be appropriated to achieve various aims
- Why building FCMs with mixed, non-traditional expert groups can be valuable
- What the metrics of FCM might infer in complex adaptive systems analysis contexts
- What inferences might (and might not) be drawn from 'group models'
- What the strengths and weaknesses of the various ways to facilitate FCM development are

7.1.4. Findings of paper 2

The paper found that there are clear strengths of FCM at either ends of a 'knowledge capture' and 'stakeholder learning' use case spectrum, and despite their different aims, these can inform and support each other well. However, as with all participatory modelling techniques in general, but perhaps FCM in particular, facilitation is a critical determinant of outcomes. An individual stakeholder's FCM will all too easily be skewed unless careful consideration is given to how nodes and edge relationships are elicited from participants, and how individual models are brought together to form a group model reflective of the group's shared position on a given issue. The risk of bias can nevertheless be minimised through careful planning and (unfortunately time consuming) preparation and validation.

When arrived at with the requisite rigour and impartiality, the metrics of FCM provide very useful points of inference about not only the system under study, but also the needs of the individuals involved in the process in terms of additional capacity-building resources and information. These are useful in diagnosing where the emerging insights of the Climate Adaptation Services literature can be brought to bear in moving stakeholders from unstructured problem dialogues and discourses to highly participatory adaptive governance (Hurlbert and Gupta, 2015). It could be argued that FCM offers unique insights in this respect, as other approaches lack the direct insights into stakeholder perception and framing that FCM does.

7.1.5. Objectives of paper 3

The primary objective of Paper 3 was to describe a method for coastal climate change adaptation which departed from intuitive-logic scenario orthodoxy to have instead at its core an FCM-based approach to participatory adaptation. The paper then set about assessing the FCM-based approach by:

- Setting out (via reference to the literature) FCM's credentials in respect to facilitating decision making in data scarce/uncertain contexts
- Describing in detail the FCM-based method of facilitating coastal climate adaptation
- Describing the use of the method via reference to a case study in Tralee Bay, Ireland
- Using the barrier framework developed in paper 1 to assess the FCM-based method's capacity to overcome adaptation barriers
- Highlighting FCM's utility, potential for facilitating knowledge integration, and any other potential strengths or weaknesses of the approach that might warrant further inquiry

7.1.6. Findings of paper 3

The primary finding of paper 3 is that an FCM-based coastal adaptation process offers greater potential to overcome adaptation barriers (at all stages of the adaptation cycle) than does a scenario analysis-based adaptation process. Looking across the adaptation barrier framework as mapped against the claimed strengths of FCM (Figure 24 of paper 3, reproduced below), there are points of connection between the method and adaptation barriers throughout the understanding and planning phases of the adaptation cycle.

	Barriers encountered in adaptation cycle stages 1 – 3: understanding and planning								
	1. Assessing risks and vulnerabilities			2. Identifying adaptation options			3. Assessing options		
Claimed attributes of FCM	Understanding the system	Detecting the problem	Gathering and using information	Re-defining the problem	Core adaptation assumptions	Identifying local adaptation stewards	Identifying adaptation options	Assessing options	Selecting option(s) to implement
Copes with complexity	2,4,7	2,4	4,5,7	4,5,7	7	1,4,7	7	7	7
Identifies, makes explicit contrasting system views	4	4,7	4,7	4,7	5,7	1	5,7	7	7
Integrates knowledge across domains and scales	2,4,7	5,7	4,5,7	4,5,7	5,7	5,7	7	7	7
Generates new insights	4,7	4,7	4,7	4,5,7	4,5,7	4,7	5,7	7	7
Facilitates social learning	4,7	4,7	4,7	4,7	5,7	4,7	7	7	7
Builds a shared conception of the system	4	4,7	4,7	4,5,7	4,5,7	4,7	5,7	7	7
Bridges gaps between science and decision making	4 ,7	7	7	5,7	5,7	5,7	5,7	7	7

Figure 59: Locating stages of the FCM-based adaptation process within the matrix of claimed benefits of FCM and known barriers to adaptation at the local scale.

The findings of case study experimentation supported this estimation of contribution value, with stakeholders coming to similar conclusions in post-process discussions and reflections on its strengths and weaknesses. Although this finding is perhaps unsurprising given the 'tailor-made' differences between the two methods, with the FCM-based method having been designed with the shortcomings of scenario-based adaptation in mind, there is nevertheless considerable value in learning from the specific gains of the FCM-based approach in connecting with coastal adaptation stakeholders and bringing adaptation to them, rather than having them come to adaptation.

This key difference offers an insight which the adaptation services practitioners can benefit from in designing interventions where co-creation of knowledge is an explicit aim – as is frequently the case. The adaptation services community has acknowledged that connecting information on anticipated climatic and socioeconomic change at national and regional scale with the immediate decision-processes of stakeholders at the local scale has proven problematic over the years, with the disjuncture in prioritisation between longer term and to some extent purely conceptual concerns of climate change coming a distant second to the immediate pressure exerted by the need to provide homes, jobs and cultural points of connection for the stakeholders of today. I would argue that during the course of this research it became clear that simply ‘turning up the volume’ on climate impacts – whether via visualisation, statistics or descriptive projections – is perhaps necessary but insufficient if altering the priorities of stakeholders in any meaningful way is our aim. Simply increasing the level of climate information alone cannot be expected to change the need for coastal decision makers to respond to the demands of their key stakeholders in the present.

Perhaps a more defensible proposition is that incorporating climate drivers into the mental models of decision makers in the ways described in paper 3 will allow the signals of climate change to incrementally become central to the thinking of coastal decision makers (and their stakeholders) as decisions are taken over time, and the FCM-based tool for communicating them becomes more commonplace in stakeholder deliberation. Reinforcing the ‘shouts’ of visualisations of catastrophic futures with the ‘whispers’ of constant low levels of change as illustrated by climate drivers in FCM contexts may achieve more than shouting alone can. It would be useful to conduct more research in this field to establish the optimum role and balance between these approaches.

Nevertheless, no adaptation support method comes without significant drawbacks. For FCM, the overhead of using the method is much greater, requiring the investment of time and development of specific capacities that might potentially undermine its added utility in real world settings unless it is supported at a level beyond the local. It also cannot provide the unexpected ‘shout’ of surprise alluded to above. FCM is a linear and deterministic tool, reflecting whatever is initially encoded into its opening matrix as the pool from which all futures must emerge. This can be (and has been) circumvented to provide simulated surprise – either via linkage to random number generation at specific points in an FCM iteration cycle or creating timed intervention points at which pre-programmed ‘surprises’ can be introduced through the clamping of different parts of the matrix than the initial scenario envisaged. These are nevertheless rather clunky workarounds for the inherent limitations of FCM and cannot truly compensate for them.

Further research into how best to exploit the strengths of FCM and compensate for its limitations would be valuable, given the considerable benefits it offers in overcoming early stage adaptation barriers and moving stakeholders forward in an adaptation process to tackle more difficult decisions than might otherwise have been possible.

7.1.7. Objectives of paper 4

The main objective of paper 4 was to assess the utility of FCM in diagnosing the problems caused by specific adaptation barriers. This was achieved by:

- Describing the analytical metrics and measures available via FCM
- Illustrating how these might be used to gain important insights into the problem framing of coastal adaptation decision makers
- Describing the use of the method via reference to case studies in Tralee Bay, Ireland, and the Outer Hebrides, Scotland
- Analysing the differences between stakeholders in key barriers encountered during the ‘understanding’ phase of an adaptation process

- Highlighting the implications of any differences in signal detection, problem framing, etc between central and local scale agents of adaptation action

7.1.8. Findings of paper 4

It became very clear during the course of the research underpinning this paper that local scale adaptation decision makers develop a mental model of the coastal system quite different to that of national scale specialists. The key influences in how local scale decision makers create a coastal systems model are temporally, spatially and socioeconomically immediate. They do not have the luxury of conceptual distance from the subject of coastal vulnerability – it is rooted in the people and places they must interact with on a daily basis, and is therefore (in my view appropriately) subjectively skewed toward the parochial needs of the community. The point at which these needs intersect with the challenges raised by global environmental change is important to understand, and perhaps worthy of future research.

Local modellers saw fewer connections between biophysical ecosystem services and climate resilience than national scale modellers did, but nevertheless prized the habitats providing them very highly – often for reasons related to tourism, amenity and culture, noting their crucial role in other aspects of the socio-economic life of the area.

They also saw less evidence of a signal of long term environmental change influencing the coastal system, and advocated management decisions reflecting a temporal prioritisation of (anticipated) immediate cause and effect over longer term patterns of change. For example, a mooted adaptation measure in Scotland with dune protection measures comprised of car tyre stacks was not immediately rejected on the grounds of its impermanence and ecological harm. Instead the more immediate and obvious attempt to intervene in dune retreat and mollify concerned local stakeholders was seen as valuable (although ultimately did not go ahead).

Insights from the local scale are nevertheless much more nuanced and context specific than the generalisable scientific perspective of the national scale. The potential to be somewhat rail-roaded into potentially counterproductive or ineffective adaptation choices aside, the important connection local scale decision makers have with the needs of coastal communities is valuable and useful to harness.

Bridging between these views is necessary in order to see pre-emptive and locally legitimate adaptation action become more commonplace. If national science providers and policy makers can find the appropriate mechanisms to connect with decision makers at the local scale the quality of adaptation initiatives undertaken will only improve. This is where methods such as FCM, or a similarly participatory mental modelling technique, must be employed to achieve substantive breakthroughs in understanding and prioritisation. Information provision alone will not suffice.

7.1.9. Objectives of paper 5

The primary objective of paper 5 was to assess whether progress toward (or away from) desired social-ecological system resilience attributes can be measured using FCM, by:

- Describing a method of participatory resilience analysis using FCM

- Establishing the FCM baseline scenario as a corollary of the resilience theory ‘basin of attraction’
- Illustrating the role of variable ‘clamping’ and/or the addition of new concepts to create alternate scenarios, potentially indicating a transition to an alternate basin of attraction
- Assessing the extent to which the method might be employed in resilience assessment via reference to a case study in Tralee Bay, Ireland.

7.1.10. Findings of paper 5

Attributes of systems modelled by climate adaptation stakeholders make a compelling case as illustrative of a notional ‘basin of attraction’ within a conceptual resilience landscape. Some of these attributes have a degree of universality – spanning different social-ecological system types in their application (ecosystem services such as food provision, habitable land, and bioremediation). Others are highly coastally specific (sea level rise buffering, coastal amenity and marine navigation). Using them to differentiate whether a system is moving toward or away from a desired equilibrium (or long term persistent steady state) makes sense from first principles. How else are we to judge our environmental interventions unless against the extent to which they preserve or enhance the attributes of our social-ecological systems that we value most highly?

Moving this first principle analysis into the world of adaptation evaluation is a similarly intuitive step. FCM provides useful measures of these attributes, arrived at via the mental models of expert stakeholders. Although of course, not objectively parameterised measures, these nevertheless provide a shorthand via which decision makers can convey their views of the systems they are attempting to manage. This allows the influence of climate change impacts and adaptation efforts to be estimated in an engaging way by altering the structure and/or composition of an FCM, which in turn provides different baseline scenario signatures.

These signatures might be argued to reflect a change in the position of the system in relation to it basin of attraction. This becomes an increasingly tenuous claim to make given the entirely subjective nature of the system model, and perhaps just as damningly, the inability of the modelling technique to truly represent non-linear dynamics, or indeed any form of surprise, in its handling of system behaviour. Whatever is inbuilt in the initial conditions of the system must play out, unless artificially manipulated to do otherwise.

Despite serving to negate the validity of using FCM as a de-facto determinant of resilience, in the sense of where the system sits in a notional basin of attraction, the approach can offer useful insights into what decision makers *think* they are doing when they intervene in a complex social-ecological system such as a coastal zone. By stripping out the complex non-linear dynamics and capacity for surprise, an FCM can offer a reasonably informative ‘ceteris paribus’ tool for sense-checking adaptive interventions. Although this falls some way short of a much-hoped for metric for determining resilience, it is nevertheless a valuable contribution to the field of adaptation and warrants continued attention.

7.2. SUMMARY AND FUTURE RESEARCH NEEDS

This research has found that FCM offers a significant improvement on existing scenario-based approaches to adaptation, without fully achieving the kinds of breakthroughs in stakeholder perception and resilience enhancement that it initially promised.

These limitations are due to the method's inability to model dynamic, non-linear relationships between variables, and it's inability to work well with existing datasets to bridge gaps between the known and unknown. This does not denigrate from its capacity to overcome adaptation barriers (particularly at the earlier stages of an adaptation process) where stakeholders are struggling to communicate their understanding of the coastal system to each other, discuss the problems they believe it faces, gather information about how to overcome those problems, and make assumptions about how they want to adapt.

These barriers are now well established as critical issues to resolve, and any decision support approach which can help to do so is hugely valuable. It need not be perfect to be useful, as evidenced in both Tralee Bay and the Outer Hebrides, where a number of otherwise difficult obstacles to progress were overcome with relative ease due to the type of conversations and exchanges of knowledge which the FCM methodology made possible. It was clear that scenario analysis alone most certainly did not have the same effect in Cork Harbour, or in any of the other 8 case study locations where it was employed under the IMCORE project.

This is an important factor to bear in mind when evaluating the performance of FCM as a means of facilitating good adaptation decision making – other methods which perform less capably ultimately create additional barriers by causing stakeholders to dis-engage with the process. Arguably the greatest virtue of FCM was its engaging 'fuzziness' which kept a broad range of people, who were experts in different fields, with different forms of data at their disposal and often widely diverging views, actively and good-naturedly engaged around a table and discussing adaptation. Anyone who has spent any time in mixed stakeholder settings where contentious decisions must be arrived at will attest to the value of that particular attribute of the method. The tongue in cheek 'Caught by the fuzz' title of paper three in this thesis referred to this characteristic, in keeping stakeholders in the room, in the conversation, and not staring distractedly at phones or making their excuses to exit early.

More work can be done with FCM to make it fit for adaptation purposes, and the fact that progress in that direction has stalled somewhat in recent years is concerning. Developing FCMs that can serve as useful 'off-the-shelf' backbone supports for adaptation projects at sub-national scales should not be an onerous task, and would add much needed rigour and validity to stakeholder-based studies in regions where scientific support is frequently patchy. The ongoing doubt with which systems modelling approaches appear to be viewed by funding bodies and policy makers appears at odds with the enthusiasm of the research community, and increasingly, the approaches being taken up by the more progressive branches of systems-based sustainability analyses supported by organisations such as FutureFit,[12] or recent adaptation guidance promulgated by the International Standards Organisation such as ISO14090.

[12] https://futurefitbusiness.org/

These sources indicate an increasing interest in modelling complex systems to allow us to conceive of them as holistic, integrated and interdependent across scales. While FCM can do little to illustrate to us the consequences of connections we cannot account for or understand, it can nevertheless make starkly clear where the limitations of our understanding lie, and in so doing, forces us to question the certainty with which we believe our chosen interventions will achieve the ends we seek.

This is no mean feat. We all operate to long established heuristic rules and mental models which make the incorporation of long-term, conceptual drivers beyond our immediate day to day experiences almost impossible to account for. This is particularly so when we envision their prioritisation as needing to not only equal but surpass the drive to live in, earn a livelihood from and draw a cultural identity from our vulnerable coastal fringe.

It is clear that no decision support framework or tool can necessarily provide profound insight or the generation of new understandings on its own. Yet FCM stands out as perhaps offering greater potential to do so than comparable alternatives, intersecting as it does with the very mental model structures and heuristics which have served us so well in evolutionary terms but now hinder our acceptance of the need to acknowledge our contribution and vulnerability to global environmental change. It is with this particular strength in mind that the future use and development of FCM should be pursued.

There must therefore be further effort invested in determining what can and cannot work, and to what extent, before the adaptation community leaves FCM behind in describing and promulgating best practice. There is no doubt that support for the development of complex and potentially burdensome approaches such as FCM needs to be provided at national or regional scale, rather than left to vagaries of resourcing at the local scale. Determining with greater accuracy just how locally specific a coastal systems model built using FCM needs to be in order to support local scale adaptation would be an important step forward.

Similarly, determining which metrics must be focussed on in order to meaningfully assess progress toward (or indeed away from) a desired system steady state underpinning transition would be of enormous benefit to coastal communities faced with an increasingly unpalatable range of decisions, and a narrowing window of time in which to make them. Achieving a mainstream acceptance of the need for SES resilience assessment, and further breakthroughs in the potential to measure states of transition, may be essential factors if limited resources are to be harnessed in support of maximum adaptation efficacy.

Much of the SES analysis work described in this thesis underpinned the development of the Local Authority Adaptation Strategy Development Guidelines (and its supporting vulnerability analysis tools) included as supplementary material in this thesis. However, in the absence of resources being made available at regional or national scale to support capacity development at local scale, a more orthodox approach is described within it. The guidelines nevertheless begin to pave the way for SES analysis of the mode described here, introducing elements of fuzzy logic characterisation of relationships between climate impacts and local authority service provision.

SUPPLEMENTARY MATERIAL

https://www.epa.ie/pubs/reports/research/climate/researchreport164.html