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"We can't do it on our own!"—Integrating stakeholder and scientific knowledge of future flood risk to inform climate change adaptation planning in a coastal region

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A B S T R A C T

Decision-makers face a particular challenge in planning for climate adaptation. The complexity of climate change's likely impacts, such as increased flooding, has widened the scope of information necessary to take action. This is particularly the case in valuable low-lying coastal regions, which host many competing interests, and where there is a growing need to draw from varied fields in the risk-based management of flooding. The rising scrutiny over science's ability to match expectations of policy actors has called for the integration of stakeholder and scientific knowledge domains. Focusing on the Broads — the United Kingdom's largest protected wetland — this study looked to assess future flood risk and consider potential adaptation responses in a collaborative approach. Interviews and surveys with local stakeholders accompanied the development of a hydraulic model in an iterative participatory design, centred on a scientist-stakeholder workshop. Knowledge and perspectives were shared on processes driving risk in the Broads, as well as on the implications of adaptation measures, allowing for their prioritisation. The research outcomes highlight not only the challenges that scientist-stakeholder integrated assessments of future flood risk face, but also their potential to lead to the production of useful information for decision-making.

1. Introduction

Climate change poses a particular challenge due to the significant uncertainties that exist over its timing, magnitude and impacts. These impacts, such as the potential increase in flood risk, are likely to have widespread and disastrous effects without the adaptation of human and natural systems (IPCC, 2014). The prevailing complexities associated with climate change have contributed in the last decades to a paradigm shift in both flood policy and flood risk research. In England for example, there has been a transition away from traditional structural and engineering-based flood protection policies to an integrated management of flood risk (Environment Agency, 2000). Integrated Flood Risk Management (FRM) looks to recognise the interrelationships between risk management measures at the catchment level within changing social, economic and environmental contexts (Hall et al., 2003). The trend for more risk-based management emphasises the need in climate change adaptation planning not just to look at environmental hazard, but also to account for vulnerability and exposure (IPCC, 2012).

Research on flood risk has followed a path that is parallel to flood policy to examine the challenges introduced by climate change. Studies taking an interdisciplinary stance and drawing from different scientific fields to evaluate climate impacts and vulnerability have gained in popularity (e.g., Kaspersen and Halsnæs, 2017; Xie et al., 2017). Many of these works are part of the emerging methodological framework of Integrated Assessment (IA). Kloprogge and Sluijs (2006) defined IA as the "process of combining, interpreting and communicating knowledge from diverse scientific disciplines". The rationale for IA is that single-field assessments are inadequate to deal with global environmental risks and to provide useful information to decision makers (Rotmans, 1998). While IA is described as a "link between knowledge and action" (Farrell and Jäger, 2005), there is still concern over a gap between science and policy on climate adaptation (Mastrandrea et al., 2010; Kirchhoff et al., 2015). This has spurred recent efforts to expand the scope of IA towards knowledge claims other than from just scientific domains, notably with participation of multiple stakeholders in the input of information (Kloprogge and Sluijs, 2006).

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Participatory approaches have gained in popularity alongside a shift in the relation between science and policy. The rejection of science's traditional "top-down" stance to inform decision-making unilaterally (Pielke, 2007) has indeed been accompanied by efforts to make science more accountable and therefore more likely to be seen as acceptable (Voinov and Bousquet, 2010; Chilvers and Kearnes, 2016). Additionally, participation can be seen as a way to empower stakeholders, giving them a more central role in the generation of knowledge and therefore increasing their capacity to make use of that knowledge (Stringer et al., 2006). Studies have moreover found that a participatory approach can lead to social learning (e.g., Steyaert et al., 2007; Evers et al., 2016), where stakeholders gain from each other, leading them to appreciate each other's views and develop valuable relationships or networks (Reed et al., 2010). The trend for increased participation has also taken root in environmental modelling. Arguments have been made for a change in the traditional stance modellers take, including in FRM where computer programs typically take up an important role (Landström et al., 2011). Krueger et al. (2012) argued that stakeholder scrutiny could not only be applied to model results, but also on the technical process of modelling itself to generate new knowledge.

Being closely linked to civil engineering, FRM remains a field where expert knowledge holds a significant role and in which stakeholder engagement may even be perceived as a threat, rather than the solution (Edelenbos et al., 2016). Stakeholder engagement in general faces many challenges, which has led debates over its actual benefits (Reed, 2008). Tseng and Penning-Rowsell (2012) identified key barriers to stakeholder engagement in FRM ranging from the lack of an institutionalised and early engagement process to resistance experienced from stakeholders. Few et al. (2007) moreover described the challenges created by power dynamics, where leading authorities may use the pretence of participation as a way to steer outcomes to predefined goals in lieu of engaging with stakeholder perceptions or interests.

The potential gains from participation remain important in climate adaptation, as impacts are likely to be felt throughout society and experienced or perceived differently by various actors. Moreover, the effects of climate change may exacerbate cross-sectoral competition for resources and funding leading to different preferences for action. Coastal regions in particular are faced with the challenge of hosting greatly varying interests from a wide range of stakeholders (Tompkins et al., 2008; Day et al., 2015). The expansion of IAs to include stakeholders allows for new opportunities to produce knowledge in these areas through the collaboration of scientists, policy makers and other societal actors (Hegger et al., 2012). In practice however, there are still few studies that attempt a participatory approach in the IA of flood risk to inform adaptation planning (Kettle et al., 2014; Löschner et al., 2016).

This paper describes the work that was carried out in the Broads wetland in the United Kingdom (UK). The goal of the research was to combine different knowledge domains to assess flood risk and consider potential adaptation measures for the study area. Stakeholders were engaged, most notably in a collaborative workshop, with information from a scientific analysis of flood risk from a hydraulic model developed as part of this project. The aims of this research were to determine (1) how scientific information and stakeholder knowledge and perceptions on flood risk can be integrated, (2) how such a collaborative approach can translate risk-based management principles relevant for climate adaptation planning and (3) the lessons that can be derived from the participatory IA of flood risk to inform adaptation planning in the context of the Broads.

1.1. Study area

1.1.1. The Broads, UK

Located on the eastern coast of England, the Norfolk and Suffolk Broads form Britain's largest designated wetland (Fig. 1). This network of interconnected rivers and shallow lakes – or "broads" – covers a total area of 303 km^2 at the downstream end of the Broadland Rivers catchment. A predominantly freshwater ecosystem, the Broads is a low-lying area that covers more than 30,000 ha of floodplain. It is the home of 28 Sites of Special Scientific Interest and is internationally recognised for its rich biodiversity, nature conservation, landscape and cultural features. The Broads executive area, closely drawn around the floodplains of its three main rivers, namely the Bure, Yare and Waveney, is managed by the Broads Authority (BA).

The Broads also hold significant economic value both at the local and national level. Agriculture in the area, which primarily consists of livestock grazing and arable cropping, represents an important contributor to the economy. This location is moreover a popular destination for over 7 million visitors a year with tourism contributing to approximately £568 million (Broads Authority, 2019). Additionally, the area's unique hydrological features allow for many recreational or leisure activities, including boating and angling. While the population count in the Broads reaches just above 6000 residents, the National Park is bounded by large urban areas in Norwich, as well as the coastal towns of Lowestoft and Great Yarmouth.

1.1.2. Flood risk management

Much of the land in the Broads is either at or below sea level. The close proximity to the North Sea as well as a complex riverine system leads this area to be at risk from both tidal and fluvial sources of flooding. The Broads have a long history of floods. Most notably, the storm of January 1953 had severe impacts in East Anglia and led to significant subsequent investments in flood protection and forecasting in the country. Several institutional bodies hold a role in the management of flood risk in the Broads as shown in Table 1.

The Broads today are highly engineered with over 240 km of earth embankments serving as flood defences alongside the rivers Bure, Wensum, Waveney, Yare and Ant. These structures have been maintained and strengthened as part of a 20-year strategy that began in 2001 and is being implemented through the Broadland Flood Alleviation Project (BFAP). Flood defences were severely tested in December 2013 by the largest storm surge since 1953, but were successful in minimising flooding in the Broads. Still, the 2013 event is often qualified as a "near miss" and underlined the need for better preparedness.

On the coastline, 14 km of sea defences extend between the villages of Eccles and Winterton to protect the region from coastal flooding. The current strategy for the length of the coastline set up by the Shoreline Management Plan (SMP) adopted in 2012 is to "hold the existing defence line" for the short and medium term (up to 2055). It is worth noting that previous SMP proposal were met with negative reactions and concern from many local communities and organisations. Day et al. (2015) argued that the main reasons for the negative response were that scientific projections were made without associated management plans and with insufficient stakeholder input. Since then, emphasis has been put on stakeholder engagement, but findings ways to integrate the wide range of perspectives remains a challenge.

As the current SMP points out, climatic changes and sea level rise are putting increasing pressure on the region and raising concern over the technical and economic sustainability of current structural approaches. A high level review of flood risk management on the coast and inland conducted in 2016 highlighted that climate impacts should be taken into account to consider a wider range of options in the future (CH2M, 2016). With BFAP ending in 2021, an overarching plan for the Broads is yet to be agreed on, providing an opportunity to update the FRM strategy in the area.

2. Methods

2.1. Preliminary interviews and modelling

A combination of quantitative and qualitative methods were used both as a way to generate research material as well as to assess the

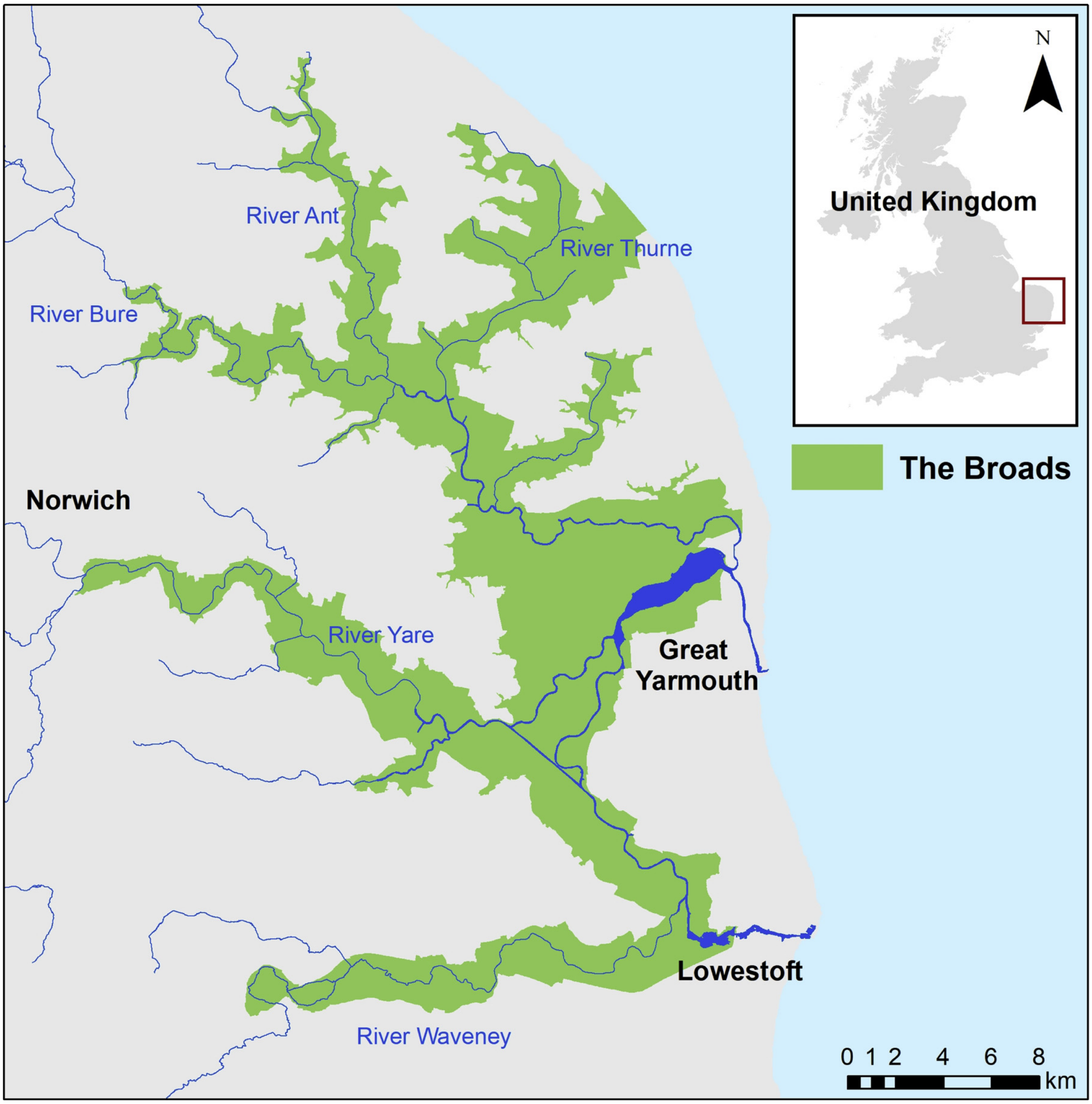

Fig. 1. The Norfolk and Suffolk Broads National Park.

knowledge generation process itself. The main sources of information on flood risk in this project originated iteratively from the development of a hydraulic model and stakeholder engagement exercises (Fig. SM1). For this study, stakeholders were identified and recruited through different methods. This included presenting the research and handing out information leaflets at community meetings in the Broads, advertising stakeholder events on online BA newsletters and by snowball sampling. The different participatory activities in the research design received prior ethical approval from the General Research Ethics Committee of the University of East Anglia.

Exploratory semi-structured interviews were first conducted to identify key overarching issues and interests related to flood risk. A total of 11 interviews were conducted with actors with various interests, namely farmers, conservationists, anglers, local elected officials, coastal managers and engineers.

Findings from the interviews guided the development of the first version of a hydraulic model of the River Bure sub-catchment in the Broads. The model, described by Pasquier et al. (2018) was used to assess the sensitivity of the Broads to fluvial, tidal and coastal sources of flooding under different rates of sea level rise throughout the 21 st

Table 1
Organisations responsible for managing flood risk in the Broadland Catchment (adapted from Broads Climate Partnership, 2016).

Organisations	Role and responsibilities
Broads Authority (BA)	As the local planning authority, the BA can control development in floodplains and manages conservation, recreation and navigation in the Broads.
Environment Agency (EA)	Government agency managing flood risk from main rivers, estuary and the sea. Responsible for river and tidal defences.
County and District Councils	The County Councils are Lead Local Flood Authorities, managing flood risk from surface water, ordinary watercourses and groundwater. The District Councils on the coast take on a coastal erosion protection role.
Water and sewage companies	Manage the risk of flooding to water supply and sewerage facilities and the risk to others from the failure of their infrastructure.
Internal Drainage Board (IDB)	Manage land drainage in lowland areas and the many pumping stations that operate in the Broads.

century. Simple deterministic ("what if") long-term scenarios of extreme storm surges and river discharge were designed to create maps of flooding extent and depth. The flooded area of different land use types was calculated along with the number of flooded buildings by depth to provide a basic comparison of impact. The model as well as the derived analysis and maps served as the foundation for discussions during a stakeholder workshop, the central engagement activity in this research.

2.2. Stakeholder workshop

The workshop design was loosely based on the "Scientific-Stakeholder Workshops" proposed by Löschner et al. (2016) but deviated from that approach in several ways. A method for stakeholder analysis in environment management studies (e.g., Reed et al., 2009; García-Nieto et al., 2015) is to classify stakeholders based on their levels of influence in decision-making and interest, here in FRM. A balanced number of *higher interest/higher influence* (7) and *higher interest/lower influence* (7) stakeholders (Table 2) attended the workshop. Three individuals had previously participated in the exploratory interviews while the remainder were new to the project. The attendees were asked in the week prior to the workshop to respond to an online survey created with Lime Service[1] . A total of 9 responses were submitted. The survey was structured into 4 parts to (1) assess the participant's level of knowledge on flood risk and modelling, and to record their perceptions of (2) current flood risk and management, (3) future conditions and (4) possible adaptation measures in the Broads.

The workshop was divided into three sessions, working under the basic instruction that all perceptions could be shared. Session I aimed to define and get a shared understanding of the problem at hand, using modelling results (i.e. flood maps as shown in Fig. SM2) to spark discussions on hazard, vulnerability and exposure in the Broads. The stakeholders then separated into three groups to discuss potential adaptation strategies for Session II. Each group was moderated by a member of the research team and asked to use detailed A1-size paper maps to draw their proposed adaptation measures. While stakeholders were encouraged to be speculative and not to feel restricted by concerns over economic cost or political will, they were asked to discuss the feasibility of each measure. Indicators to assess these options were purposefully left undefined and open to stakeholder interpretation. The groups were aware that the researchers were interested in modelling the adaptation measures derived from the workshop in subsequent work. The participants were however advised not to limit the solutions they proposed to ones they thought were technically possible to model.

The outcomes from Session II were presented to the rest of the workshop participants during the final Session III. Stakeholders reflected on their respective discussions and lessons learned. Participants carried out a simple prioritisation task for the measures derived from Session II. Each individual had five votes to distribute to any number of options. The workshop ended with final comments, including reflections on the workshop itself. A survey was filled in by the stakeholders to obtain feedback on the workshop and its outcomes.

The workshop was recorded and its transcription coded under the broad headings of vulnerability, exposure, hazard, modelling method, participation process, adaptation and FRM. The last heading referred to statements relevant to flood policy but not directly related to adaptation options, such as land ownership, funding, or the management of competing interests. The coded transcripts, in combination with other sources of data (i.e. the interviews and pre-workshop survey) were analysed to highlight the themes emerging from the stakeholders' perceptions of flood risk and adaptation in the Broads. Perceptions of the scientific information and method represented by the hydraulic model were also considered.

[1] https://broads-floodworkshop.limequery.com/911555?newtest=Y&lang=en

Table 2
Workshop stakeholder affiliations grouped by individuals' levels of influence and interests in FRM.

Higher interest/Higher influence	Higher interest/Lower influence
Broads Authority	Norfolk Wildlife Trust
Internal Drainage Board	Royal Society for the Protection of Birds
Norfolk County Council, Suffolk County Council	National Farmers' Union, farmers
Broadland District Council	Broads Angling Services Group
Coastal engineers and managers	Broads Navigation

2.3. Modelling adaptation measures and final feedback

Outputs from the workshop were used to refine the modelling methodology and define future scenarios. The adaptation measures which received the most votes during Session III of the workshop were implemented within the hydraulic model. The ensuing simulations showed the impact of these measures on flooding extent and depth in the Broads under future scenarios of climate change and sea level rise up to 2080. The resulting flood maps were finally presented individually to stakeholders who had participated to the workshop, to obtain their feedback on the proposed adaptation measures and future flooding risk.

3. Results

The research results are divided into three sub-sections. The first describes the outcomes of the integration of stakeholder and scientific domains within the participatory process. The second focuses on the assessment of future flood risk in the Broads from different knowledge domains. The last sub-section focuses on stakeholder perceptions of adaptation drawn from their engagement and reactions to model results.

3.1. Outcomes of the participatory process

The participatory process allowed for multiple phases of interaction between different knowledge domains. The preliminary stakeholder interviews provided information on which to base early hydraulic modelling choices such as the geographic extent (from inland to the coast), processes to depict in scenarios (e.g., compounding events of simultaneous extreme river flow and sea level), model design (represent coastal urban areas in more detail), as well as the choice of modelling software itself (HEC-RAS, a freely available online software). All stakeholders agreed (100%) that the flood maps resulting from this model were suitable for stimulating discussions during the workshop (Fig. 2).

The workshop's format was deemed appropriate as the main interface between scientific and stakeholder knowledge, but it also brought together participants who had never met and who were not accustomed to exchanging knowledge in such a setting. Still, varying opinions and experiences were represented. Stakeholders agreed (93%) that they were able to appreciate cross-sectoral challenges and competing interests (Fig. 2). One of the workshop's concluding statements reinforced this finding:

"It's all about partnership working. We can't do it on our own! This is why these types of meetings are so important" (Stakeholder 5, conservancy)

While the majority of responses (93%) found the mix of workshop participants to be appropriate, *lower influence* stakeholders expressed in written feedback and during discussions that they would have preferred to see more representation from the EA. Only 43% of stakeholders agreed that their views of adaptation measures had changed from the workshop. Still, all participants (100%) found that the event allowed them to expand their knowledge of flood risk.

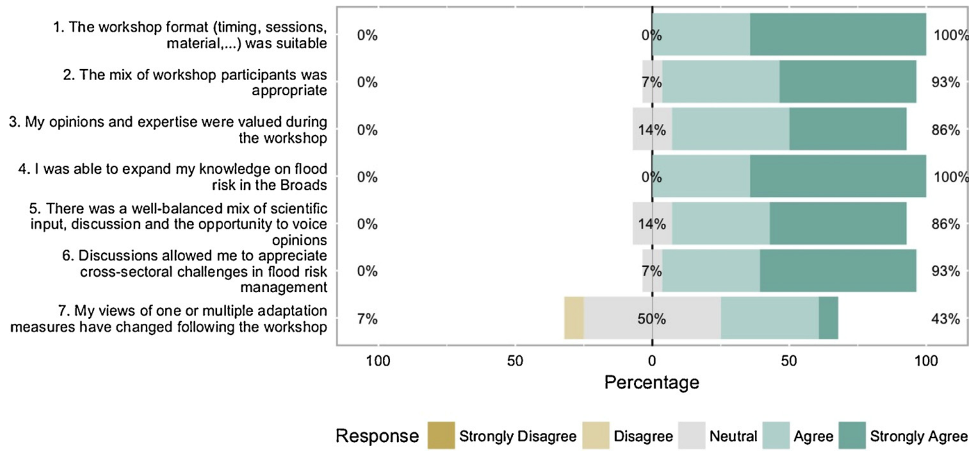

Fig. 2. Post-workshop stakeholder reflections and feedback (n = 14).

Based on the interest and knowledge of stakeholders, information was generated at the workshop that influenced scientific modelling choices. Recommendations were made to expand the model's coverage from the River Bure catchment to the rest of the Broads (Fig. SM3). Concerns were indeed raised – particularly from coastal managers – that flood alleviation measures implemented in one area could have unintended negative consequences in another. A more comprehensive model would therefore be able to capture interlinked processes leading to flooding. In another effort to facilitate their decision-making on actions to take, *higher influence* stakeholders requested to see scenarios in the short to medium term to show how risk will progress with time. Finally, as will be discussed further, stakeholders stressed the importance of assessing flooding risk alongside salinity issues. A water quality module was therefore added to the hydraulic model, capable of simulating in-channel salinity concentration and its ingress within Broads Rivers during storm surges.

3.2. Risk assessment

Information used to assess flood risk in the Broads originated from both scientific findings and stakeholder input. The preliminary hydraulic modelling showed that sea level rise represents a considerable threat for the Broads and its flood defences under extreme storm surge conditions. Simultaneous extreme river discharge and sea level events were found to exacerbate flooding in upstream areas. While urban areas, farmland, and protected areas were affected by flooding, the magnitude of impacts were highly dependent on the rate of sea level rise over the next decades (Pasquier et al., 2018).

While stakeholders had varied backgrounds with different levels of expertise in FRM, the exploratory interviews as well as the pre-workshop survey emphasised the general agreement that flooding risk is a critical concern for the Broads (Fig. 3) and is likely to increase in the future (89% of positive responses, Fig. SM4). Storm surge events were mostly perceived as the main cause for flooding in the Broads (67%), with compound events representing a particular concern (89%). These perceptions therefore aligned with the scientific information provided by the hydraulic model, though a more detailed analysis is required to understand the physical processes behind compound events.

The 2013 "near miss" event was mentioned by two *higher influence* stakeholders as a reference for the type of hazard experienced in the Broads and to set the context during the workshop's Session I. Although both *higher influence* and *lower influence* stakeholders expressed concerns for compound events in the workshop's first two sessions, there were differences in the perception of such hazards:

"I'm very pleased that the problem of coinciding events is emphasised in the model. Tidal surges with high river flows. There isn't really an issue without that coincidence." (*Stakeholder 1*, navigation)

"I don't agree with that statement. We have had rainfall events, such as in 2012, that have had significant impacts." (*Stakeholder 2*, catchment engineer)

And:

"It's interesting to look at dual events, which we haven't faced so far." (*Stakeholder 3*, local administration)

"I'm pleased that this has been brought in because it is something that has been overlooked. The [current strategy] didn't really address that at all." (*Stakeholder 4*, local administration)

The issue of salinity within the Broads system was raised during the workshop and was primarily brought forward from the perspective of angling interests. The threat that encroaching saline waters pose to protected areas and farmland was also emphasised. Farmers pointed out the impact that salinity has on agricultural land in greatly increasing recovery time from flooding. Despite the general agreement that — the Broads being a predominantly freshwater system — increased salinity due to sea level rise would challenge current management practices, workshop discussions highlighted differences between angling and conservation interests:

"I find it interesting that people are thinking that salt is necessarily bad. Salt is bad in a fresh system. But in an area dedicated as salty, it can be good. It's about making sure…" (*Stakeholder 5*, conservancy)

"What we're talking about here is saline incursion going 18 miles from the sea. It's just not right, it's killing everything." (*Stakeholder 6*, angling)

"No it's not. But if there was an option to create an area to divert all the salt water into. A system designed to cope with that salt water. Then the system would eventually adapt to be able to cope with that salt water. Then it becomes a positive." (*Stakeholder 5*, conservancy)

Cross-sectoral interests were represented at the workshop in discussions of vulnerability and exposure. Stakeholders stressed the unique exposure that the Broads face due to their flat and low-lying landscape as well as their proximity to the sea. Close to equal attention was attributed to the vulnerability of freshwater habitats (located in *"some of the most unsustainable locations in the long term" Stakeholder 2, catchment engineer*), population centres, farming, tourism, fisheries and other businesses. The impact of flooding on key infrastructure such as important roads or power installations were mentioned in light of how it may affect the resilience of communities, in particular in Great Yarmouth on the coast.

Finally, while a small majority of stakeholders (56%) agreed that existing flood alleviation measures were successful in limiting present flood risk, the agreement was much less pronounced (33%) over whether the current level of defence provided to vulnerable areas in the Broads was sufficient (Fig. 3). Following the workshop, model outputs showed that the southern parts of the Broads (e.g. Yare and Waveney catchments) were more exposed to flooding than northern catchments.

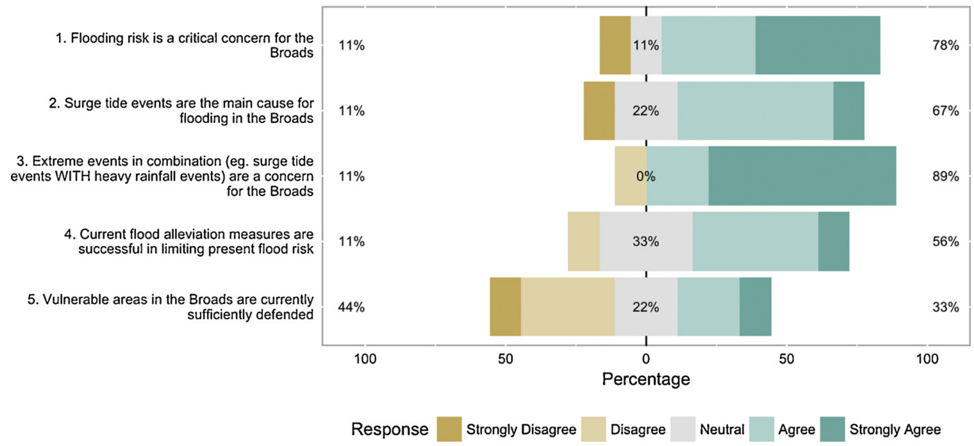

Fig. 3. Stakeholder perception of current flood risk and its management in the Broads (n = 9; 5 stakeholders present at the workshop did not submit responses). Data gathered from an online pre-workshop survey.

Local stakeholders from farming, conservation and engineering positions confirmed this finding met their expectations, indicating the model was performing as intended.

3.3. Climate change adaptation

When asked in the pre-workshop survey to rate adaptation options from a list (or any other measures of their choice) stakeholders overwhelmingly rated “do nothing” as the least preferable. 89 % of stakeholders either agreed or strongly agreed that measures should be taken to anticipate future flood risk. This view was represented during the workshop:

“We have choices, and they are all expensive, but unless we start planning for change, nature will take its course, change will be unplanned and that’s not desirable either.” (*Stakeholder 5*, conservancy)

Three *higher influence* stakeholders from local public administration mentioned the economic constraints of adaptation at the workshop, referring to the cost of raising flood defences. While two of the three stakeholder groups in the workshop's Session II listed raising defences as an adaptation option, this measure received the least number of votes during the prioritisation exercise (Table 3), and was deemed the second least preferable (after "do nothing") in the pre-workshop survey.

The most popular adaptation measure, which was mentioned in all three workshop groups by both *higher* and *lower influence* stakeholders, was to allow water to flood designated areas (referred to as "sacrificial land") to increase the Broads' storage capacity and therefore alleviate flooding in the rest of the system during extreme events. Although stakeholders were able to identify areas that could serve for flood storage, farmers and conservancy managers respectively stated that such efforts would require a plan to compensate land owners and create new habitat. The model results showed that while dedicating a large area of close to 8 km^2 to store water could have local advantages in protecting surrounding land, it could not on its own prevent flooding across the Broads. The consideration of salinity in the hydraulic model was considered an important addition to support decision making on this measure. Land flooded with saline water as opposed to fresh water would indeed require a prompt pumping scheme following an extreme event to prevent long lasting damages.

The construction of a tidal barrier on the River Yare received attention at the workshop, as it has in the past in the Broads (CH2M, 2016). The most commonly proposed design is a vertical gate in Great Yarmouth – approximately 4 km upstream from the North Sea – which would close off the river at high tide to prevent upstream flooding. As an important infrastructure, the issue of its financing were met with statements by engineers that this option "may become more cost effective than upgrading embankments" with climate change. Despite the interest it generated during the workshop, concerns about the barrier were raised by emergency planners and local officials as a response to model results. The simulated impact of the tidal barrier indeed showed that while it would be able to limit flooding in the Broads, it would also increase risk for Great Yarmouth, a key population centre, and would require substantive engineering work to raise flood walls in the coastal town.

The feedback on the model results showed an understanding among different stakeholders that the Broads’ future adaptation strategy could not rely on a single measure. Both during the workshop and final feedback exchanges, there were interests expressed in moving away from hard engineering options to more natural management strategies. Environmental managers brought forward the idea of sustainable management of drainage and water flows in upstream parts of the catchment, which received a high number of votes at the workshop (Table 3). Discussions however also highlighted two fundamental contrasting stances around floodplain management. While farmers expressed their desire to restore the natural flow and connectivity of rivers with surrounding floodplains, catchment engineers pointed out that letting water flow out-of-bank would infringe on other interests

Table 3
Results of prioritisation exercise during stakeholder workshop.

Adaptation Measure	Number of attributed priority votes
Flood Storage Areas: dedicated to hold either fresh or saline water depending on their location in the catchment	16
Tidal barrier: either a large structure near the mouth of the River Yare, or smaller structures on estuaries	15
Sustainable Drainage Systems (e.g. woodlands to slow upstream flow of water into the system)	13
Surveying floodplains	9
Communicate risks, inform and build community resilience	7
Put in place a water quality monitoring system	4
Re-site pumping stations	3
Migrate back from floodplains, creating new freshwater habitats	2
Raising defences	1

and require expensive pumping operations.

4. Discussion

The iterative process underpinning this study allowed for both stakeholder and scientific domains of knowledge to influence the other. The inclusion of different perspectives was positively received by participants and led to knowledge exchange at multiple levels. Model results were used as a basis for workshop discussions and helped stakeholders connect future hazards to potential local impacts. The expression of, sometimes competing, interests facilitated not only the definition and prioritisation of adaptation scenarios (Maskrey et al., 2016), but also the framing of the modelling methodology itself.

While stakeholders showed a willingness for action and to see a shift in FRM away from traditional measures (i.e. maintaining and raising flood defences), discussions still highlighted important hurdles for climate adaptation. The expansion of the hydraulic model and its added consideration of salinity are examples of outcomes that were directly derived from stakeholder interests and helped to overcome some of these hurdles. These results provide a case for a flexible modelling stance and the inclusion of stakeholder knowledge to co-produce information that is more relevant for decision making (Landström et al., 2011; Krueger et al., 2012). The study however also highlighted the limits to which scientific modelling alone can drive adaptation planning. Measures such as increasing flood storage or constructing tidal barriers can be successful in reducing flood hazard while coming at a cost for certain stakeholders. This cost must be carefully understood and managed for adaptation to be possible. Therefore there is a need to not only include stakeholders in the assessment of flood risk, but also to involve those affected or providing the resources necessary to make these options possible.

The composition of actors involved is a key criteria for the success of knowledge production (Hegger et al., 2012). The presence of exclusively *higher interest* stakeholders at the workshop facilitated discussions. Participants were indeed already sensitised to flooding issues in the Broads. While they represented different fields of expertise, they were able to quickly understand and react to model outputs as well as to come up with adaptation measures with few prompts. The absence of EA representatives at the workshop — who were interviewed before and after but not present on the day — was seen negatively by *lower influence* stakeholders. The EA plays a critical role in the definition of FRM policy at the national level. The traditionally top-down FRM process in England, led by the EA's technical expertise, can explain the stakeholders' expectations (Thaler and Hartmann, 2016). Limiting the workshop to local actors however represented an opportunity for discussions to be less constrained by the national context.

Löschner et al. (2016) argued that scientist-stakeholder workshops on flood risk are unlikely to become institutionalised, despite their usefulness. These types of activities indeed require considerable resources and planning. Due to time and funding restrictions, only one workshop with 14 stakeholders was held as part of this research. A better representation of perceptions of flood risk in the Broads could have been obtained by including a wider range of stakeholder interests. The multiplication of participatory events can however lead to stakeholder fatigue, which Turner et al. (2016) has already previously shown to be an issue in the Broads.

5. Conclusion

The presented collaborative approach carried out in the Broads National Park highlighted some of the benefits, potential and challenges of integrating scientific and stakeholder knowledge to generate information on flood risk and adaptation. As previous work has shown, the early and iterative exchange between these domains increases the likelihood of improving the value and usefulness of scientific results. A shared understanding among stakeholders emerged from this study showing a collective concern for flood risk alongside an interest in a potential change in FRM practices. As the Broads area enters a new phase of FRM, there is an opportunity to gain from bringing together different knowledge domains to plan adaptation going forward.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found in the online version at doi:https://doi.org/10.1016/j.envsci.2019.10.016.

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