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

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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. 1). 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

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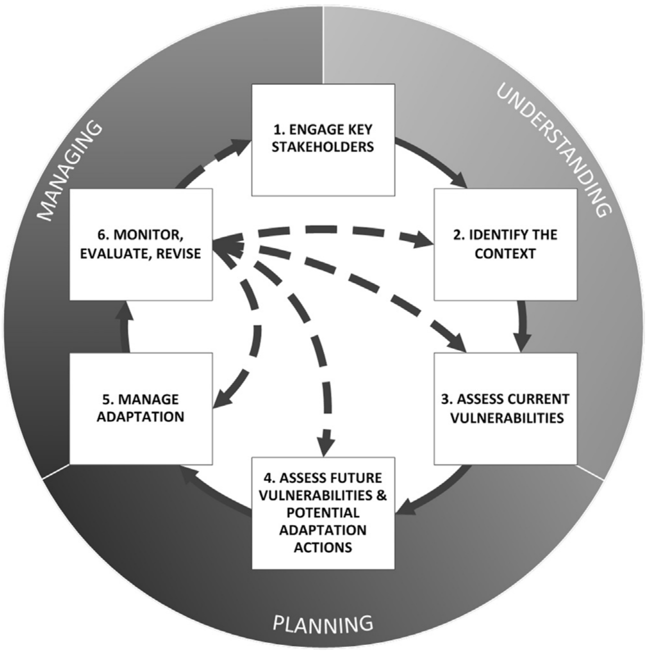

Fig. 1. An idealised adaptation process comprised of six steps over three phases. Adapted from Moser and Ekstrom, 2010; Wilby and Dessai, 2010.

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.

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 under utilized 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).

1.3.1. *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. 2). 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

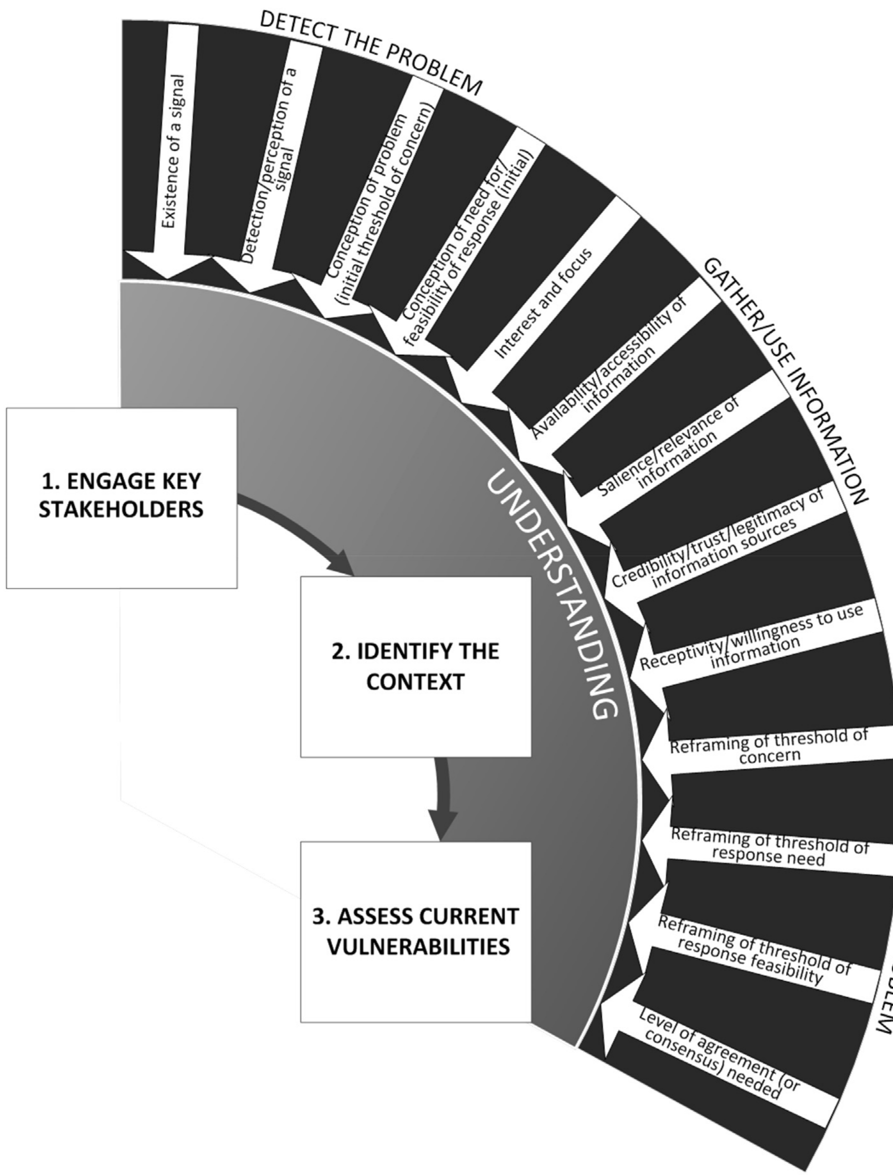

Fig. 2. Common barriers (arrows in the black arc) encountered during the understanding phase of a climate adaptation process (Moser and Ekstrom, 2010).

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.

1.3.2. 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).

1.3.3. 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. 1). 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 (Fig. 3).

2.2. Case study sites

The case study material supporting this research was collected at two sites: Tralee Bay in the Republic of Ireland (Fig. 4), and the Outer Hebrides, an island chain to the west of Scotland (Fig. 5).

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 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 (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 °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.

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).

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

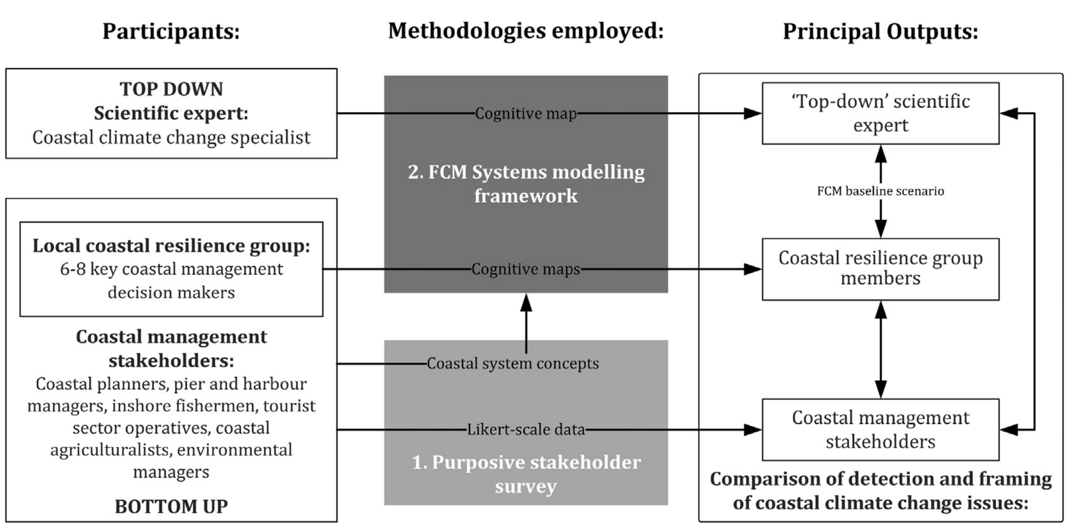

Fig. 3. Schematic of the role and relationships of research participants, methodologies, and outputs.

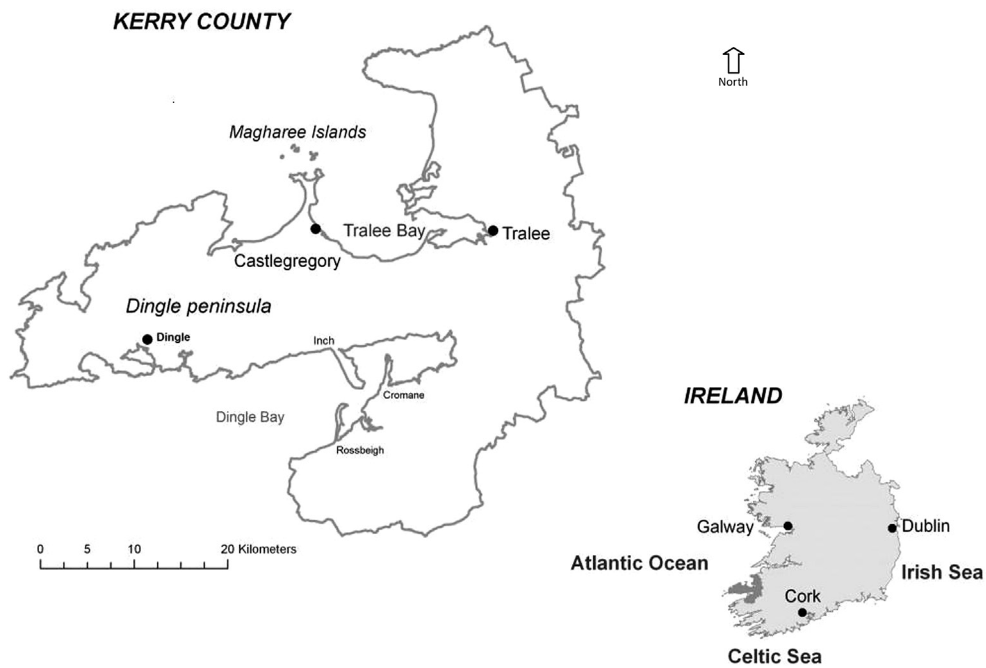

Fig. 4. The Tralee Bay case study site (CoastAdapt).

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).

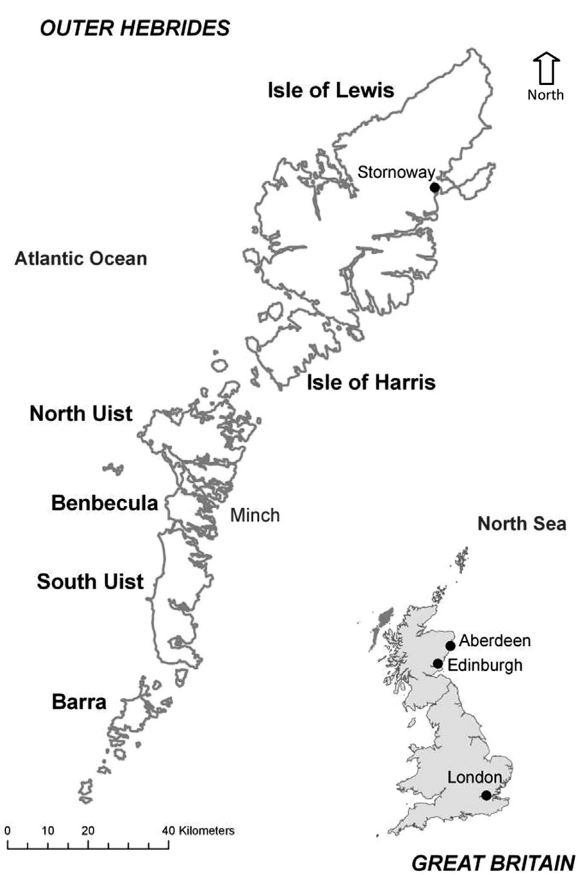

Fig. 5. The Outer Hebrides case study site (CoastAdapt).

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.[5]

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

[5] 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.

of climate 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)

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identified nine concepts to further populate the impacts group (see Table 1). These modelling elements were printed to colour coded magnetised tiles to be employed during model facilitation.

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. 6), defining causal edge relationships between concepts with marker pens as strongly, moderately or weakly[a] positive or negative, and progressing sequentially through DPSIR categories to complete their model.

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:

Table 1
Base modelling concepts employed at the Tralee Bay case study site.

DPSIR category	Modelling concept
Drivers	Agriculture; Aquaculture; Commerce, Industry & manufacturing; Tourism & recreation; Residential development; Large scale public works; 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[a]; Bioremediation of wastes[a]; Flood protection[a]; Marine transport & navigation[a]; Raw material provision[a]; Marine food provision[a]; Terrestrial food provision[a]
Responses	Re-location away from coast; Construction of coastal/flood defences; Local authority zoning; Local authority planning; Introduction/enforcement of bye-laws; Economic diversification; Civil society lobbying; NGO protest; Individual insurance cover; Seeking investment; Payment of EU fines; Voluntary community action; Increased commercial exploitation

[a] Concepts derived from literature review.

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:

$$c_D(V) = \sum(\mathrm{id}(V) + \mathrm{od}(V)) \tag{1}$$

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:

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

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 2). 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'.

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

Fig. 6. Building an individual FCM with magnetised tiles on a whiteboard.

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 3). 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).

3.2.2. Density of group member FCMs

The density scores returned by an analysis of the adjacency matrix of each of the FCMs are presented in Fig. 7. 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

Table 2
Stakeholder views on climate impacts, adaptation options, and use of scientific outputs in decision making.

	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 3
Climate change issues of concern.

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 temp.	–

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Table 4
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).

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

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.

3.2.3. 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 (Fig. 8). 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. 9). 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. This in turn diminishes the options present within resilience group member FCMs to alter the role these concepts play within the model.

3.2.4. Climate related concepts in the baseline scenario output

Fig. 10 illustrates 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

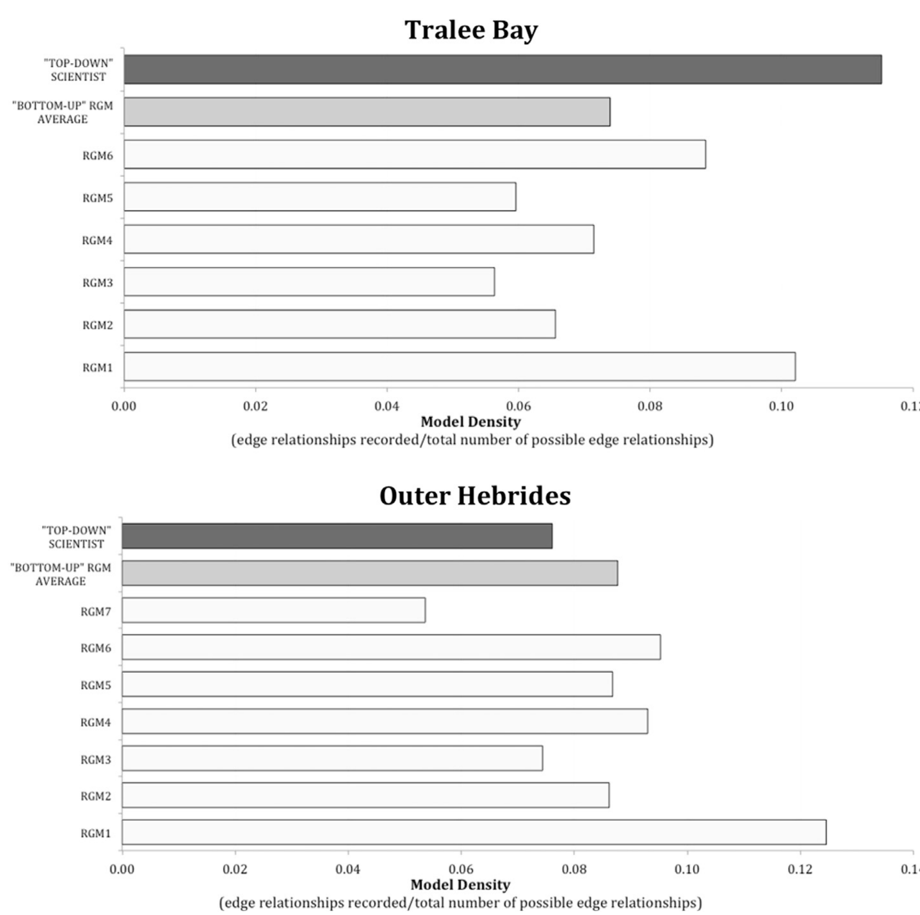

Fig. 7. Density metrics for Tralee Bay and Outer Hebrides.

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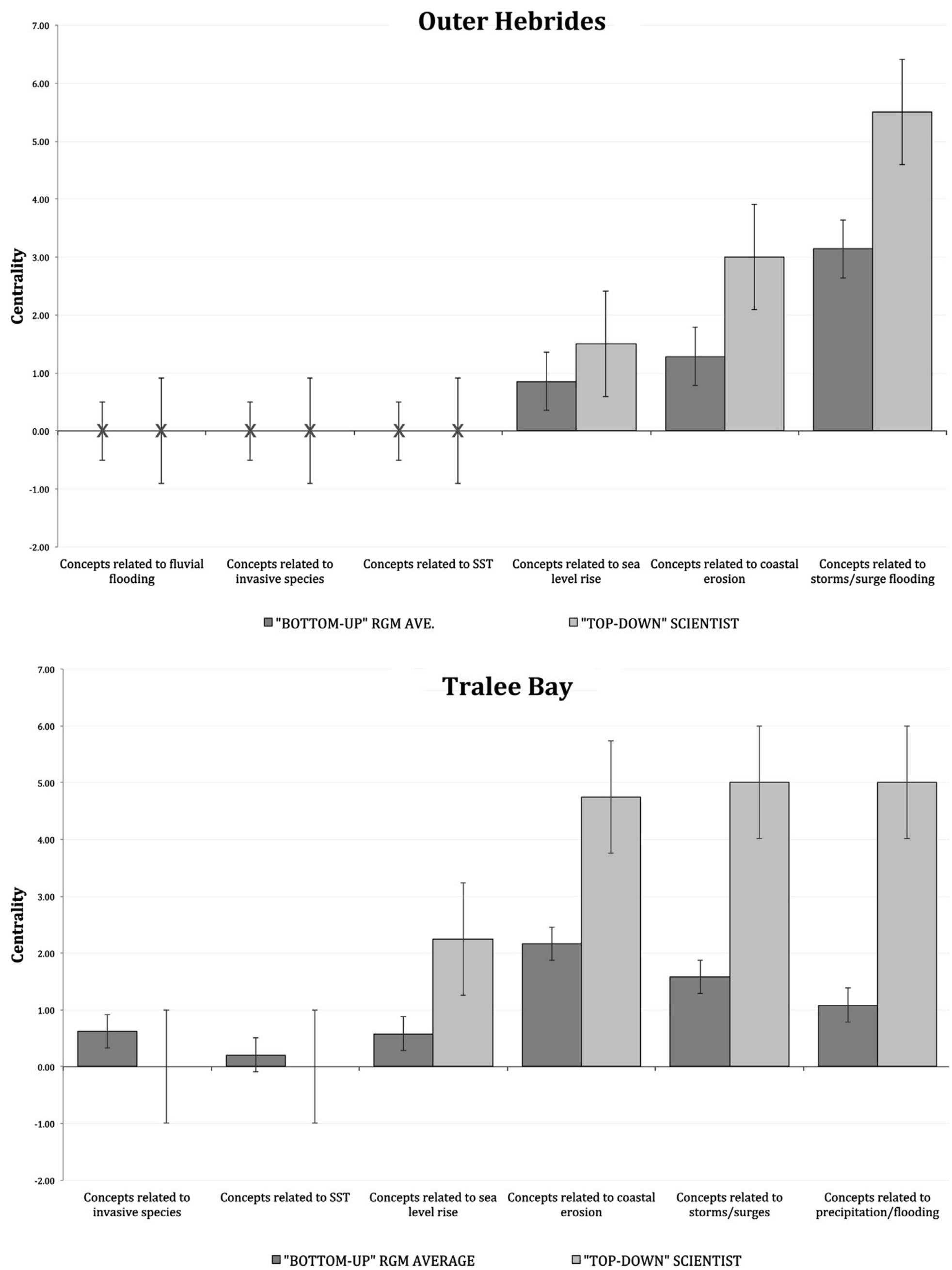

Fig. 8. Centrality of climate related issues within RGM and Top-down reference models (centrality is the summed total of all edge relationships to and from a concept within a model).

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.

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.

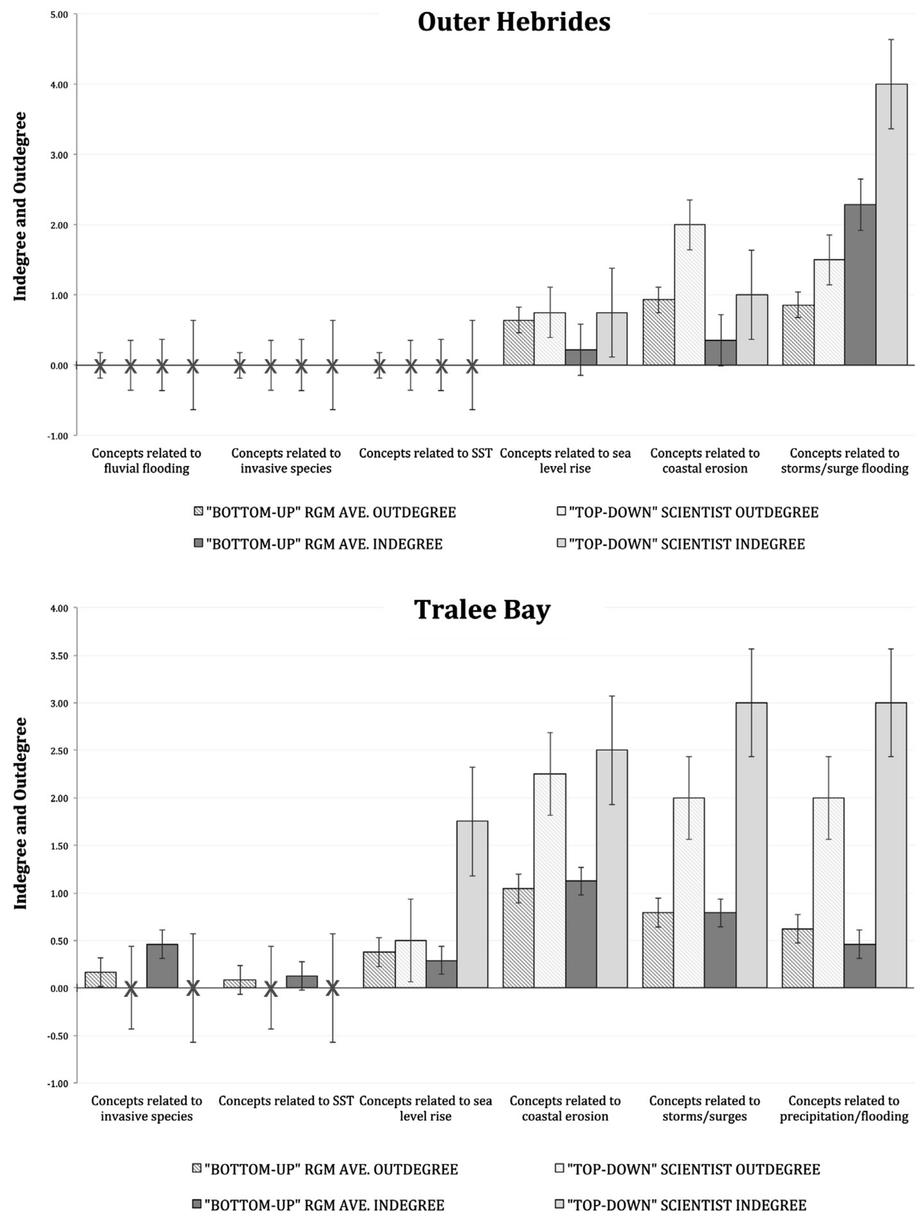

Fig. 9. Measures of indegree (all inbound edge relationships) and outdegree (all outbound edge relationships) for climate-related concepts included by resilience group members and the reference modellers.

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

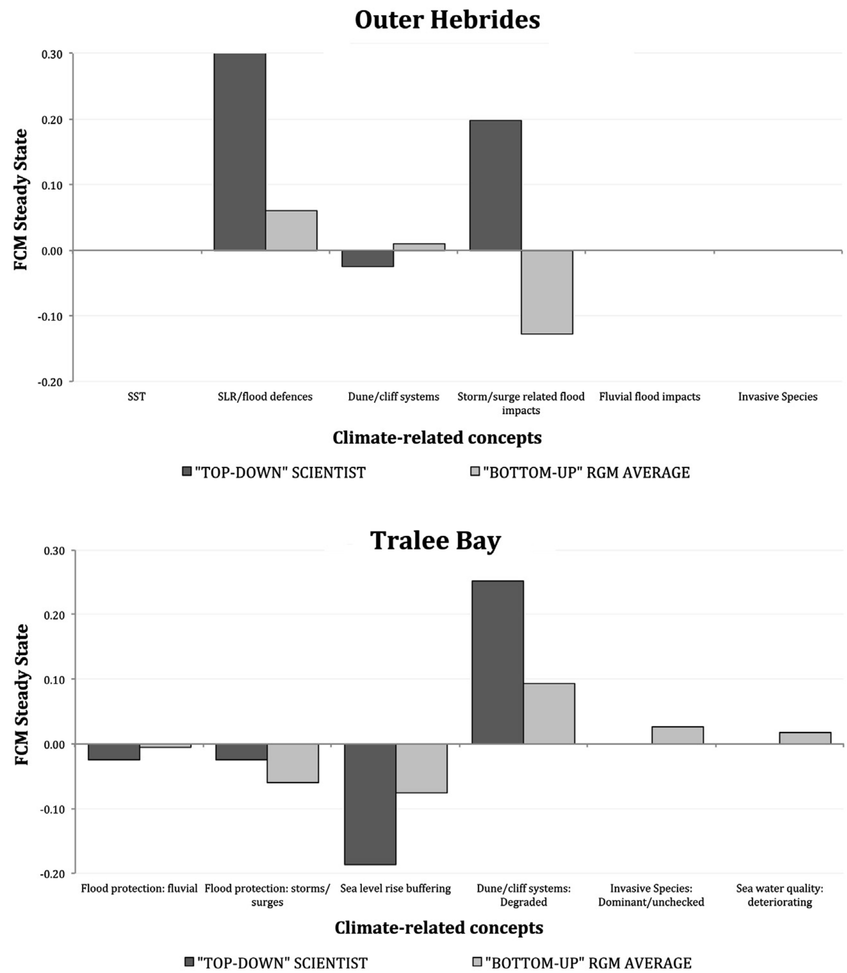

Fig. 10. Climate related concept baseline scenario output.

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 member 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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