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Mental models of sea-level change: A mixed methods analysis on the Severn Estuary, UK

Merryn Thomas [a,*], Nick Pidgeon [a], Lorraine Whitmarsh [a], Rhoda Ballinger [b]

[a] Understanding Risk Group, Tyndall Centre and Climate Change Consortium of Wales, School of Psychology, Cardiff University, Wales CF10 3AT, UK
[b] School of Earth and Ocean Sciences, Cardiff University, Wales CF10 3AT, UK

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ABSTRACT

Global average sea levels are expected to rise by up to a metre by the end of the century. This long-term rise will combine with shorter-term changes in sea level (e.g. high tides, storm surges) to increase risks of flooding and erosion in vulnerable coastal areas. As communities become increasingly exposed to these risks, understanding their beliefs and responses becomes more important. While studies have explored public responses to climate change, less research has focused on perceptions of the specific risks associated with sea-level change. This paper presents the results of a mental models study that addressed this knowledge gap by exploring expert and public perceptions of sea-level change on the Severn Estuary, a threatened coastal environment in the southwest of the United Kingdom. A model was developed from the literature and expert interviews ($N = 11$), and compared with public perceptions elicited via interviews ($N = 20$) and a quantitative survey ($N = 359$). Whilst we find a high degree of consistency between expert and public understandings, there are important differences that have implications for how sea level risks are interpreted and for what are perceived as appropriate mitigation and adaptation practices. We also find a number of potential barriers to engaging with the issue: individuals express low concern about sea-level change in relation to other matters; they feel detached from the issue, seeing it as something that will happen in future to other people; and many perceive that neither the causes of nor responses to sea-level change are their responsibility. We point to areas upon which future risk communications should therefore concentrate.

1. Introduction

Global mean sea level rose during the 20th century and is continuing to do so (Church et al., 2013). As the world warms, sea-level rise is inevitable (Nicholls et al., 2011) largely through thermal expansion (increased water volume due to temperature rise) and glacio-eustasy (increased water volume due to additions from melting land-ice). By 2100, global average sea levels are expected to rise by between 0.26 m and 0.98 m, relative to the 1986–2005 baseline (IPCC, 2013). Sea levels also change on shorter timescales, for example due to storm surges and high tides. It is the combination of mean sea levels and shorter term fluctuations that cause the most extreme water levels at the coast; mean sea-level rise raises the baseline level of the water, meaning high tides, storm surges and waves reach higher. The impacts of these extreme sea levels include flooding, erosion and intrusion into freshwater resources (Wong et al., 2014).

As coastal communities become increasingly exposed to these risks, understanding their beliefs and responses becomes more important. Ignoring lay perspectives is incompatible with democratic ideals, and lay participation can increase legitimacy and improve confidence in risk institutions (Fiorino, 1990). Some aspects of lay risk judgments are as sound (or more so) than expert risk judgments, and local knowledge can add a valuable layer to risk understandings (Fiorino, 1990; Irwin and Wynne, 1996; Lebel, 2013; Santha et al., 2014). Furthermore, without feedback from the target audience, scientists do not know how their well-intended communications are received and understood by the public: this 'strategic listening' (Pidgeon and Fischhoff, 2011, 38) is the purpose of this study.

While a growing body of research has explored public perceptions of climate change (for overviews, see Wolf and Moser, 2011; Lorenzoni and Whitmarsh, 2014), and to a lesser extent

* Corresponding author at: School of Psychology, Park Place, Cardiff University, Wales CF10 3AT, UK. Tel.: +44 029 2087 6520.
E-mail address: ThomasMJ6@Cardiff.ac.uk (M. Thomas).

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associated mean sea-level rise (e.g. Harvatt et al., 2011; Evans et al., 2012), little research has explored perceptions of sea-level change (SLC) as a wider issue. This is interesting in view of the Intergovernmental Panel on Climate Change favouring the terms 'sea-level change' and 'changes in sea level' since the Second Assessment Report (IPCC, 1996, 2001, 2013), and the role of shorter-term change in causing extreme sea levels. The other reason for using the term 'sea-level change' in this study is that solely engaging participants with the term 'sea-level rise' may preclude them from expressing a view that sea levels might fall; a perception highly relevant for risk communicators.

A complex, multifaceted issue, we expect that many of the findings regarding SLC perceptions will resonate with climate change perceptions more broadly. This is because (a) the issues are intrinsically linked: climate change causes sea-level rise, and (b) both issues contain elements that are difficult to detect without close measurement, act over long timescales and are uncertain. As complex issues, people are likely to respond to both with uncertain, conditional and partially-formed views contingent on factors such as trust and social identity (e.g. Pidgeon et al., 1992; Wynne, 1992a). A brief review of literature pertaining to climate change perceptions is therefore useful before reviewing SLC perceptions in particular.

Studies have explored multiple aspects of climate change perceptions including knowledge (e.g. Bostrom et al., 1994; Reynolds et al., 2010), psychological and socio-cultural factors (e.g. Leiserowitz, 2006), and potential barriers towards engagement (e.g. Lorenzoni et al., 2007; Gifford, 2011). They find that there is variable concern about the issue (Leiserowitz, 2005; Lorenzoni and Pidgeon, 2006; Capstick et al., 2015), and that it tends to rank low relative to other concerns, particularly day-to-day issues like health and economic security (Poortinga and Pidgeon, 2003a; Zsamboky et al., 2011). This reflects a widespread perception that climate change is remote in space and time (e.g. Leiserowitz, 2005), and has thus been described as psychologically distant (Lorenzoni and Pidgeon, 2006; Liberman and Trope, 2008; Wolf and Moser, 2011; Spence et al., 2012). Research has also shown that individuals contextualise climate change among broader perspectives. For example, people often believe that the responsibility for causing and mitigating climate change lies with others, particularly powerful external parties such as government and businesses (Poortinga et al., 2006; Spence et al., 2010; Pidgeon, 2012; Capstick et al., 2013); perhaps in part due to a perceived lack of ability in taking action and personally making a difference (Spence et al., 2010; Capstick et al., 2013). This low self-efficacy can lead individuals to employ a number of strategies to avoid thinking about climate change, and while it may be understood and cared about, information may be held at a distance in order to manage emotions (Norgaard, 2006). Optimism is another strategy for dealing with unpleasant futures, and both avoidance and optimism have been cited as potential barriers towards public engagement (Norgaard, 2006; Lorenzoni et al., 2007; Gifford, 2011).

As one of the main impacts of climate change, there has been growing interest in public perceptions of global mean sea-level rise. Most research has treated it as one of many aspects of climate change (e.g. Bostrom et al., 1994; Read et al., 1994; Reynolds et al., 2010), or as one of a number of marine climate change issues (Chilvers et al., 2014; Gelcich et al., 2014). Others have focussed on perceptions of particular aspects of sea-level rise, especially adaptation strategies (Myatt et al., 2003; Alexander et al., 2012; Barnett et al., 2013) and specific impacts (Dolan and Walker, 2006; Zsamboky et al., 2011). A few have undertaken more holistic studies of sea-level rise perceptions amongst the public (Harvatt et al., 2011; Evans et al., 2012), or stakeholders (Lonsdale et al., 2008; Poumadère et al., 2008; Raaijmakers et al., 2008).

Studies have shown that sea-level rise is one of the more commonly discussed consequences of climate change among the public, media and policy makers (Rick et al., 2011; Chilvers et al., 2014). Fully 43% of European respondents feel informed about the issue (CLAMER, 2011), and respondents in Europe and New Zealand tend to think that sea levels will rise in future (CLAMER, 2011; Evans et al., 2012). However, research suggests that in general, the UK public has a low awareness of sea-level rise (Fernandez-Bilbao, 2012). A common misconception regards the low importance assigned to thermal expansion (Read et al., 1994; Reynolds et al., 2010; Tobler et al., 2012). Like climate change, sea-level rise tends to be associated with negative feelings (Lorenzoni et al., 2006), and correspondingly, most European respondents report being concerned about it (CLAMER, 2011), although its importance is lower than other marine issues such as pollution and overfishing (Gelcich et al., 2014). Furthermore, while European survey respondents generally perceive marine environmental problems as happening now or in their lifetime (Gelcich et al., 2014), there is some evidence that sea-level rise is seen as a distant risk (Evans et al., 2012). Research also shows that individuals transfer the responsibility of acting on sea-level rise to others (Harvatt et al., 2011), but that this is accompanied by low trust in the agencies perceived to be responsible (Myatt et al., 2003; Fernandez-Bilbao, 2012).

Regarding other drivers (causes) of SLC, the public understands that the majority of climate scientists expect an increase in extreme events such as storms (Tobler et al., 2012), and some research shows good understanding of short term drivers. For example, lay people in the Philippines include an increase in the intensity and frequency of storm events in their perceptions of climate change (Combest-Friedman et al., 2012), and lay representations of stressors on marginal African coasts include storm surges, waves and high tides (Bunce et al., 2010). Indeed, local knowledge of such factors has been shown to be important for forecasting coastal hazards in India (Santha et al., 2014). Other research however highlights differences between expert and public perceptions. In the US, the public tend to perceive wind as being the greater risk from major storms, underestimating the potential impacts of storm surges (Baker et al., 2012; Morrow and Nadeau, 2012). Thus, the extent of flooding from storm surges can come as a surprise (Morss and Hayden, 2010).

While there is an emerging body of literature on public perceptions of some elements of SLC – particularly mean sea-level rise – little is known about public mental models of SLC as a complex risk issue. This study aims to address this gap by (1) examining expert and public perceptions of SLC, and (2) comparing the two to identify key areas for future communications. To do this, we use the mental models approach developed by Morgan et al. (2002). Previous research into SLC perceptions has tended to rely heavily on survey approaches (Evans et al., 2012; Ryan et al., 2012), while some have used interviews (Harvatt et al., 2011; Barnett et al., 2013; Santha et al., 2014), or surveys prior to deliberative workshops (Chilvers et al., 2014). None has used a mental models approach, despite its successful application to other risks including climate change (Bostrom et al., 1994; Morgan et al., 2002; Cox et al., 2003; Lowe and Lorenzoni, 2007). The core premise of this approach is that in order for communications to be effective in changing behaviour, audiences' internal representations of reality (their 'mental models') must be key in their development. The approach used here, developed by Morgan et al. (2002), builds on earlier work (Maharik and Fischhoff, 1993) to do this systematically. First, the audience's mental models are explored using participant-centred semi-structured interviews that allow individuals to respond to whichever aspect they feel is most important, in a way that is meaningful to them. The researcher does not assume what these perceptions might be, or how they might be

framed. These perceptions are then examined with a wider sample of the population by means of a survey, before expert and lay perceptions are compared to identify similarities and differences.

2. Case-study area

The Severn Estuary is a valuable case study for exploring perceptions of complex SLC risks because it is a diverse, dynamic environment with multiple stressors and impacts. The Estuary has the second largest tidal range in the world, with an average mean spring tidal range of 12.3 m (Langston et al., 2010), which commonly leads to the formation of a tidal bore that propagates up the Severn at a height of up to 2 m (Uncles, 2010). The Estuary also drains the UK's longest river, and at 21,590 km^2 has one of the largest catchments in the UK (Severn Estuary Partnership, 2011). The rivers that flow into the Estuary supply a vast amount of sediment (Severn Estuary Coastal Group and ATKINS, 2010a), much of which is deposited as mudflats. These mudflats support considerable biodiversity, and the Estuary contains the largest aggregation of salt marsh habitat in the south and south-west of the UK (Severn Estuary Partnership, 2011). Partly due to these features, the Estuary is of high ecological significance (Severn Estuary Coastal Group and ATKINS, 2010b), and is a designated Special Protection Area, Special Area of Conservation and Ramsar site.

There is a mixture of urban and rural land uses around the Estuary, and its shores are home to around one million people (Severn Estuary Partnership, 2011). It is also the site of significant industrial development including chemical processing, power stations and ports, which are supported by good transport links, cooling water and offshore aggregates for construction (IMCORE, 2011). The Estuary is also important for recreation and tourism (Knowles and Myatt-Bell, 2001) and may in future become a key source of renewable marine energy, with proposals including a tidal barrage (House of Commons, 2013) and a series of tidal lagoons (Emanuel, 2013).

Governance on the Estuary is complex (Dodds, 2010), shared across two Governments (Westminster and the Welsh Government), fourteen Local Authorities and two County Councils. Accordingly, many different groups are responsible for managing flood risk: land owners/developers, local planning authorities, regional planning bodies and government agencies (Department of Communities and Local Government, 2006). While flood risk on the Severn Estuary (including flood defences and flood awareness promotion) is managed mainly by England's Environment Agency and Wales' Natural Resources Wales, Local Authorities are heavily involved in local Shoreline Management Plans, which are responsible for drafting coastal management policies. The vast majority of the Estuary coastline is protected by coastal defences, some of which date back to Roman times (Sustainable Development Commission, 2007). Shoreline management strategies feature widespread defence maintenance and improvements (Severn Estuary Coastal Group and ATKINS, 2010a; Environment Agency Wales, 2011), although some areas have undergone managed realignment. This is a controversial policy whereby an area is allowed to flood through the removal of hard structures in order to create a soft coastal defence. A benefit is that it creates or protects intertidal habitats, which are currently under threat on the Estuary from rising sea levels (Environment Agency, 2011).

Mean sea level on the Severn Estuary has been rising throughout the current interglacial period (Environment Agency, 2006); a trend that is expected to continue in future (MCCIP, 2010). The global trend is exacerbated here by isostatic subsidence in response to the last glacial, which is causing the shoreline to subside at a rate of around 0.76 mm/year (Shennan and Horton, 2002). With regards to shorter term SLC, the Estuary is particularly vulnerable to storms because of its low-lying topography, funnel-shaped coastal configuration, orientation with respect to prevailing winds, and tidal setting, which together enhance surge heights from storms tracking east and north-eastward (Horsburgh and Horritt, 2006; Haslett and Bryant, 2007). Historically, these factors have contributed to a number of severe coastal flooding events, including a catastrophic event in 1607 that flooded more than 500 km^2 and killed more than 2000 people (Bryant and Haslett, 2007). Severe fluvial flood events have also affected the Estuary, including major floods in Gloucester in 2007, and recent extensive flooding on the Somerset Levels in early 2014 (BBC News, 2014).

3. Methods

Our approach followed Morgan et al. (2002), whereby an expert model is compared with public perceptions elicited by way of qualitative interviews and a quantitative survey. The use of mixed-methods approaches like this adds value by combining evidence from different methodologies (Pidgeon, 2012): while qualitative interviews can scope viewpoints and provide deep insight into the contexts of these views, quantitative surveys can elicit perceptions from a large population and triangulate findings (Cohen et al., 2000). Our approach is outlined in Fig. 1, and elaborated in Sections 3.1–3.3 (also see Appendices A and B).

3.1. Developing an expert model of SLC

The first stage of the research developed an expert model of SLC in order to provide a comparison with public perceptions. The model was developed from a literature review and interviews with experts (N = 11), carried out in 2011. Interviewees were selected on the basis of their professional expertise in relation to long- and short-term sea-level changes, and impacts and responses on the Severn Estuary (cf. Rice, 2010). They consisted of six academics, two national government officials, one local government official, one Environment Agency coastal engineer and one marine environmental consultant.

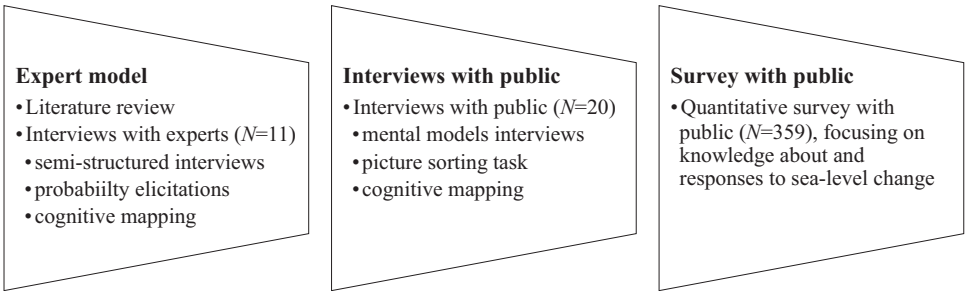

Fig. 1. Methodological approach.

Interviews entailed three phases: a semi-structured interview, a cognitive mapping task and a probability elicitation. The semi-structured interview was designed to scope the risks of SLC on the Estuary, and to find out as much about these risks as possible, while the creation of a cognitive map (cf. Kearney and Kaplan, 1997) explored relationships between themes and acted as a prompt for further discussion. The subjective probability exercise (e.g. Spetzler and Stael Von Holstein, 1975) elicited SLC probabilities for the Estuary, and is reported in Thomas et al. (in press). The format of the expert model was inspired by decision theory (e.g. Miller et al., 1976) and previous mental model studies (Morgan et al., 2002, Lowe and Lorenzoni, 2007), while the conceptual framework was influenced by the cognitive maps created by experts, and various literature resources (particularly Nicholls, 2010). To build the model, interview transcripts were coded using a structured approach based on central themes in the literature (Hansson and Bryngelsson, 2009), with other themes coded as they emerged. The codes were then sub-categorised to form the basis of a hierarchy, which was iteratively developed into a map structure. To enable respondent validation (Henwood and Pidgeon, 1992), participating experts were sent a copy of the model and invited to comment.

3.2. Qualitative interviews with public participants

Interview sessions were carried out in 2012 with a diverse sample of 20 members of the public living around the Severn Estuary (Fig. 2). A sample of this size is deemed sufficient for mental models interviews in order to reveal most of the common beliefs held by the population (Morgan et al., 2002; Bruine de Bruin and Bostrom, 2013), and the saturation of major themes appeared to have been reached by the twentieth interview. Recruitment was topic-blind, with participants informed only that the interview was about 'change on the Severn Estuary' prior to the session commencing. A purposive sampling technique was employed, whereby acquaintances ('gatekeepers') who lived in target areas were asked to pass the lead researcher's contact details to people who might be willing to participate (see Warren, 2001). Participants were offered an honorarium of £10. The approximate locations of respondents and their demographic characteristics are shown in Fig. 2 and Table 1. Compared with the Severn Estuary region, the sample was underrepresented by 18–24 year olds and 35–44 year olds, and was over represented by home owners and those with higher qualifications (Office for National Statistics, 2011 Census).

The purpose of the interview sessions was to explore what people already perceive regarding SLC on the Severn Estuary, and therefore provided participants with minimal new information and gave them plenty of scope to talk about everything they considered relevant. Sessions lasted around 90 min, and were in

Table 1
Summary of participant demographics.

Demographic	Interview sample	Survey sample	Severn Estuary region[a]
Age			
18–24	5%	5%	13%
25–34	30%	20%	17%
35–44	5%	18%	17%
45–54	20%	23%	17%
55–64	25%	21%	15%
65–74	15%	10%	11%
75+	0%	2%	10%
Female	50%	58%	51%
Own their own home (outright or with mortgage)	85%	61%	68%
Bachelor's degree/equivalent or higher	60%	38%	29%

[a] Statistics are from 2011 Census data for complete Local Authorities bordering the Estuary: Vale of Glamorgan, Cardiff, Newport, Monmouthshire, Forest of Dean, Gloucestershire, Tewkesbury, Stroud, South Gloucestershire, City of Bristol, North Somerset, West Somerset and Sedgemoor (Office for National Statistics, 2011 Census).

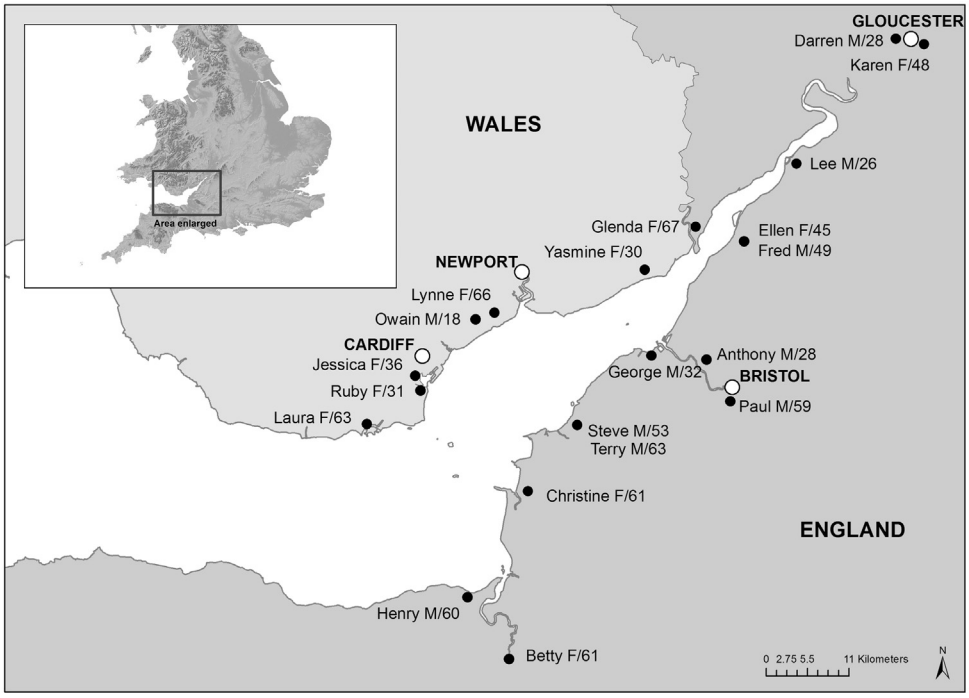

Fig. 2. Approximate location of interview participants around the Severn Estuary, in the south west of the United Kingdom. Gender (M/F) and age are indicated alongside pseudonyms. © Crown Copyright and Database Right 2014. Ordnance Survey (Digimap Licence)

three parts. The first consisted of a semi-structured interview, with open-ended questions designed to elicit as much information as possible without leading the participant. During this session, participants were asked to talk about what comes to mind about the Severn Estuary, before being asked about the main issues they feel face the Estuary now and in the future. At this point, participants were told that the study was about SLC, and asked to 'talk about sea-level change'. In practice, this was a question that all participants were able to engage with, and elicited top-of-mind thoughts on the topic before each was followed up in more detail (Morgan et al., 2002). The interview then became more directed by prompting participants about major parts of the expert model: processes, historical and future changes, impacts, adaptation and mitigation, and 'the bigger picture' (How do you feel about the issues? How important are they?). Detailed aspects of each theme were only discussed if the participant raised them. The semi-structured interview was followed by a picture sorting task, designed to prompt discussion on topics that did not arise during the semi-structured interview (Morgan et al., 2002). This involved participants sorting a pile of images into those that were related to SLC and those that were not, explaining their reasoning for each decision. The final stage was a cognitive mapping task (adapted from Kearney and Kaplan, 1997) to further prompt discussion and explore how participants grouped and linked ideas. Interview sessions were audio recorded and transcribed.

The traditional mental models approach tends to focus on what people *know* about a risk (Bostrom et al., 1994; Read et al., 1994; Morgan et al., 2002). This has been criticised because personal engagement may be determined by factors in addition to knowledge (Baumann and Sims, 1978; Irwin and Wynne, 1996; Lorenzoni et al., 2007; Kahan et al., 2012), including how people feel about a risk (Slovic et al., 2004), their values (Kahan et al., 2011), and wider social context (Darier and Schüle, 1999; Bulkeley, 2000; Pidgeon et al., 2003). Therefore, we expanded the traditional approach to also investigate some of these other issues (cf. Cox et al., 2003, 2005). To this end, coding proceeded in two stages. First, a content analysis was carried out to investigate the presence or absence of the themes in the expert model, noting whether each was mentioned before or after prompting. Second, transcripts were analysed using a grounded approach (Glaser and Strauss, 1967; Henwood and Pidgeon, 1992), whereby concepts 'emerged' from the interviews, and codes were developed to fit the data. Themes that emerged during the qualitative analyses were followed up in the quantitative survey.

3.3. Quantitative public survey

The quantitative survey ($N = 359$) was carried out in March 2013 to explore perceptions amongst a broadly representative sample of people living within ten miles of the Estuary shoreline. An online protocol was used, and participants were recruited using a specialist participant recruitment agency, incentivised by the agency's own loyalty points. All responses were anonymous and recruitment was topic blind, with participants knowing only that the survey was about 'the Severn Estuary and the changes that happen there' before commencing. The demographic profile of participants is shown in Table 1. Compared with the Severn Estuary region, the sample was overrepresented by females and people with higher qualification levels, and underrepresented by the oldest and youngest groups and home owners.

Survey content was informed by the results of the expert and public interview phases. After consenting to take part, participants viewed a map of the Estuary and surrounding area, and then answered 35 questions relating to their understanding of and responses to SLC. The first question asked participants to tick up to five of 13 things that they think are main issues of concern around the Severn Estuary today and for the next 20 years. The list was drawn from concerns expressed during the interviews and included SLC, flooding, risks of nuclear accident, and a decline in traditional industries and crafts. Participants were then asked about rates of future SLC, measured with sliders representing sea-level rise and fall (significant, moderate, slight or no change). They were asked to state what level of risk or benefit sea-level rise and sea-level fall would pose to the Estuary, before stating how concerned they were about SLC. The next question asked whether 11 statements about the causes of long and short-term SLC were true or false (see Read et al., 1994; Cox et al., 2005; Reynolds et al., 2010); five that were consistent with the expert model and five that were inconsistent.

At this point in the survey, participants were presented with a short description of what causes sea levels to change on short and long timescales, and estimates of mean sea-level rise on the Estuary by the year 2100. This description was designed to provide participants with enough information to be able to complete the rest of the survey, and to clarify the meaning of the term 'sea-level change'. The next two questions presented statements about the physical and social impacts of sea-level rise on the Estuary, and asked participants to indicate whether they were true or false. Next, they were asked to tick any of 17 potential impacts that would personally concern them, including physical and socio-economic impacts. They were then asked to select measures that they thought would be most effective in limiting the amount of sea-level rise on the Severn Estuary, and another question asked which would be most effective in reducing the impacts. Participants then stated their level of agreement with a number of bipolar statements relating to their opinions on who/where/when SLC would impact, whether they think about SLC a lot, whose responsibility it is to respond, whether they feel personally able to do anything about causes/impacts, whether they trust the government/Environment Agency to protect residents from flooding, and whether they are informed about SLC.

4. Findings

4.1. Expert perceptions

The full expert model is highly complex, consisting of more than 100 themes (Thomas, 2013). A summary is shown in Fig. 3. The model consists of drivers of extreme sea levels, which can lead to physical and socio-economic impacts such as flooding and damage to homes and property. These impacts are moderated by factors that affect vulnerability, including mitigation and adaptation measures. The full model contains a number of uncertainties. Some are due to gaps in knowledge that can in theory be reduced by further research (epistemic uncertainties), while others are a function of factors such as random variability that cannot be reduced by further research (aleatory uncertainties). They include uncertainty over whether storms will worsen in future, how the Greenland and West Antarctic Ice Sheets will respond to warming, and the rate and extent of future climate change. A key uncertainty regards the magnitudes of future SLC (see Thomas et al., in press).

Whilst we recognise that factors in addition to knowledge affect expert risk judgements (e.g. Tversky and Kahneman, 1974; Wynne, 1992b), we do not address these in this paper. Experts concentrated primarily on processes and impacts, and expressed their own feelings and concerns much less than public participants did. We expect that this was largely due to the focus of the expert interview protocol, and also perhaps because they did not see it as their role to express such viewpoints. For public participants on the other hand, such factors played a large role in their conceptualisations of SLC (see Section 4.2).

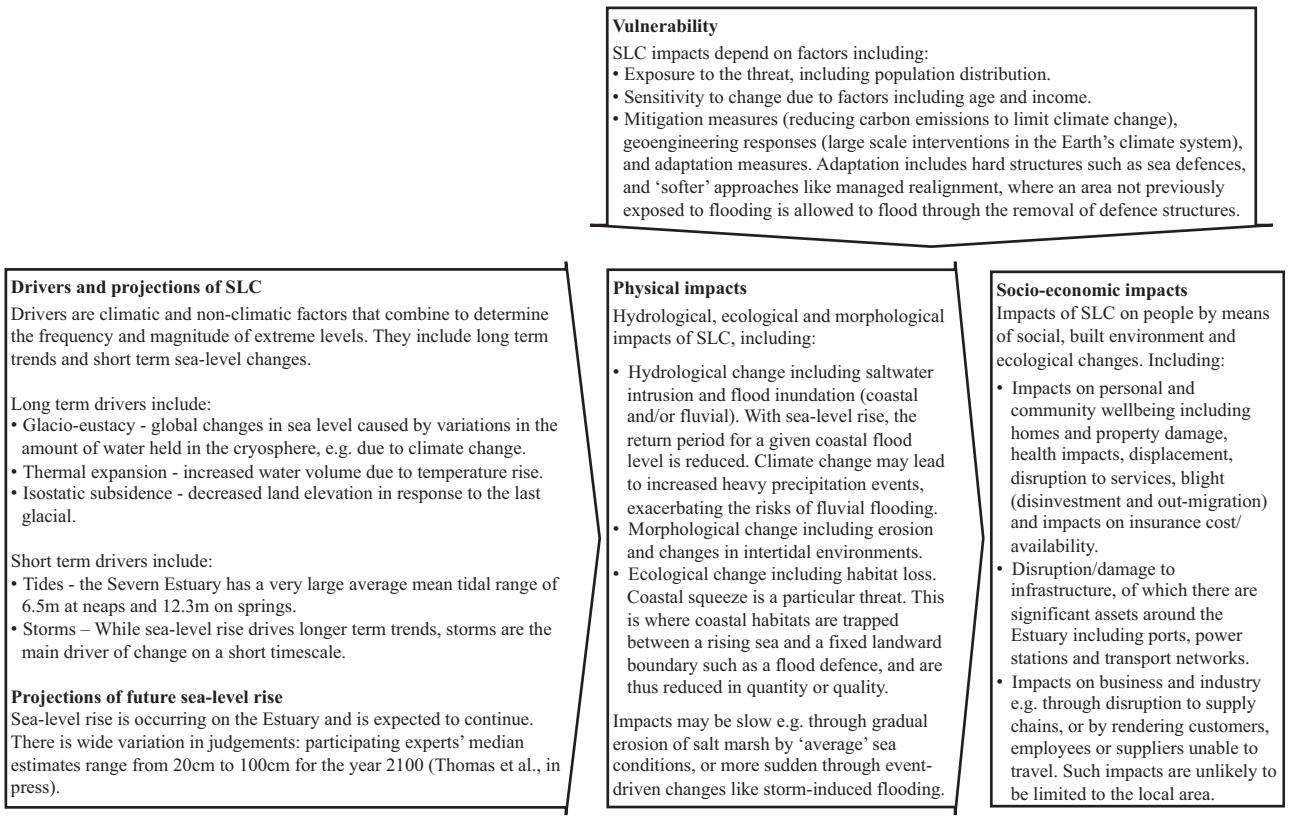

Fig. 3. Overview of expert model summarising SLC on the Severn Estuary.

4.2. Public perceptions

Fig. 4 summarises public understandings of each part of the expert model – SLC drivers, rates, impacts and vulnerabilities – to enable comparisons with the expert perceptions summarised in Fig. 3 (see Appendix C for full results). As well as these 'knowledge' aspects, the public model consists of other factors such as concern, responsibility and trust, which are elucidated here before we compare the two models in Section 5. The first aspect relates to concern, levels of which varied amongst survey and interview participants. Their comments ranged from Darren's '[SLC] wouldn't be the end of the world' and Owain's 'neither here nor there', to Henry stating that he feels 'passionate' about the issues. Christine was unsure if sea levels were rising or falling, but stated that 'if sea levels were definitely rising, like if they rose an inch last year and were forecast to rise another inch this year, I suppose we might think about selling our house'. Indeed, the subject of SLC evoked negative feelings amongst interviewees, who particularly expressed fear of flooding. Karen remembered driving through floodwaters during the 2007 Gloucester flood, and said, 'that was quite horrific really [...] I was so frightened'. Betty expressed similar feelings, stating that 'it's a terrifying thing, water, when it does that'. Despite these emotions, SLC is not something that individuals tend to think about much, and it did not factor highly amongst interviewees' concerns when compared with other issues. Ruby for instance noted that there are levels of concerns about things, and that her main concerns are more society-based. Similarly, when asked how SLC compares in importance to other issues that might concern him today, Anthony answered 'not even the slightest, to be honest with you'. However, when compared with issues that may affect the Severn Estuary in particular, survey respondents rated SLC highly, above the local economy and local society/community issues.

Interview participants tended to view SLC as something that would affect other people and places worse than it would affect their local area. Although a few stated that 'SLC would affect everyone' (Steve) and 'be no respecter of age, disability or how nice they are' (Ellen), interviewees tended to think that it would particularly affect other countries such as Thailand, The Maldives, and Bangladesh. Closer to home, participants talked about SLC as a risk to other places in the UK, particularly the East Coast and London, as well as places around the Severn Estuary; but rarely where the interviewee lived. There was also a widespread belief among interview participants that the impacts would be felt by future generations, rather than themselves. For example, Christine (age 69) stated that 'I don't think it'll happen in my lifetime', Karen (age 48) that 'I won't be around by the time it rises to a serious level', and Jessica (age 36) that 'it seems as though it's something that might happen to somebody in the future'. Despite this, some residents voiced concerns about the impacts on future generations, stating that 'I do worry about the future' (Ruby), and 'we have to do the right thing by our kids' (Betty). To some extent, survey responses were contrary to these interview findings, because more respondents felt that SLC would affect the Severn Estuary than the rest of the world.

Some interview participants actively engage with mitigating SLC, for example by saving energy or using solar panels. As landowners bordering the Estuary, two participants were heavily involved in adaptation through surrendering their land for managed realignment, although they were opposed to the scale and nature of these measures. Despite a level of engagement however, some interviewees responded with optimism or avoiding

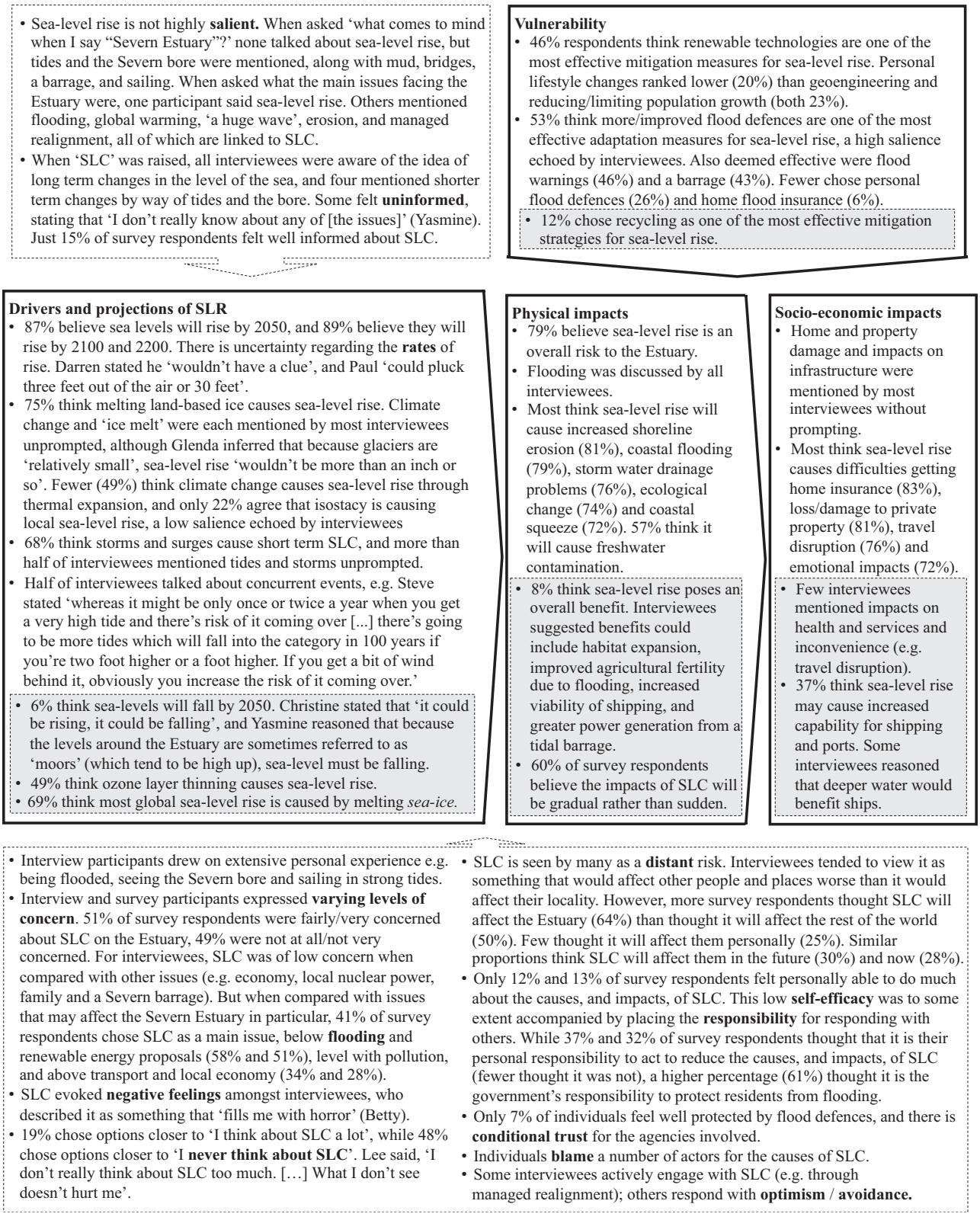

Fig. 4. Summary public mental model of SLC on the Severn Estuary. Themes that are inconsistent with the expert model are summarised in grey dashed boxes. Non-knowledge factors are shown in open dashed boxes. Question wording has been truncated (see Appendix B for full wording). All percentages refer to survey results.

the issue entirely. For example, Jessica stated that 'I'm hoping [global warming is] going to be cancelled out by the next little ice age. Possibility, maybe. Trying to think positively', while Lynne said, 'I don't see it being a big permanent rise, not really. I have to say. I'm probably a bit [of a] half full person really'. Some interviewees also talked about trying not to think about the issues because they find them depressing, frightening or too big to deal with. Ruby for instance said 'I deliberately didn't watch [the film 'An Inconvenient Truth'] because I do find this kind of stuff quite frightening. It makes you feel powerless as well'.

Such feelings of powerlessness were common among survey and interview participants, who felt that 'there's not a lot we can do about [the sea level rising]' (Lee) or 'certainly nothing I can do personally' (Fred). Amongst interviewees, low self-efficacy was accompanied by placing the responsibility for SLC with others. While nature could not be blamed because 'when the sea comes to get you it doesn't mean anything by it' (Ellen), interview participants laid the blame with a variety of actors including corporations, rich people, ignorant people, government, and other countries. Contrary to impressions from interviewees however, more survey respondents thought that it was their responsibility to reduce the causes and impacts of SLC than thought it was not. However, interviewees and most survey respondents felt that it is the government's responsibility to protect residents from flooding. Ruby for example thought that the government would 'somehow protect us', and Lynne believed they would have their 'contingency plans'.

Although participants transferred the responsibility for flooding to others, the relevant agencies are not fully trusted to carry out their responsibilities effectively, and a number of interview respondents expressed exasperation with the government and the Environment Agency over flood management. For example, Lynne stated that 'I can't believe that no one's working on a solution. But they probably aren't. But, you know, at the end of the day, they're telling people to get in a supply of sand bags. Well I'm sorry, that was pre first war. [...] It's just ridiculous really'. Terry, who is personally involved in surrendering his land for managed retreat, said that the process is an 'absolute disgrace, it is abysmal what they've done over there'. Fred felt that individuals are treated unfairly, and provided an example of building a garage: 'we were initially refused planning permission, because they complained, said we were consuming the floodplain. [...] well what was interesting was when it comes to build a new nuclear power station, three buildings of six reactors, the fact that that will consume 100 acres of floodplain doesn't matter. Hence come back to my point about there's rules for us little people, but when it comes to big businesses like that, "oh no this is judged by different criteria"'.

5. Discussion

5.1. Comparing expert and public perceptions

In this section, we compare each aspect of public SLC understandings with the relevant part of the expert model. We find that, despite the public not feeling well informed about SLC, many aspects of their mental models align with expert understandings. Regarding the drivers and rates of SLC, most participants think that sea levels will rise, and half of interview respondents recognised the significance of combined events such as a storm surge at high tide. There is much uncertainty about the rates of future sea-level rise, which is consistent with the expert model, and is unsurprising considering the complexity of the issue and an increased range of projections in recent media coverage (Rick et al., 2011). As would be expected in mental models research, some aspects of the expert model are more salient (i.e. prominent or important) amongst the public than others. Ice-melt is salient, although there is some confusion over which ice is more important. Whilst *land-based* ice melt is one of the two dominant drivers of long-term mean sea-level rise in the expert model (the other being thermal expansion), most survey participants thought that it is mainly caused by *melting icebergs/sea-ice*. While this highlights a difference between public and expert mental models about the main causes of sea-level rise, it may indicate that participants link it with melting ice per se rather than the specifics. Indeed, most survey respondents also agree with the expert model that *melting land-based ice* causes global sea-level rise. This finding is perhaps not surprising considering it is a very specific aspect of the science, which could be easily confused by communicators and the public. More interesting and significant perhaps is the finding that there is a lower awareness of thermal expansion of ocean-surface water (also noted by Read et al., 1994; Lorenzoni et al., 2006; Reynolds et al., 2010; Tobler et al., 2012), and of the role of local subsidence in raising relative sea levels. All of these factors are important because they may affect individuals' risk assessments, as exemplified by Glenda, who having seen glaciers melting in Norway and not having heard of thermal expansion, inferred that because glaciers are 'relatively small', sea-level rise 'wouldn't be more than an inch or so'.

Public understandings of the physical impacts of SLC are also broadly consistent with expert understandings, with most survey respondents believing sea-level rise will be an overall risk to the Estuary and posing threats of erosion, flooding and ecological change. Regarding socio-economic impacts, damage to homes and property was of high salience amongst interviewees, and most survey participants also think that rises in sea level will lead to difficulties obtaining home insurance, travel disruption and emotional impacts. Interviewees rarely mentioned knock-on impacts such as inconvenience. This may be because people are more likely to think about impacts that directly concern them, and echoes previous research showing that public knowledge of climate change consequences tends to focus on immediate physical impacts such as flooding rather than more indirect impacts such as social disruption (Lorenzoni et al., 2006; Capstick et al., 2013).

Regarding what can be done to mitigate or adapt to SLC, there was generally good alignment between public and expert models. Renewable technologies were perceived by a large proportion to be an effective mitigation measure, a view consistent with the expert model (notwithstanding substantial time lags and committed rise) and with previous research (Parkhill et al., 2013). The finding that 12% of respondents rank recycling amongst the top three most effective mitigation measures is inconsistent with the expert model, and also echoes previous research (e.g. Read et al., 1994, Lowe et al., 2006) showing that recycling is consistently cited as a key climate mitigation measure, even though other responses are deemed much more effective.

5.2. Other factors contributing to public mental models of SLC

A key contribution of this study is to illuminate other factors, in addition to knowledge, that contribute to public mental models of SLC. As shown in Fig. 4, these include levels of concern, perceptions of self-efficacy and responsibility, trust and ways of actively engaging with or avoiding the issue. We found that such responses vary widely. This may in part be because the public does not feel well informed, and so do not have clearly defined responses to it. Despite large variation however, some patterns emerge. Firstly, the issue is not highly salient, in line with research that shows climate change has low salience due to its complexity and distance in space and time (e.g. Lorenzoni and Pidgeon, 2006; Spence et al., 2012; Parkhill et al., 2013). Individuals do not tend to think about it much, and among interviewees at least, concern is low compared to other issues such as the economy. These findings echo research that shows climate change per se similarly receives a low priority compared to day-to-day issues, particularly personal economic security (Lorenzoni et al., 2007; Zsamboky et al., 2011). Compared to specific issues facing the Severn Estuary however, SLC ranks highly, and flooding is a particular concern. Indeed, flooding was the most salient theme in the public model, which is consistent with the high importance assigned to it by experts, and would be

expected considering the historical record and personal experience of flooding on the Estuary (e.g. Marx et al., 2007).

One reason that many participants express low concern about SLC may be that although most believe SLC will affect the Estuary, in general people see it as something that will happen to other people, in the future. It is a nuanced picture however, and our findings resonate with research that shows climate change is perceived as 'being both distant and local in nature' (Spence et al., 2012, 970). Indeed, the psychological distancing of SLC can be interpreted in a variety of ways. First, as a rational evaluation of the evidence. Interview and survey participants tended to think that SLC would affect the rest of the world more than it will affect them personally, and this is valid if we assume the 'rest of the world' means low-lying developing countries (as indicated by interviewees), which will likely be affected more than the Severn Estuary (Nicholls and Cazenave, 2010). And while interviewees widely talked about SLC predominantly affecting future generations, this is also likely to be true when we consider time lags and increasing rates of rise (IPCC, 2014). Second, it can be interpreted in the context of the availability heuristic (Tversky and Kahneman, 1973). Ruby (from Penarth) for instance thought Gloucester was vulnerable to SLC, linking it to recent events there that she easily recalled: 'I mean there was the huge flood wasn't there? A few years ago, Gloucester way'.

While a third explanation for psychological distance could be denial and dissociation from personal involvement (Lorenzoni and Pidgeon, 2006), our results show that a significant proportion of survey participants perceive that the causes and impacts of SLC *are* their responsibility. This is counter to research that shows a transferral of responsibility in relation to sea-level rise (Harvatt et al., 2011), and climate change more generally (Poortinga et al., 2006; Spence et al., 2010; Pidgeon, 2012; Capstick et al., 2013). The situation is not straight forward however, and a larger proportion think that it is the government's responsibility to respond to the associated risk of flooding, indicating that at least some of the responsibility is transferred to others. Interviewees expressed similar views, and consistent with previous literature (Kreibich et al., 2009; Harvatt et al., 2011), survey respondents focused more on mitigation and adaptation measures that are the responsibility of the government (e.g. dredging and geoengineering) rather than the individual (e.g. personal lifestyle changes). The relatively high importance assigned to geoengineering and reducing or limiting population growth (Fig. 4) are interesting considering that these are perhaps the most 'extreme' measures, but *may* have been viewed as options that require little or no personal day-to-day sacrifice. This responsibility transferral was accompanied by a distrust in the agencies perceived to be responsible. Participants did not tend to feel well protected by flood defences, and expressed exasperation with how SLC was being dealt with. Our results therefore suggest that the public has a 'critical trust' in these agencies (Poortinga and Pidgeon, 2003b; Walls et al., 2004), whereby they do not distrust them outright (they expect them to deal with the issues), but do not uncritically accept their decisions either; instead viewing them with a degree of scepticism.

The finding that people respond to SLC with optimism or avoidance is no surprise when we consider reactions to climate change and other risks (e.g. Norgaard, 2006; Bickerstaff and Simmons, 2009), but both have been noted as potential barriers towards climate change engagement (Lorenzoni et al., 2007; Gifford, 2011). While these responses may provide ways of coping with SLC, they are 'maladaptive' because they do nothing to prevent negative impacts, and may even make them worse, for instance by encouraging building on floodplains (Grothmann and Patt, 2005).

5.3. Implications

The public do not feel well informed about SLC, and there are some important differences between public and expert perceptions, indicating that improved communications are necessary. The complexity of the expert model means that communications will not be straightforward, and must be selective and carefully designed. They must focus on key messages so as to not waste the public's time and effort (Wynne, 1991) or divert their attention from the most important aspects (Morgan et al., 2002), such as effective adaptation measures. Our findings points to ways in which this might be done.

Although the majority of participants thought that sea levels are rising on the Severn Estuary, some thought that they are falling, and many were unsure about how much long term change is expected in future. Communications should therefore feature estimates of future sea-level rise in the region. Without such estimates, residents are unable to make informed decisions, such as considering moving if sea levels are rising by more than an acceptable amount (Christine). In order to be most salient in decision-making, these might best be communicated when long-term choices are being made, such as buying or renovating a home, or in the context of debates about local planning or development (e.g. house-building, flood defences, renewable schemes). In this respect, communications would not only be timely, but also link to issues that are of greatest concern to residents. Considering visualisation is one of the most powerful ways of making climate change meaningful (O'Neill and Smith, 2014), projections could be communicated using flood depth maps that graphically show the impacts of combined sea-level rise/extreme water level scenarios (cf. Poumadère et al., 2008; Purvis et al., 2008).

Other inconsistencies between public and expert mental models should also be addressed through relevant public communications and within the context of formal education. Many lay participants believe that most global sea-level rise is caused by melting icebergs/sea-ice, and while there is understanding that melting *land*-based ice causes sea-level rise, many do not understand the roles of thermal expansion and isostatic subsidence; perceptions that have implications for how risks are interpreted. Another factor that should be communicated is the concept of combined events, because those who do not understand that rising sea levels exacerbate the effects of extreme levels (e.g. tides, waves, surges) may underestimate the risks. Related to this, communications should draw attention to the potential for abrupt change resulting from these combined events, because those who believe that the impacts of SLC will be gradual may be less prepared for surprises such as storm surges, which have in the past caused extensive loss of life on the Estuary.

Providing information about the risks of SLC may be one step towards increased public engagement. However, in line with previous research (Cox et al., 2003, 2005), we show that public mental models contain many factors in addition to knowledge. These are important, because some may act as barriers to engagement. Individuals who are unconcerned about SLC and see it as a distant threat may be less likely to respond to information about it; those who express low self-efficacy may feel that engagement is futile (Sims and Baumann, 1972; Breakwell, 2007; Lorenzoni et al., 2007); and optimistic individuals may perceive mitigation/adaptation as unnecessary. Risk communications should therefore make the issue relevant to the here and now, and include information about the most effective actions that individuals can take (Bubeck et al., 2012; Pidgeon, 2010). A further option would be to target communications towards segmented audiences (Hine et al., 2014); for example according to whether they are engaged, avoidant, optimistic or concerned.

5.4. Reflections

An underlying difficultly of mental models research is that a definitive model of 'true risk' cannot necessarily be constructed (Rosa, 2003). The terms 'misunderstandings' (Cox et al., 2003), 'misinterpretations' (Cox et al., 2005) 'misconceptions' (Morgan et al., 2002), 'misperceptions' (Austin and Fischhoff, 2011; Lata and Nunn, 2011) and 'incorrect beliefs' (Read et al., 1994; Morgan et al., 2002; Reynolds et al., 2010) are common in mental models literature, and imply that the expert model is definitively correct or true, while the public model is not. This is of course not necessarily the case (see for example Kuhn, 1962; Edge, 1995). Though an expert model is a very useful tool in exploring public perceptions, as it proved to be here, an appraisal of local and tacit knowledges and how these inform day-to-day and long-term decision-making would be a valuable extension to the research.

The expert model is a snapshot of understanding, so might change if different experts were interviewed or different literature consulted, at a different time. The same applies to the public respondents; surveying a different group of people may have offered different insights. Here, the interview and survey samples overrepresented participants with higher education levels. The researcher too is not a passive arbiter, and the diagram summarising the expert model inevitably bears some imprint of the researchers who produce it (Lowe and Lorenzoni, 2007). In our case, we approached the issue with prior assumptions that SLC is a cause for concern on the Estuary, alongside first-hand experience of living in and having studied the region for some years.

Finally, the ways in which models are elicited, recorded and analysed can all affect research outcomes. The use of the term 'sea-level change' as opposed to the more usual 'sea-level rise' may have influenced results. Indeed, survey respondents felt less informed about SLC than participants felt about sea-level rise per se in the CLAMER study (2011); which may have been due to the positioning of the question after 'knowledge' type questions in the current survey, or it may have been due to some confusion over the use of the term 'SLC'. However, responses to the term during interviews indicated that it was not confusing: all interviewees talked about long term change, and some talked about short-term change in addition. Indeed, likely due to the use of this term, some respondents expressed the belief that sea levels might fall, yielding a valuable insight for future communications.

6. Conclusions

This study has shown the merits of utilising a mental models approach to gain a deeper, more holistic understanding of public perceptions of SLC, and has provided insights for how risks might best be communicated in future. While concentrating on the Severn Estuary facilitated an in-depth assessment of a specific area, a case-study focus limits our potential to contribute to discussions of SLC perceptions more widely. Thus, the study should be replicated in other, different at-risk areas. Furthermore, addressing the barriers to engagement that we have outlined may not be the end of the story. There are currently many institutional obstacles to engagement, such as a lack of enabling initiatives (Lorenzoni et al., 2007), planning legislation (Barnett et al., 2013) and coastal-defence spending cuts (Zsamboky et al., 2011); which public communication campaigns cannot address. Improved communications must therefore be accompanied by initiatives that enable residents to respond to risks in appropriate ways, and by timely and effective coastal management that is understood and trusted by those it is designed to serve.

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Appendices. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2015.04.009.

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