Marine Management Organisation

Potential spatial effects of climate change in the South and East Marine Plan Areas

March 2016

Potential spatial effects of climate change in the South and East Marine Plan Areas

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Executive Summary

This report identifies sectors specified in the Marine Policy Statement within the East Inshore and Offshore, and South Inshore and Offshore Marine Plan Areas that are likely to be at risk from the effects of future climate change. This report reviews existing evidence on climate adaptation and mitigation strategies and includes potential impacts on usage of the marine area.

The objectives of this report are to:

1. Confirm which information from UK climate projections 2009 (UKCP09) is the most useful for marine planning and explain why.
2. Produce maps at appropriate temporal and spatial scales for the East Inshore and Offshore Marine Plan Areas and South Inshore and Offshore Marine Plan Areas.
3. Identify within the East Inshore and Offshore Marine Plan Areas and South Inshore and Offshore Marine Plan Areas which sectors are likely to be at risk or to benefit from the effects of climate change, and what the impacts may be.
4. Identify where conflicts between sectors may arise as a result of changing use patterns in response to the impact of climate change.
5. Review and build on climate adaptation and mitigation advice in national publications making specific recommendations for the East Inshore and Offshore Marine Plan Areas and South Inshore and Offshore Marine Plan Areas.

A list of activities has been produced for the South and East marine plan areas based on existing MMO literature and the following industries or sectors have been identified as being at particularly high risk from the effects of climate change: ports and shipping, aggregate extraction, fisheries, aquaculture, tourism and recreation, protected areas, power stations, waste water management, and defence. A number of negative and positive impacts of climate change on marine sectors have been highlighted and the key risks prioritised in terms of urgency and severity.

The following climate change drivers have been taken into account in this report: sea level rise/coastal flooding, extreme storms and waves, air and sea temperature rise, ocean acidification, changes to terrestrial inputs (riverine flow and flooding), and changes to ocean currents. A standard risk assessment methodology has been used to compare probability against impact for these climate change variables and their impact on current and future activities has been assessed. The analysis produced ten highest scoring risks and five highest scoring benefits, in summary:

- Ports and shipping: structures and infrastructure are likely to be negatively affected by changes in storminess but potentially benefit through opening of northern routes through the Arctic.
- Aggregates: operations at sea may be disrupted but there will be increased need for aggregates for use in coastal defence.
- Fisheries: a decline of some traditional stocks may occur but new opportunities may arise based on incoming species.

- Aquaculture: increased risk of some diseases and nuisance species but potentially new opportunities to grow and culture novel species.
- Tourism and recreation: storm damage to structures and beach erosion but increased visitor numbers and participation in leisure activities.
- Protected areas: storm and sea level damage to certain protected habitats, shifts in species distributions beyond marine protected area (MPA) boundaries.
- Power stations: site integrity and safety at risk from inundation and flooding.
- Waste water management: increased pollution risks.
- Defence: inundation and flooding of Royal Navy facilities – damage to equipment and structures.

The activities identified as being most at risk have been mapped spatially and these maps reveal sites of potential conflict and concern. The potential conflicts between sectors as they expand and adapt to climate change are discussed.

A number of climate change adaptation recommendations are made, for the MMO to consider either with regard to the South and East marine plan areas or in consultation with partners, these include:

1. Marine plans should take account of the information already available “off the shelf” from UKCP09 and other sources.
2. The next tranche of marine plans should draw upon new probabilistic scenario outputs that will become available as a result of the Defra MINERVA project.
3. The feasibility of using Shoreline Management Plans for each area to promote specific policies regarding climate change adaptation should be explored.
4. Proactive planning policies relating to changing shipping routes and ship designs that include consideration of vessel sizes (draught), traffic movements and future requirements for new port facilities or dredged channels should be explored.
5. The MMO should keep abreast of information regarding the opening up of the northern shipping routes and in particular whether new or reconfigured port facilities may be required to accommodate polar vessels.
6. Marine planning policies should consider emerging marine renewable industries (e.g. growing marine biofuels) and the potential for co-location of these areas with other activities where possible.
7. The MMO should engage in regular “horizon scanning” exercises to determine what, and where, activities might occur in the future.
8. The MMO should consult the emerging scientific literature concerning future projections of distribution for commercial fishes and conservation species under climate change scenarios.
9. The MMO could encourage the commissioning of work that attempts to predict the future distribution of fishing vessels as a consequence of changing fish distributions.
10. Marine planning should consider the need for new localities for aquaculture where pathogen loads may be lower in the future, or which may be more sheltered from storms.
11. Should there be a drive from industry to develop aquaculture of new species sufficient space should be set aside in marine plans to accommodate these new developments.

12. The MMO should re-visit marine plans once new information about ocean acidification is available, and in particular to examine spatial outputs/projections from computer modelling and monitoring components of these programmes.
13. That marine plans consider what new areas for different sectors might be needed in the future as a result of climate change.
14. Information from the forthcoming Marine Climate Change Impacts Partnership (MCCIP) “special topic card” on MPAs to refine existing marine plans and MPA networks, once the reviews are published.
15. The MMO should engage with the NERC/Defra project on “blue carbon”, to determine the carbon storage potential of different offshore areas and to consider “trade-offs” in permitting certain areas to be used for development whilst preventing development at sites that are deemed useful/essential for carbon sequestration.
16. Investigations should be carried out to review the potential changing of boundaries of protected areas if they become unsuitable or ineffective due to climate change.
17. How the “adaptive pathways” approach might be used within the context of marine spatial planning should be explored.

1. Introduction and background

This report identifies which sectors within the South and East marine plan areas are likely to be at risk from the effects of future climate change. The study has used data from the UK climate projections 2009 (UKCP09) projections[1] and information on the current and predicted use of the East Inshore and East Offshore, and South Inshore and South Offshore Marine Plan Areas. The UKCP09 projections are the leading source of climate information for the UK and its regions. This report reviews existing advice on climate adaptation and mitigation strategies and includes consideration of potential impacts, both positive and negative, on usage of the marine area, highlighting areas where conflicts and opportunities may arise. Where references are not provided statements are the opinion of those writing this report. This report was originally written in 2014; as such, some sections may include statements about future publications or events which have since occurred.

1.1 Aims of the project

The aim of this project has been to combine future climate data from the UKCP09 projections with information on current and predicted marine activities in the South and East marine plan areas to identify potential climate change impacts and benefits. The project will inform marine policy development by reviewing, and building upon, existing climate adaptation and mitigation documents to enhance marine planning and management of climate change impacts.

The specific objectives are:

1. Identify the information from UKCP09 projections that is the most useful for marine planning needs as outlined in these objectives, and process this data to provide spatial datasets to the MMO as an ESRI Geodatabase according to the Marine Environmental Data and Information Network (MEDIN) metadata discovery standards. Provide details of confidence in the data and information about any data processing that is undertaken.

2. Produce maps of relevant climate change data at appropriate temporal and spatial scales for the East Inshore and Offshore Marine Plan Areas and South Inshore and Offshore Marine Plan Areas.

3. Identify within the South and East marine plan areas which sectors described in the Marine Policy Statement are likely to be at risk or to benefit from the effects of climate change, and what those impacts may be. Provide an assessment of the likelihood of impact based on the confidence of the data used.

4. Identify where spatial conflicts between sectors may arise as a result of changing use patterns in response to the impact of climate change.

[1] http://ukclimateprojections.metoffice.gov.uk/21678 [accessed 06/03/14]

Present this spatially to enable identification of where issues may need to be considered in the future.

5. Review and build upon climate adaptation and mitigation advice in national publications to make specific recommendations for the East Inshore and Offshore Marine Plan Areas and South Inshore and Offshore Marine Plan Areas. This advice will enable marine planners to develop plan policies in relation to climate change mitigation and adaption, and facilitate the implementation of climate change policies in the East and South Marine Plan Areas.

1.2 Background

As outlined in the UK Marine Policy Statement[2], the MMO is required to ensure that the use of the marine area is adequately planned and that such plans take account of potential climate change impacts. Marine plans must contain information about overarching climate change policies and will need to consider appropriate climate change mitigation and adaptation measures.

Information is currently available through government-commissioned sources which outline the potential effects of climate change on the marine environment, such as changes to sea surface temperature, sea level rise and changes in weather patterns. While UKCP09 information provides a strategic long-term (over this century) UK wide view of potential climate change impacts, in their current form the maps available for the marine environment are difficult to interpret for use as part of the marine planning process to support policy development. Tailored information that can be related to specific marine plan areas and timescales in line with marine planning cycles are clearly required.

The UK Marine Policy Statement makes explicit mention (Ref 17, on page 23) of “Climate change adaptation and mitigation”. Specifically, it states that “In marine planning and decision making, consideration will need to be given to how the marine environment can adapt to the impacts of climate change. When developing marine plans, marine plan authorities should make an assessment of likely and potential impacts from climate change and their implications for the location or timing of development and activities over the plan period and beyond”.

Understanding the impacts and effects of climate change and mitigating for, or adapting to these impacts through management is crucial to maintaining a safe, healthy and biodiverse marine environment. This will influence how we use and value our coasts and seas both now and in the future. Adaptation, including in the marine area, is necessary to deal with the potential impacts of these changes. The UK National Adaptation Programme (NAP) along with MCCIP report cards[3] and the UK Climate Change Risk Assessment 2012[4] provide a wealth of information on climate change and its impacts for use in formulating marine plans.

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[2] https://www.gov.uk/government/publications/uk-marine-policy-statement [accessed 05/03/14]
[3] http://www.mccip.org.uk/annual-report-card.aspx [accessed 7/03/14]
[4] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15747#RelatedDocuments [accessed 06/03/14]

1.3 East Inshore and East Offshore Marine Plan Areas

The East Inshore and East Offshore Marine Plan Areas were announced as the first areas for the preparation of marine plans in 2010 (Figure 1). The East marine plan areas include over 58,700 square kilometres of sea.

Key features of the East marine plan areas are:

- The Port of Felixstowe (Suffolk), the largest container port in the United Kingdom, dealing with over 40% of Britain's containerised trade.
- The Sizewell Nuclear Power Stations A and B. A third station, C, has been proposed for development with two reactors located on land next to the current Sizewell B. Sizewell C aims to supply low-carbon energy for up to five million homes.
- The Wash, the largest tidal embayment in England. It is made up of very extensive salt marshes, major intertidal banks of sand and mud, shallow waters and deep channels. The bay is surrounded by low lying land and fed by multiple tidal rivers. It is a Special Protection Area (SPA) under European Union legislation.
- Extensive offshore wind farms (both planned and existing).

The East Inshore Marine Plan Area includes the sea from Flamborough Head to Felixstowe and extends out to the limit of the territorial sea (12 nautical miles). Inshore areas include tidal areas as defined by the Marine and Coastal Access Act 2009 (MCAA)[5].

The East Offshore Marine Plan Area extends from the seaward limit of the territorial sea out to the boundary of the Exclusive Economic Zone declared under the United Nations Convention on the Law of the Sea (UNCLOS)[6].

1.4 South Inshore and South Offshore Marine Plan Areas

The South marine plan areas were the second areas to be announced for the preparation of marine plans, and include over 20,000 square kilometres of sea.

Key features of the South marine plan areas are:

- The port of Portsmouth (Hampshire), a large natural harbour that has become a major commercial ferry port, with regular services to France, the Channel Islands and the Isle of Wight. It is also a major area for leisure sailing.
- The port of Southampton (Hampshire), a major passenger and cargo port in a sheltered location. It is the busiest cruise terminal and second largest

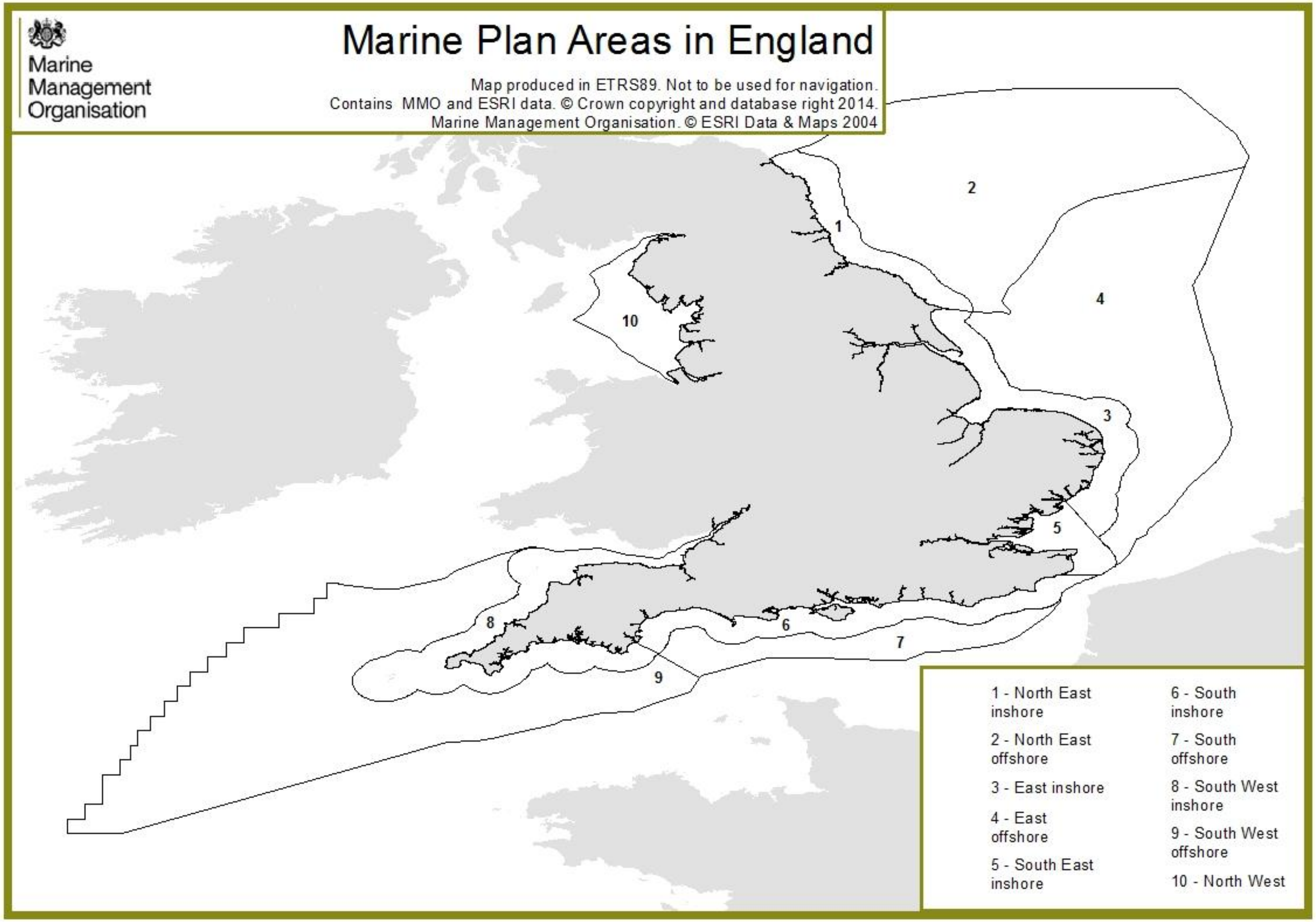
[5] Marine and Coastal Access Act 2009, Section 42 http://www.legislation.gov.uk/ukpga/2009/23/contents [accessed 06/03/14]
[6] http://www.un.org/depts/los/convention_agreements/texts/unclos/part5.htm [accessed 06/03/14]

container port in the UK. The port's special tidal regime allow the largest container and cruise ships access to the port for up to 80 percent of the time.
- Forty local authorities (including six counties).
- 6 Areas of Outstanding Natural Beauty (AONBs).
- 2 national parks (New Forest, South Downs).
- A UNESCO world heritage site in Dorset and a geo-park site in Devon.
- Ten Blue Flag beaches.
- The Dungeness Nuclear Power Station is located on the Dungeness headland and consists of two stations, A and B, of which only Dungeness B is operational. Dungeness B is an advanced gas-cooled reactor power station capable of supplying energy to over 1.5 million homes and will be operational until 2018.

The South Inshore Marine Plan Area covers approximately 1,000 kilometres of coastline stretching from Dover in Kent to Dartmouth in Devon, out to 12 nautical miles taking in some 10,000 square kilometres of sea. The tidal section of some rivers is included, such as the Arun, the Exe and the Dart, as defined by the MCAA.

The South Offshore Marine Plan Area includes the marine area from the limit of the territorial sea (12 nautical miles) to the median line bordering international waters, a total of approximately 10,000 square kilometres.

Figure 1: Marine plan areas in England.



1.5 Limitations of the data informing this report

The UKCP09 climate projections published by the Met Office form the basis of the climate data layers found throughout the report. It is important to point out that there are limitations to these marine projections, which do not apply to the terrestrial or atmospheric projections made available at the same time (December 2010). The marine projections only use one greenhouse gas emission scenario, one model formulation and, in the case of sea surface temperature, only one time horizon (the years to which sea temperatures are projected using the model) (e.g. 2070 to 2099), in contrast to the multiple emissions and decadal time slices (i.e. projections provided for every decade in the century) available for the terrestrial and atmospheric projections. For the models that were only run once, there are no confidence intervals. The projections also use a 25km grid square, making it difficult to make predictions about specific sites rather than local areas. For example the sea surface temperature shown for a grid square containing a bathing water location, will be representative of the 25km grid square as a whole, rather than representing local temperature changes at the particular site.

Confidence in the climate projections is complex and depends on expert opinion. MCCIP rated overall confidence in future sea surface temperature as medium - and say "Confidence in the global rise in sea surface temperature is high (e.g. IPCC, 2007) and there is high confidence in the long-term future warming trend. However our confidence in the exact rates of warming at regional scales is lower." There is also agreement with other projections of sea surface temperature around the UK that show the same general warming pattern but different domains and time periods make close comparison difficult.

For future sea level rise, MCCIP rated confidence as medium. The 50th percentile from UKCP09 gives a central estimate based on 11 IPCC model results, the range of estimates around this change (5-95th percentile range) is high e.g. under the medium emissions scenario for the UK, mean sea level change is anticipated to be 15.4cm to 75.8cm over the period 1980-1999 to 2080-2099.

For storm surges and waves, the confidence in skew surge is low. MCCIP noted that "...there are still significant uncertainties associated with the simulation and downscaling of winds, particularly extreme winds. Consequently, there is low confidence in future simulations of storm surges and waves." However there is higher confidence in the overall increasing trend of sea level rise and so MCCIP rates confidence in the increased risk of coastal flooding as a whole as high.

2. Selection of UKCP09 projections for mapping climate change in the East and South marine plan areas

Ocean climate is principally defined by temperature, salinity, circulation and exchanges of heat, water and gases (including carbon dioxide) with the atmosphere. The functioning of our marine ecosystem is highly dependent on changes to both ocean climate and ocean acidification (a concept used to describe the lowering of pH in the oceans caused by uptake of CO_2 from the atmosphere), whilst storms and waves, sea-level rise and coastal erosion also pose clear threats to human life, built structures and shipping (Birchenough *et al*., 2013a). Given these wide ranging impacts, understanding how ocean climate will change in the future is of fundamental importance to marine spatial planning.

The study of climate change effects relies on understanding changes to the physical state of the marine environment, particularly changes in sea level rise and coastal flooding; extreme storms and waves; temperature (air and sea); ocean acidification; changes in terrestrial input (riverine flood and flooding); and changes to ocean currents. In the section below, a list of important climate variables and their importance for the MMO to consider for the marine plan areas have been presented. Specific information has been provided regarding each variable and examples of the relevance to Marine Policy Statement sectors within this study.

The salinity of the surface layer of the ocean (the top 100m) is heavily influenced by changes in precipitation and evaporation (Josey and Marsh, 2005). Surface salinity is more variable when compared to deep-sea salinity. Ocean salinity is important as it could affect the density of the water with resultant impacts on ocean circulation. The reduction of sea ice, acceleration of the global water cycle and thawing of ice on land will affect the ocean’s salinity. In shelf seas, changes in salinity at the surface would have effects on the presence or absence of stratification of the water column and on the local circulation. Changes in salinity will be very dependent on local weather. In shelf seas, changes will be more sensitive to local river runoff and catchment precipitation (OSPAR, 2009). The current UKCP09 outputs suggest that salinity is likely to remain relatively constant and therefore, there may not be significant impacts for any of the sectors considered in this report.

Evidence suggests warming of the upper several hundred metres of the global ocean during the latter part of the 20th century. Both sea and land surface temperatures in and bordering the OSPAR Maritime Area have increased from 1995 to 2004 at a rate which is well above the global mean (ICES, 2008). Changes in air and sea temperature have implications for marine and coastal food-web dynamics, and hence fisheries, as well as the distribution of nuisance species. Tourism is also a key sector likely to be affected.

Sea level rise (SLR) can result in more flooding, coastal erosion and the inundation of coastal regions. It reduces the return period for extreme water levels and threatens existing coastal ecosystems. Future SLR will affect low-lying coastlines with high population densities and relatively small tidal ranges (OSPAR, 2009). This is a particular concern for coastal infrastructure (e.g. nuclear power stations with life-cycles that could exceed 100 years).

Wind-driven waves and storms are seen as the key drivers of change on many European coasts (Smith *et al*., 2000). Higher waves and increased storm-surge elevations or an increase in frequency would have important potential consequences (e.g. enhanced erosion and flooding) in estuaries and embayments (OSPAR, 2009). The effects resulting from extreme storms and waves would affect a wide range of marine structures (e.g. oil and gas platforms) and “weather” windows for operations at sea (e.g. aggregate dredging).

When atmospheric CO_2 dissolves in the ocean, this results in formation of a weak acid. Increasing atmospheric CO_2 leads to increasing acidity of the ocean (reflected by a lowering in pH). Ocean acidification may have long term implications for shellfisheries and wider marine food-webs, especially when combined with other stressors, both climatic (e.g. temperature rise) and non-climatic (e.g. pollution). Changes in terrestrial input (riverine flow and flooding) “pluvial” and “fluvial” flooding are terms used to describe an overflow of water on land. Winter rainfall has increased over northern Europe, increasing flooding along river basins and runoff into the North Sea (OSPAR, 2009; Struyf *et al*., 2004). The changes associated with rainfall lead to flooding of coastal sites, access roads, and also causing changes to the delivery of nutrients and pollutants to the marine environment.

Ocean currents include the directed movement of seawater generated by the forces acting upon this mean flow, such as breaking waves, wind, tides, Coriolis effect, temperature and salinity differences. The movement of water masses in turn influences patterns of sedimentation and affects scour patterns around fixed structures (e.g. wind farms), as well as cables and pipelines. There are also implications for the distribution of fish larvae at key life stages.

Suitable data layers have been extracted and plotted as a series of maps at the end of this section to illustrate the future climate change variables considered important in this study. It should be noted that it was not possible to provide maps of future pH or dissolved carbon dioxide (ocean acidification) for inclusion in the MMO marine planning portal because projections of these variables were not made available as a result of UKCP09. Outputs of models focussing on ocean acidification have been produced for seas around the UK (e.g. Blackford and Gilbert, 2007 or Artioli *et al*., 2012) but detailed datasets have not yet been made available by the authors of these studies.

The impacts of a reduction in oxygen levels and changes to stratification within the marine plan areas were not considered here as there was insufficient information available to include these factors in the risk assessment. Other atmospheric variables such as changing wind speeds and direction, and the prevalence of anti-cyclonic conditions (with high pressure dominating, leading to calm days or weeks), that affect weather windows for example, are poorly understood and represent emerging issues that could bring both risks and benefits.

Figure 2: Annual mean salinity change projections in the East marine plan areas.

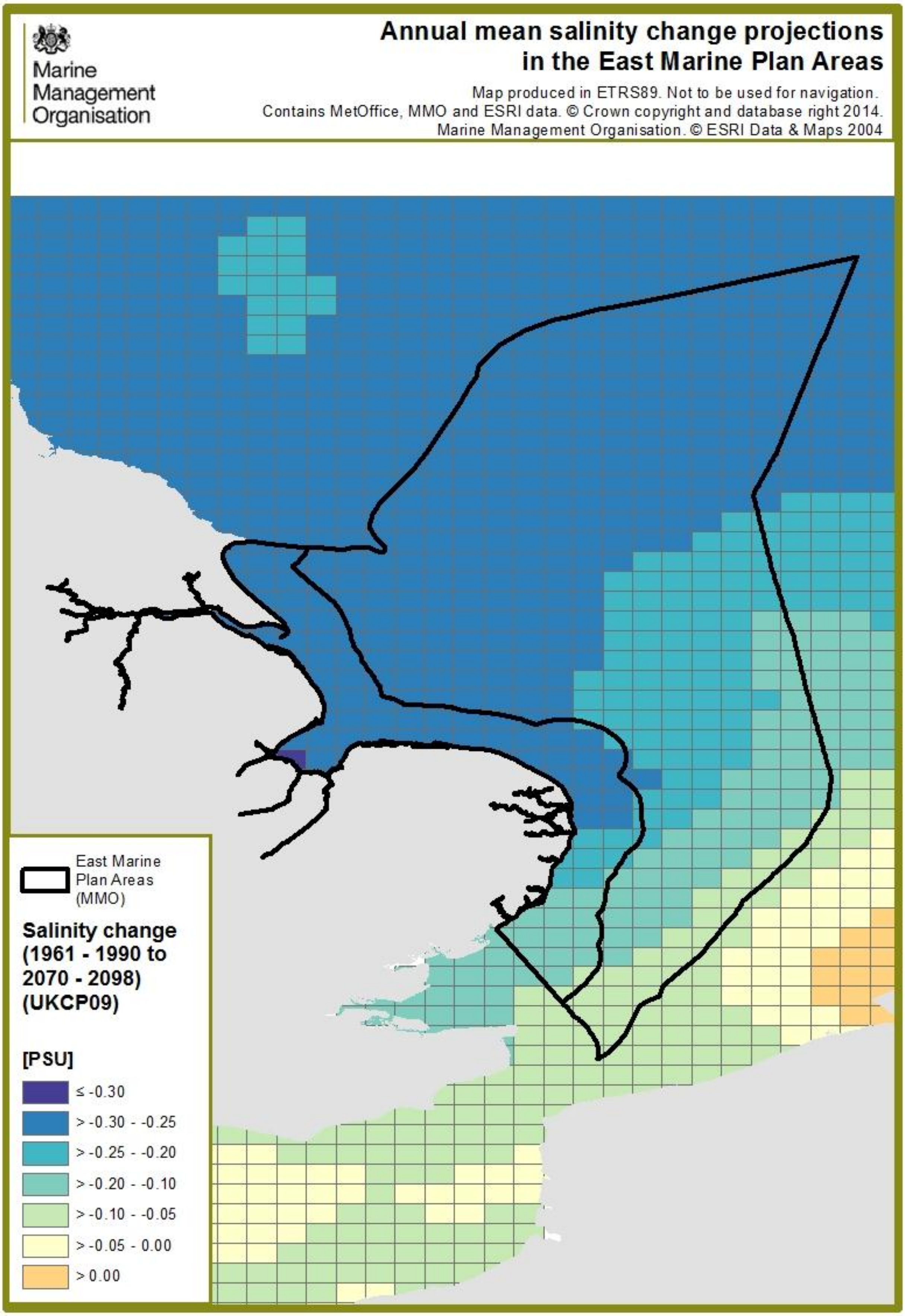


Figure 3: Annual mean salinity change projections in the South marine plan areas.

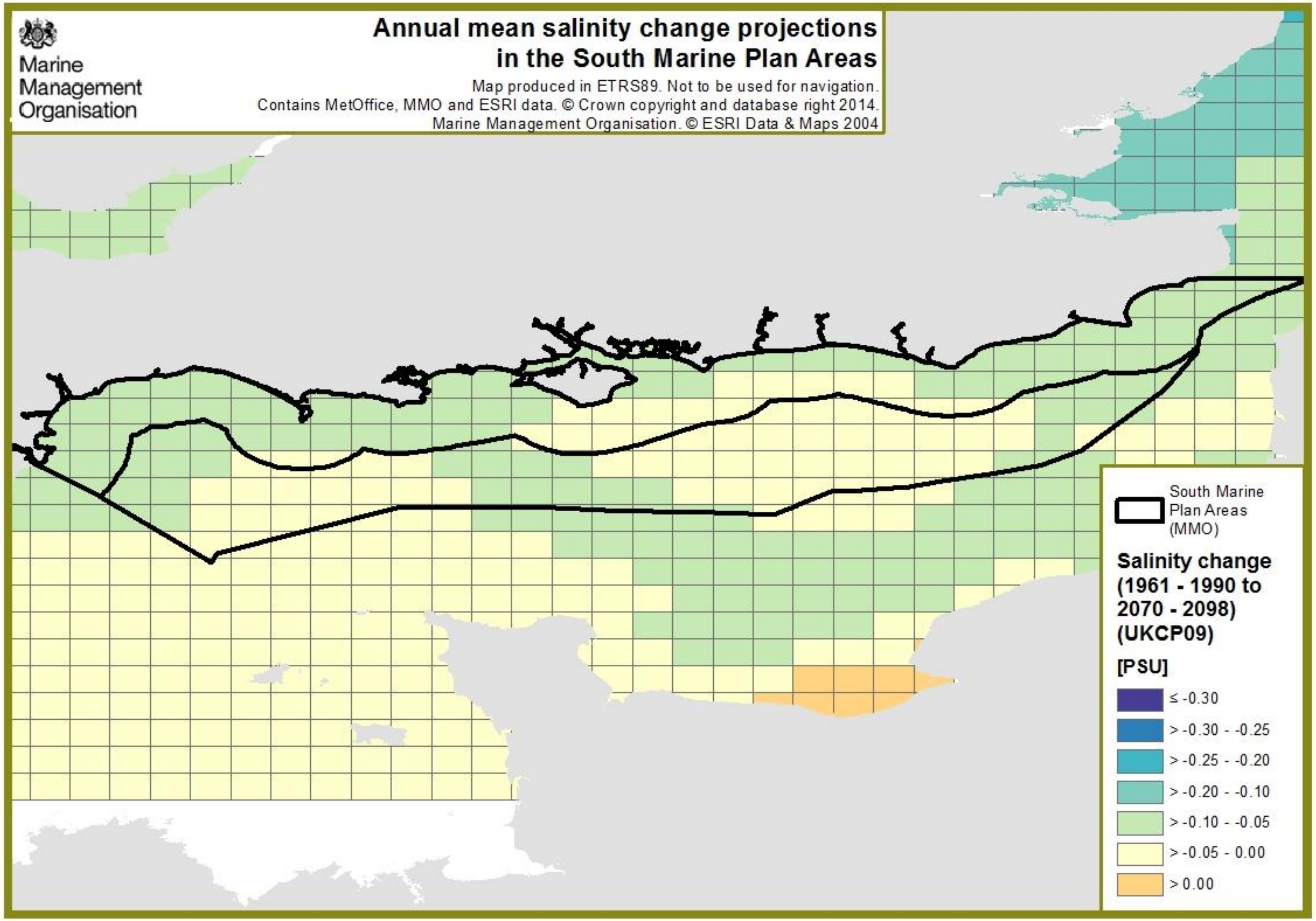


Figure 4: Annual mean sea surface temperature change projections in the East marine plan areas.

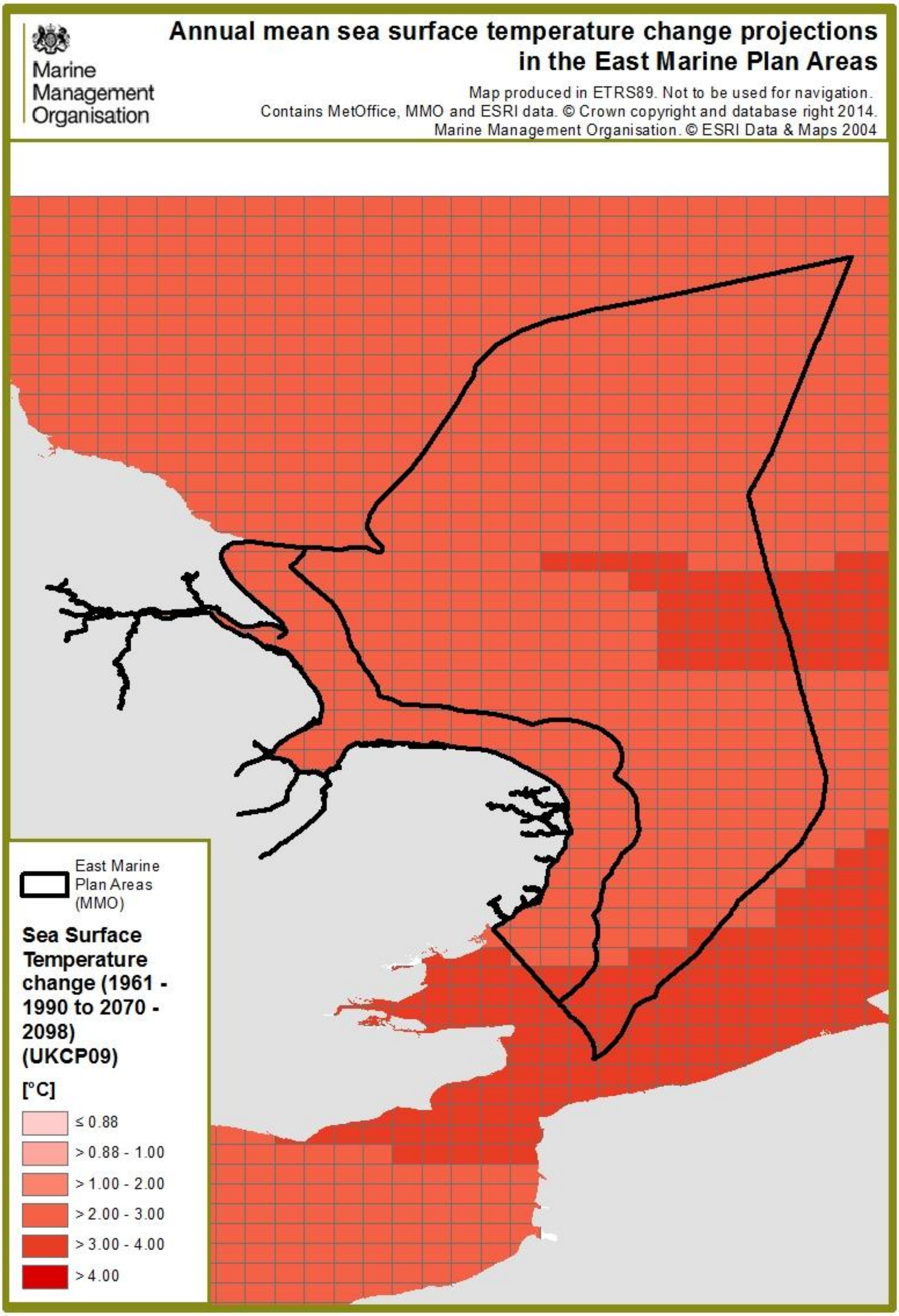


Figure 5: Annual mean sea surface temperature change projections in the South marine plan areas.

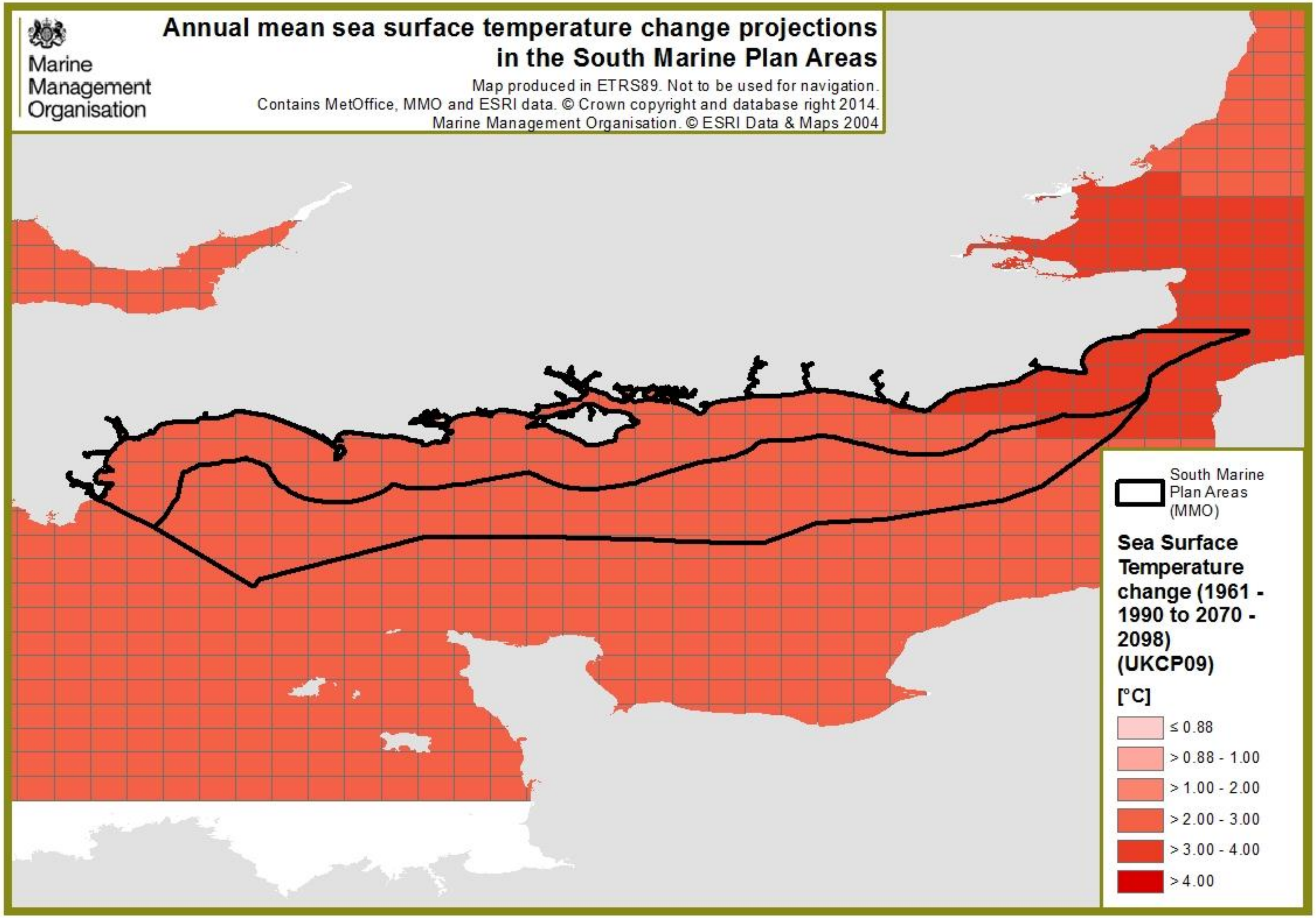


Figure 6: Spring mean sea surface temperature change projections in the East marine plan areas.

Figure 7: Spring mean sea surface temperature change projections in the South marine plan areas.

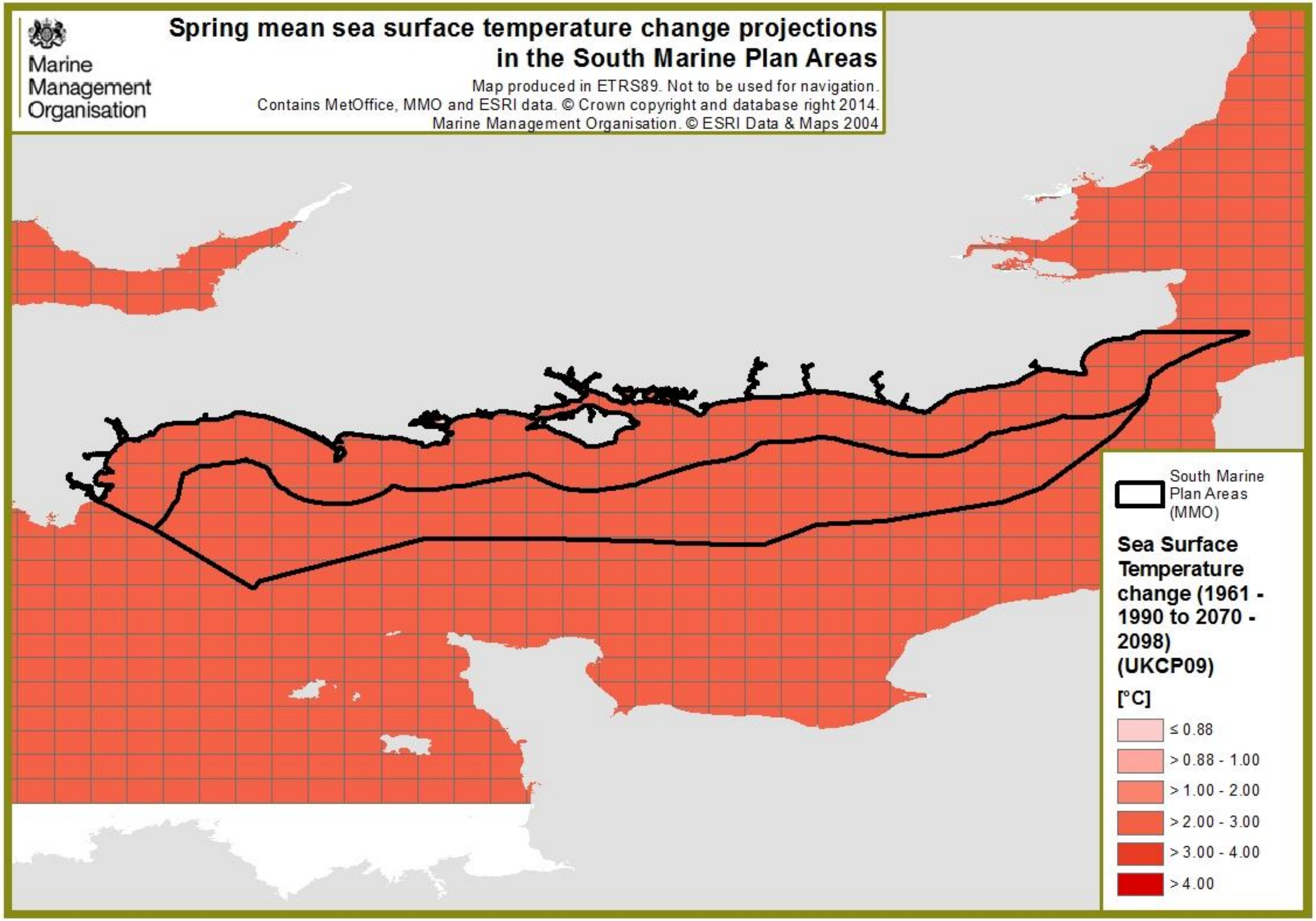


Figure 8: Summer mean sea surface temperature change projections in the East marine plan areas.

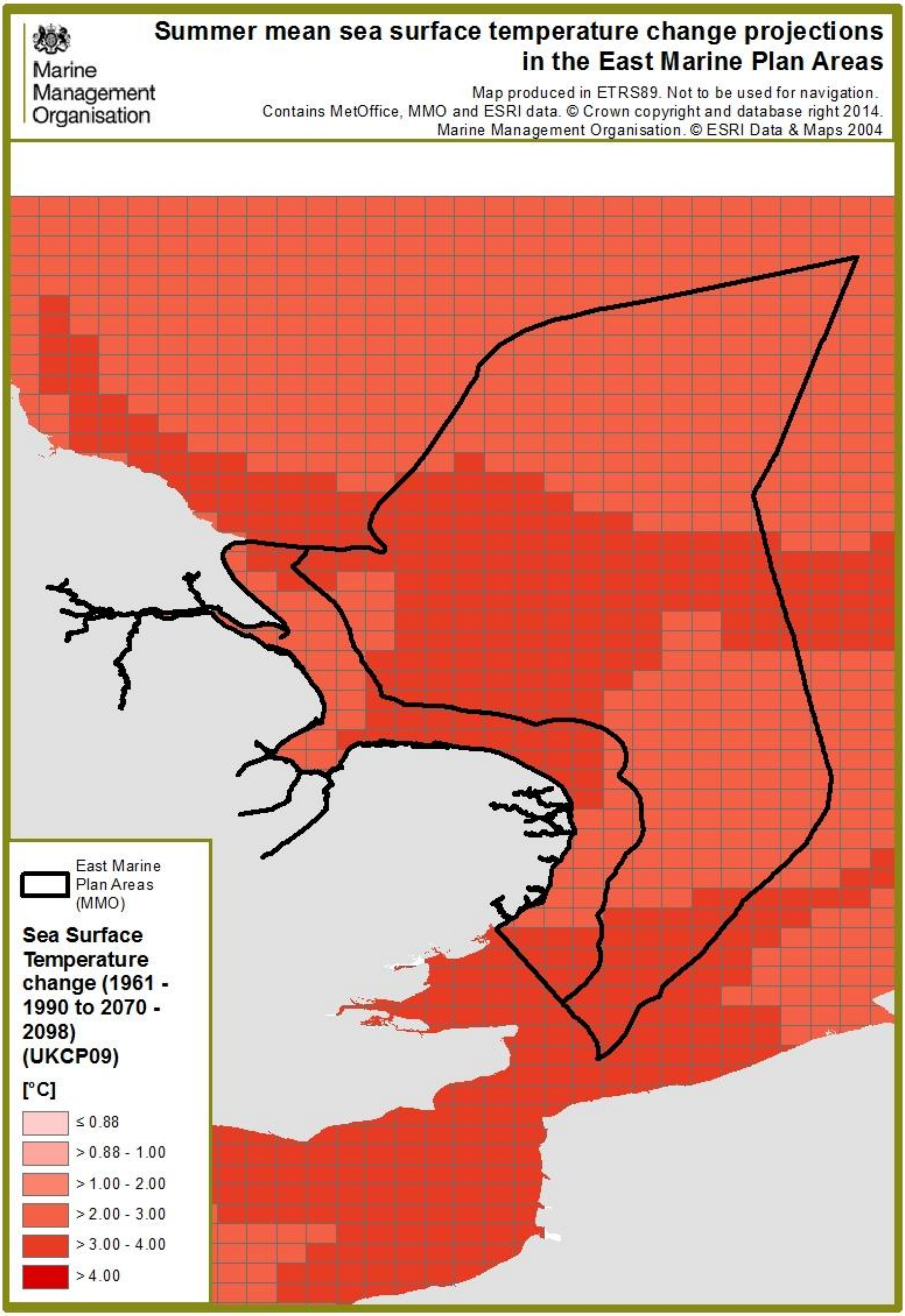


Figure 9: Summer mean sea surface temperature change projections in the South marine plan areas.

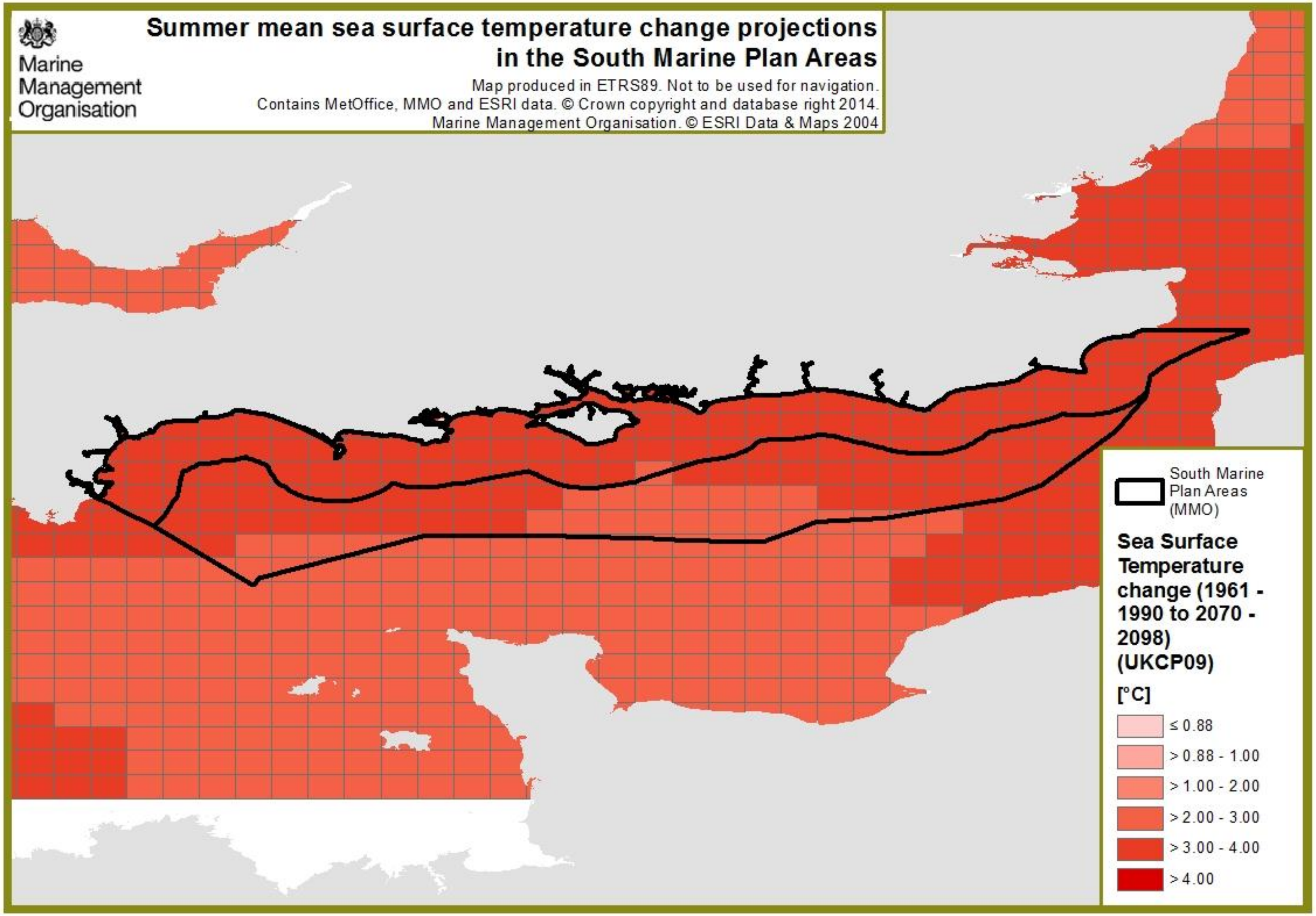


Figure 10: Autumn mean sea surface temperature change projections in the East marine plan areas.

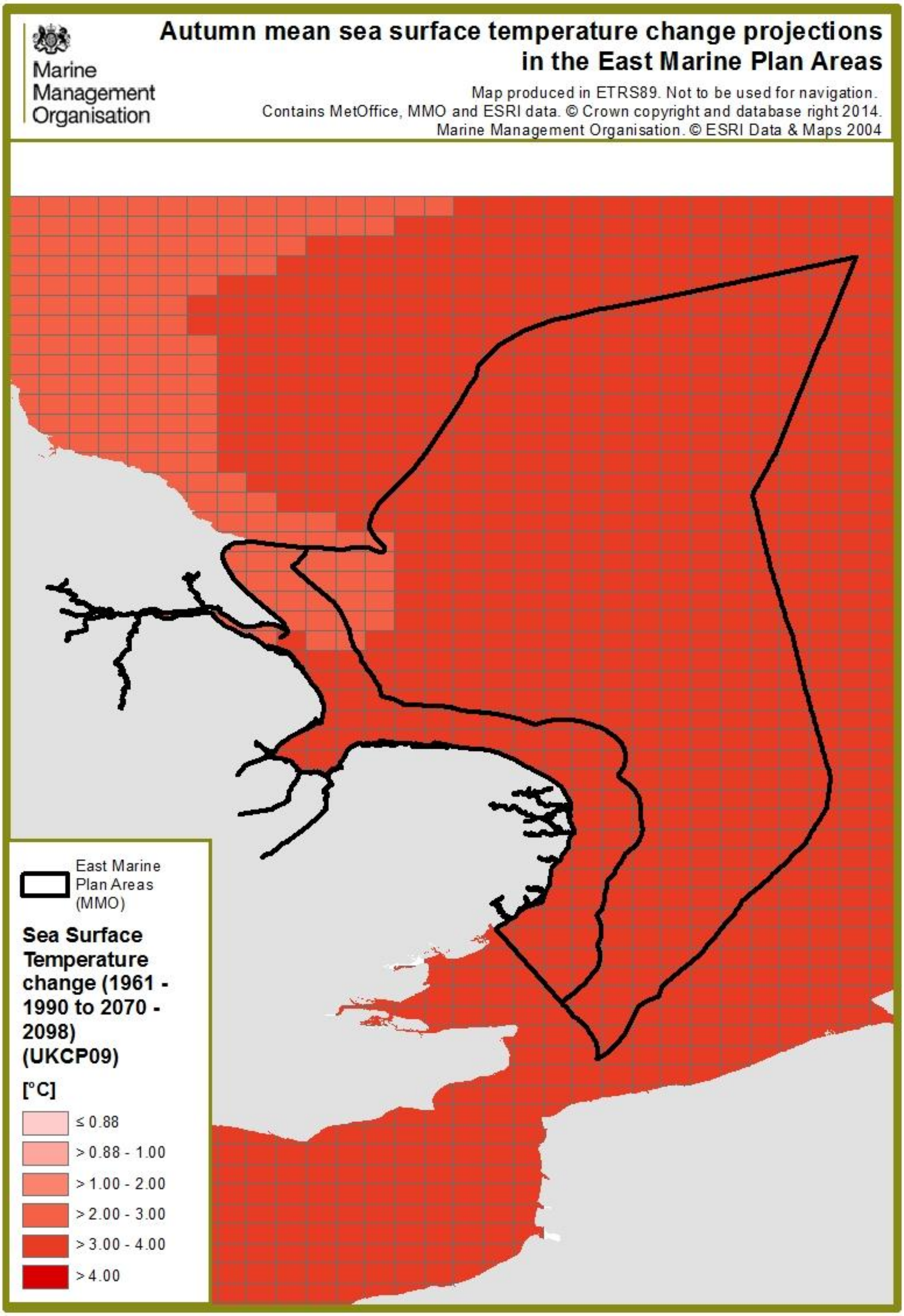


Figure 11: Autumn mean sea surface temperature change projections in the South marine plan areas.

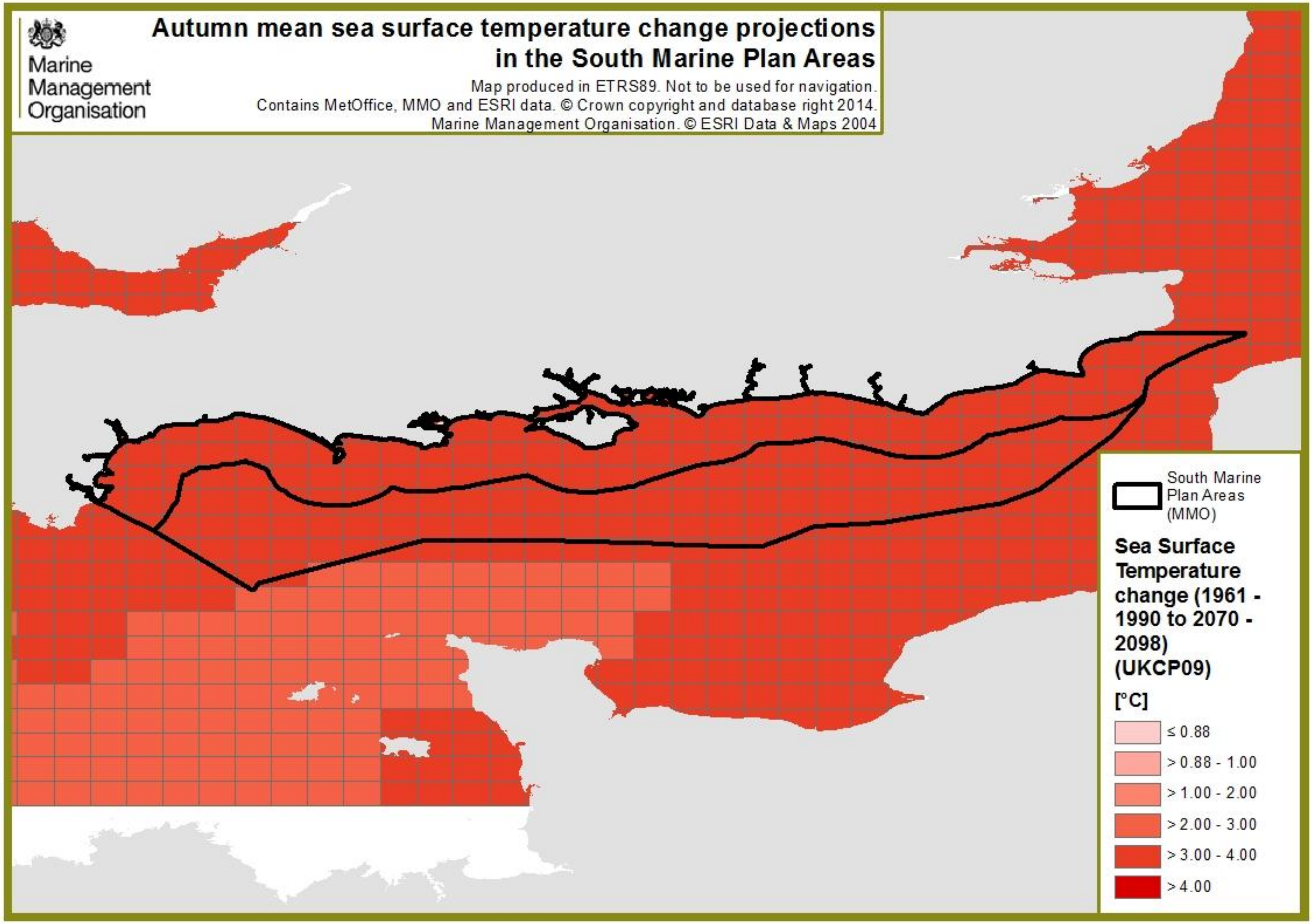
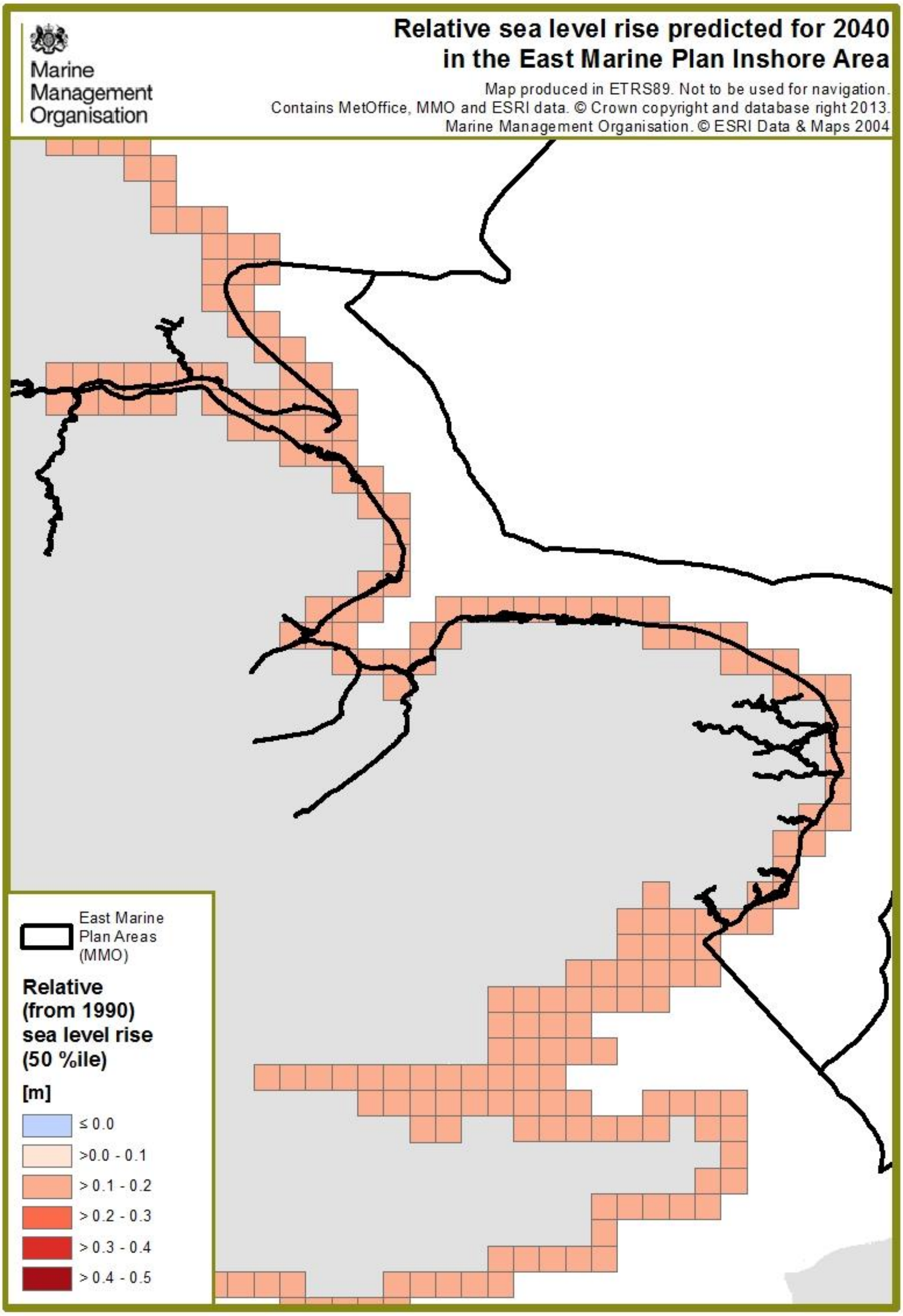
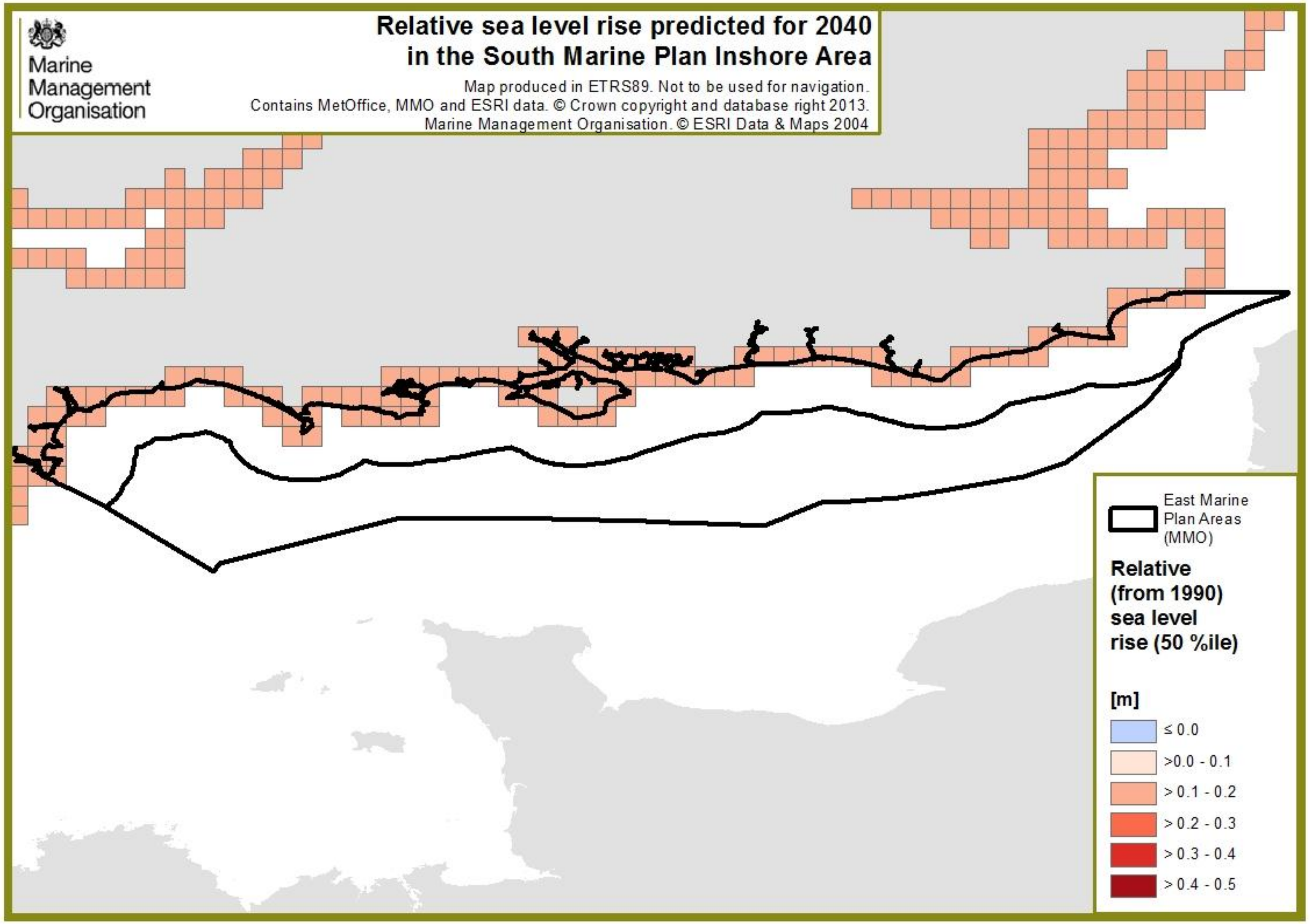


Figure 12: Relative sea level rise predicted for 2040 in the East Marine Plan Inshore Area[7].



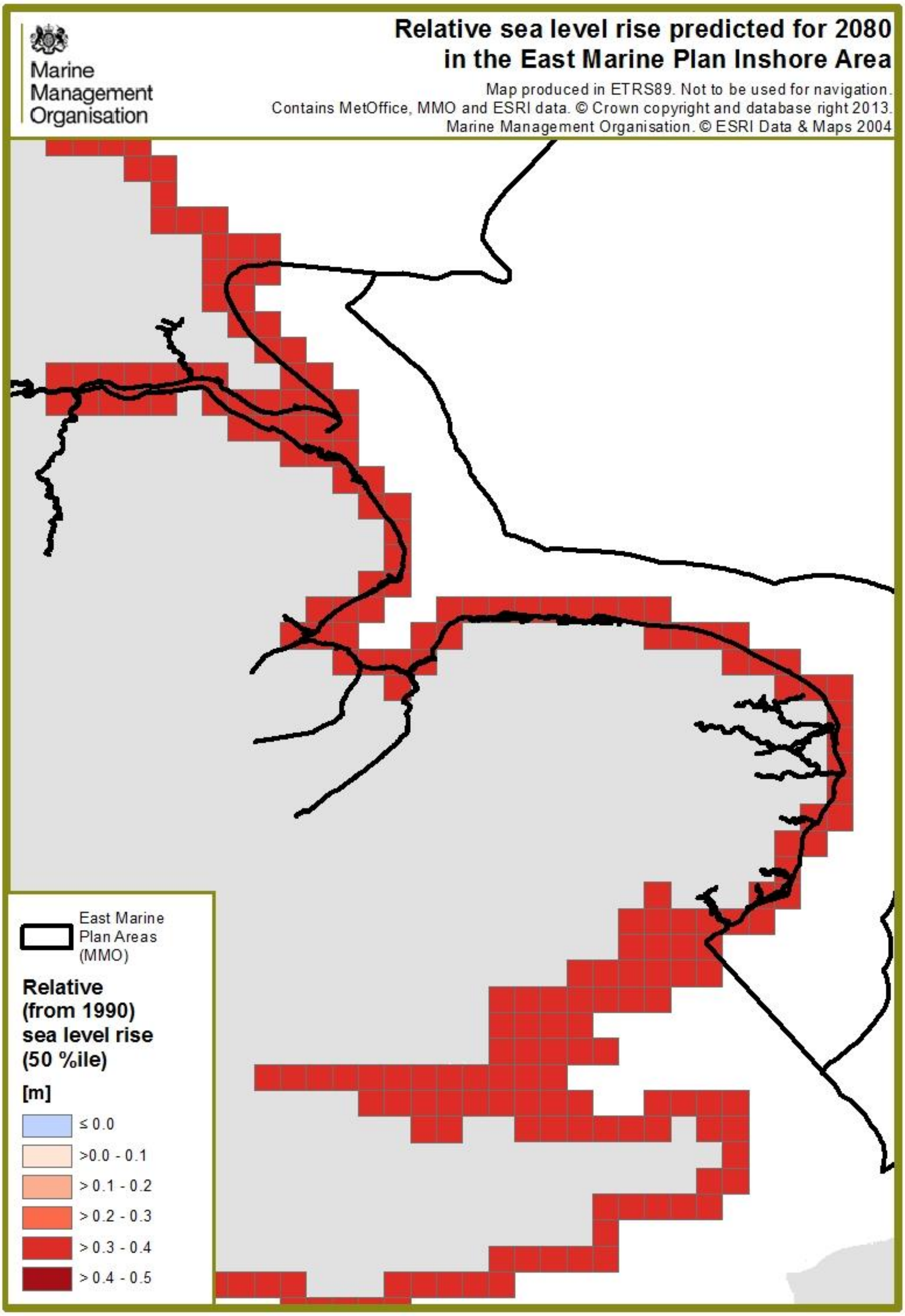
[7] Sea Level rise only mapped for coastlines as part of UKCP09. 50 %ile means It is projected that there is a 50% likelihood that relative sea level rise at that location (taking into account local land movements) will be equal to or less than the figure shown

Figure 13: Relative sea level rise predicted for 2040 in the South Marine Plan Inshore Area[8]



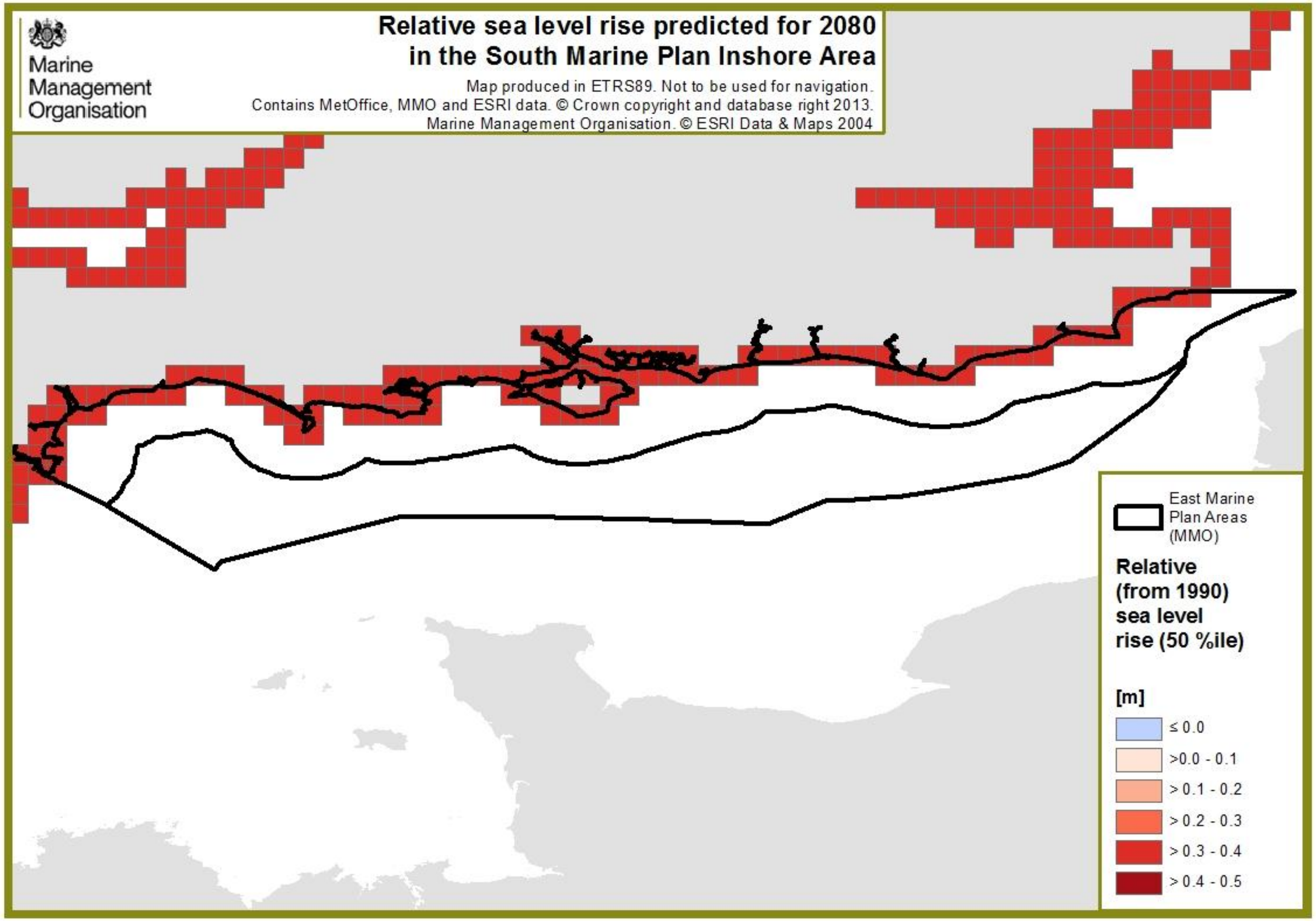
[8] Sea Level rise only mapped for coastlines as part of UKCP09. 50 %ile means It is projected that there is a 50% likelihood that relative sea level rise at that location (taking into account local land movements) will be equal to or less than the figure shown

Figure 14: Relative sea level rise predicted for 2080 in the East Marine Plan Inshore Area.[9]



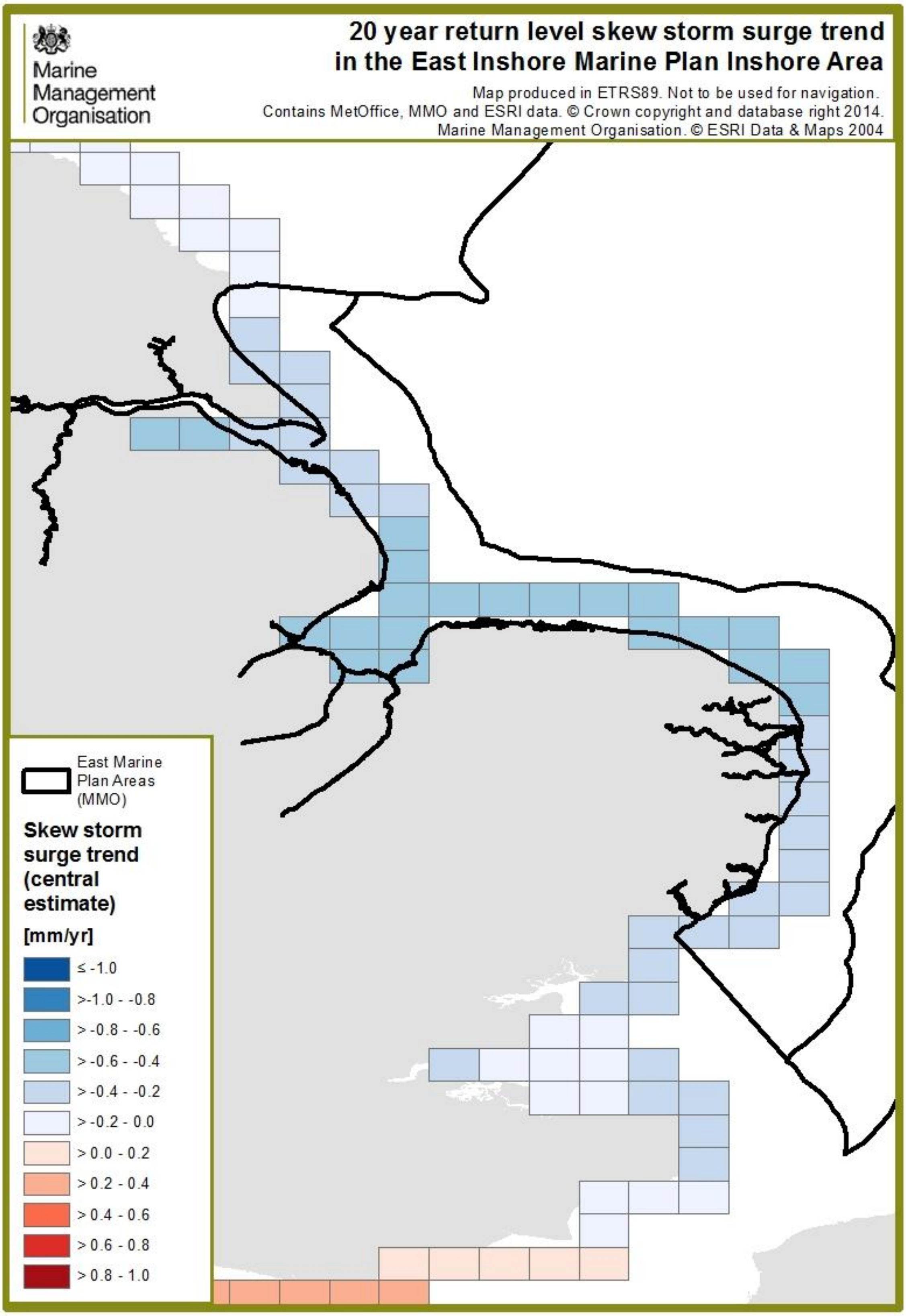
[9] Sea Level rise only mapped for coastlines as part of UKCP09. 50 %ile means It is projected that there is a 50% likelihood that relative sea level rise at that location (taking into account local land movements) will be equal to or less than the figure shown

Figure 15: Relative sea level rise predicted for 2080 in the South Marine Plan Inshore Area. [10]



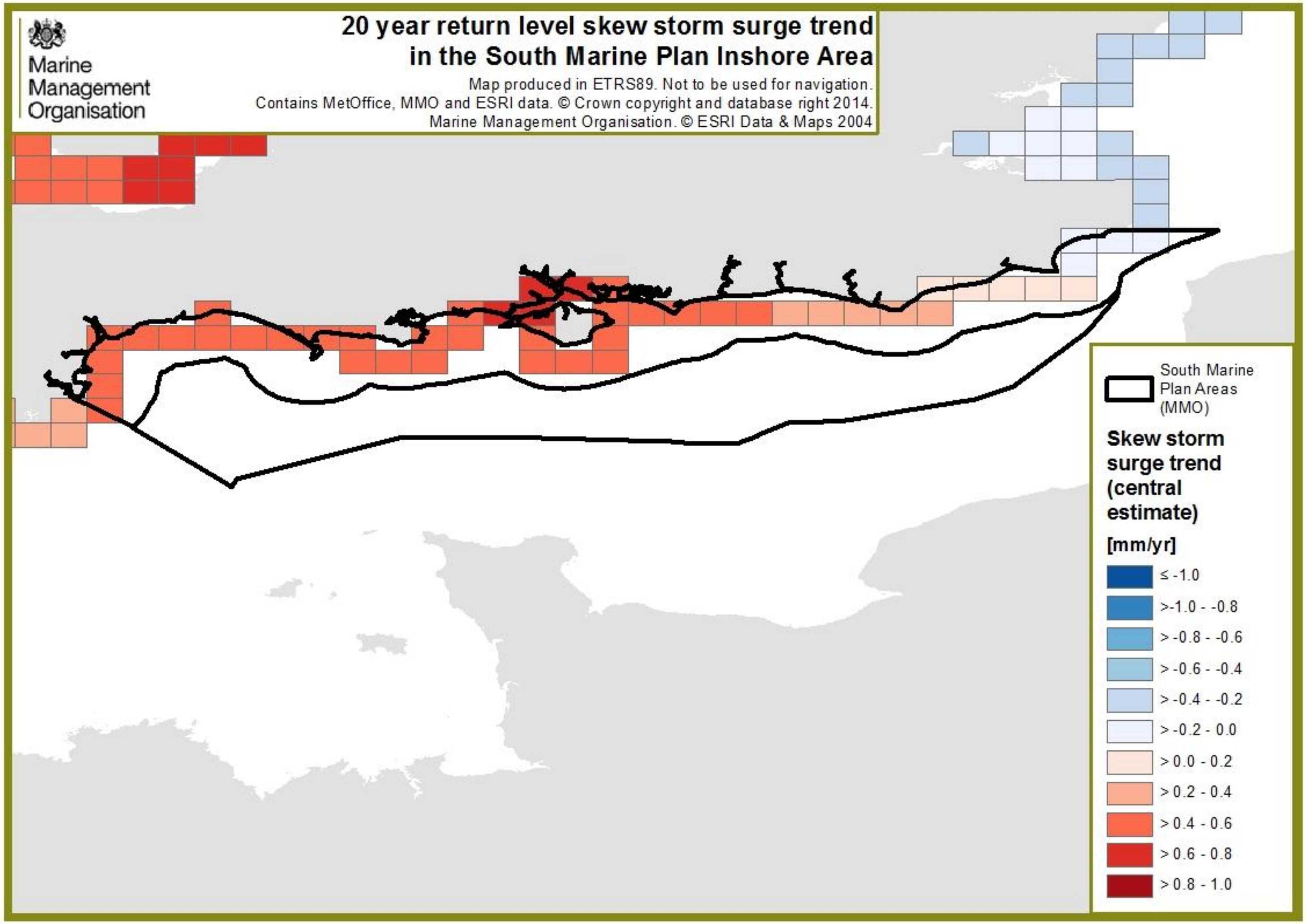
[10] Sea Level rise only mapped for coastlines as part of UKCP09. 50 %ile means It is projected that there is a 50% likelihood that relative sea level rise at that location (taking into account local land movements) will be equal to or less than the figure shown

Figure 16: 20 year return level skew storm surge trend in the East Inshore Marine Plan Inshore Area.[11]



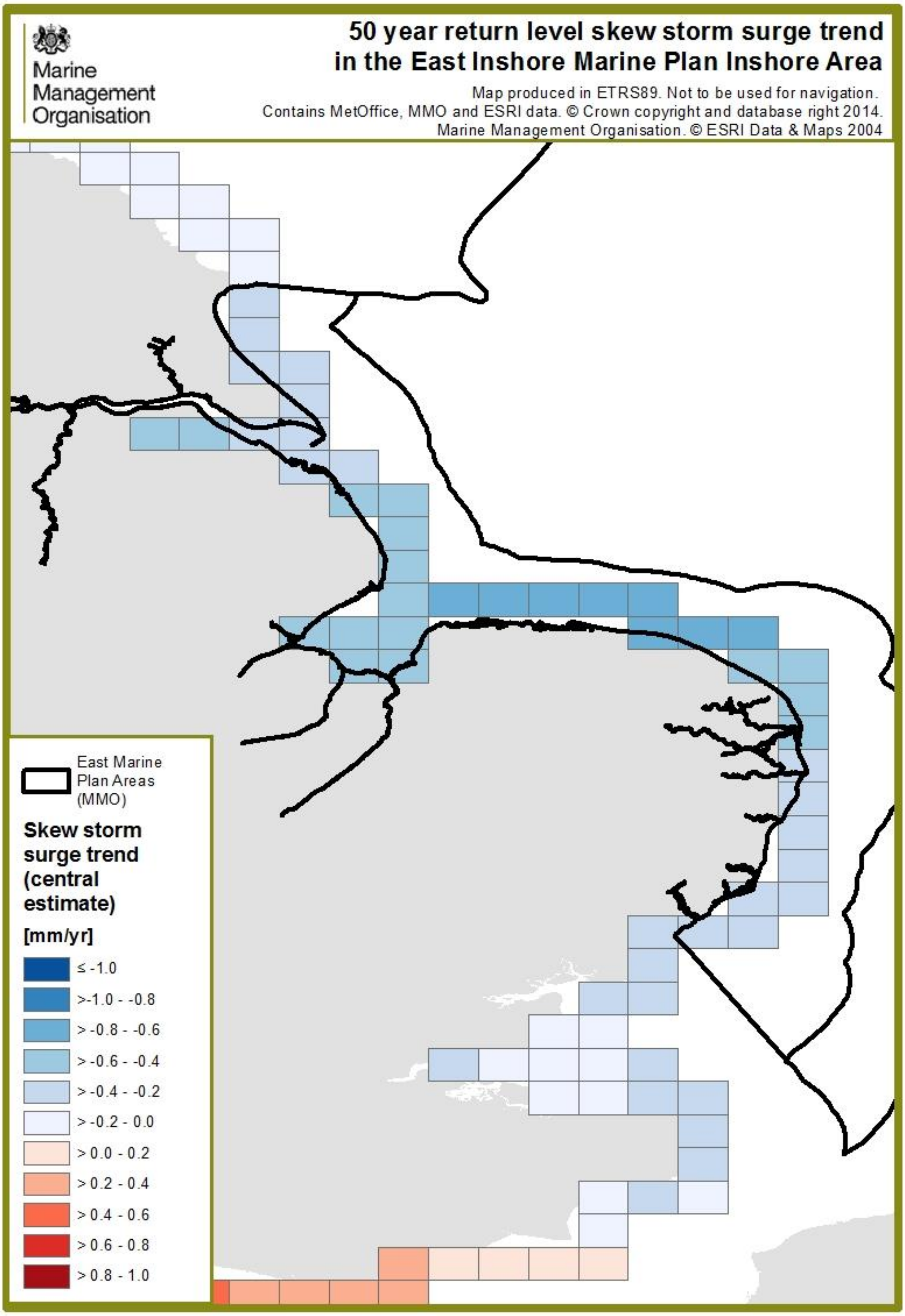
[11] 20 year return level skew storm surge trend quantifies the change in height, through the UKCP09 model time period (1951-2099), of the storm surge that has a 1-in-20 or 5% chance of being exceeded in any one year.

Figure 17: 20 year return level skew storm surge trend in the South Marine Plan Inshore Area[12].



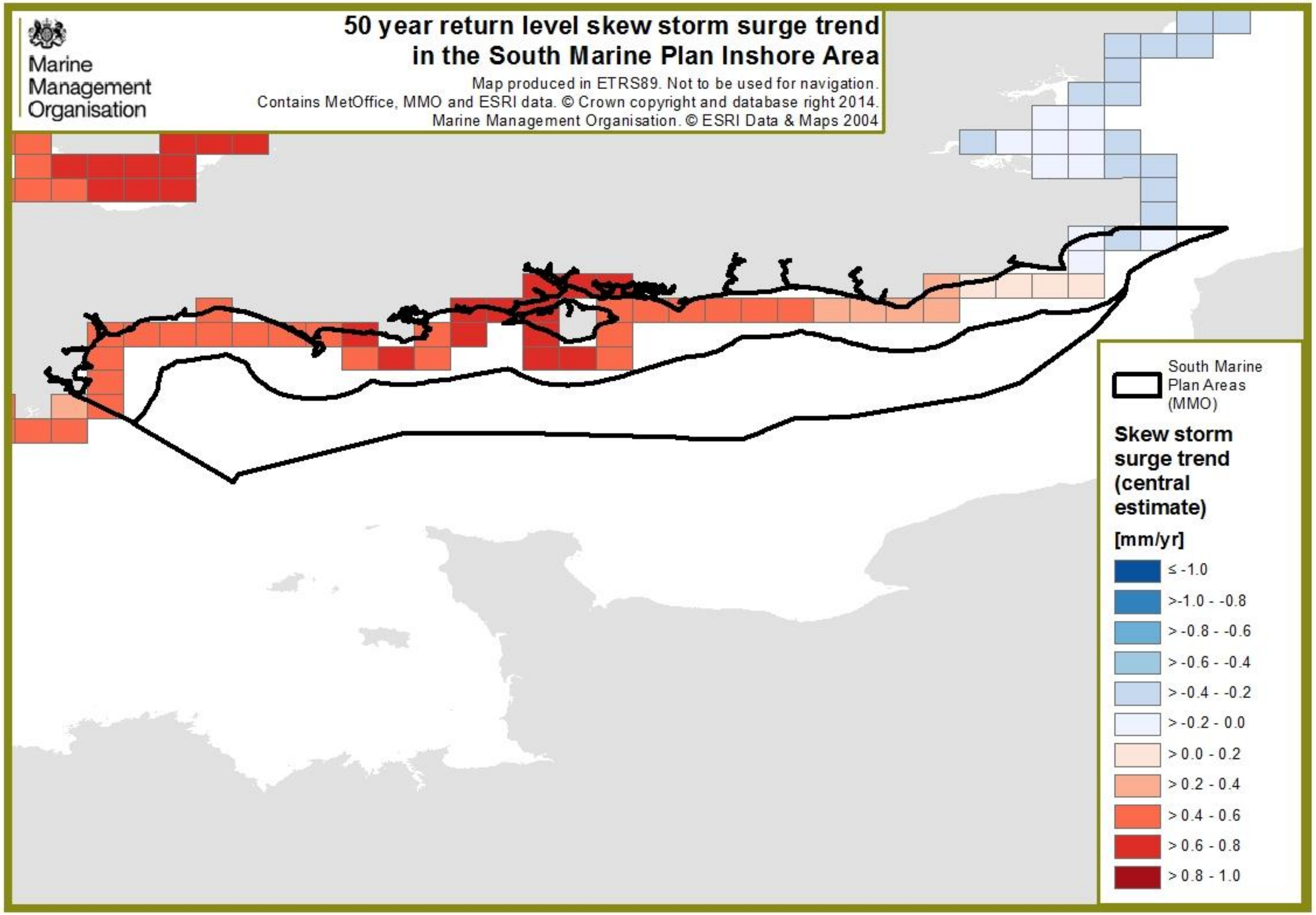
[12] 20 year return level skew storm surge trend quantifies the change in height, through the UKCP09 model time period (1951-2099), of the storm surge that has a 1-in-20 or 5% chance of being exceeded in any one year.

Figure 18: 50 year return level skew storm surge trend in the East Marine Plan Inshore Area.[13]



[13] 50 year return level skew storm surge trend quantifies the change in height, through the UKCP09 model time period (1951-2099), of the storm surge that has a 1-in-50 or 2% chance of being exceeded in any one year.

Figure 19: 50 year return level skew storm surge trend in the South Marine Plan Inshore Area.[14]



[14] 50 year return level skew storm surge trend quantifies the change in height, through the UKCP09 model time period (1951-2099), of the storm surge that has a 1-in-50 or 2% chance of being exceeded in any one year.

3. Climate change risk / benefit assessment

This section considers the potential risks and/or benefits associated the main activities in the four marine plan areas in relation to climate change. In addition to individual evidence reports published by the MMO, the background literature consulted was mainly two key MMO documents that were considered to contain the most up-to date information, notably: i) the South Inshore and South Offshore Marine Plan Areas: South Plan Analytical Report (SPAR) and ii) the East Inshore and East Offshore Marine Plans.

In the East Inshore and Offshore and South Inshore and Offshore Marine Plan Areas, the main activities when scoring risks and benefits of climate change are:

- Oil and Gas
- Offshore wind farms
- Wave and tidal developments
- Carbon Capture and Storage
- Ports and shipping
- Dredging / disposal
- Aggregates
- Cables / pipelines
- Fisheries
- Aquaculture
- Tourism and recreation
- Marine protected areas
- Power stations
- Surface water management and waste water treatment and disposal
- Defence

For the East Inshore and Offshore and the South Inshore and Offshore Marine Plan Areas, available climate change information in relation to the activities in these areas has been compiled. A summary of the potential risks and/or benefits associated with these activities in relation to climate change is presented in Annex 1.

3.1 Risk assessment methodology

The risk assessment followed a number of simple steps to identify the most critical climate change impacts for key sector activities in the East and South marine plan areas. Impacts can either be positive (benefits), or negative (risks), and the MMO and its delivery partners will need to consider how these impacts are managed.

Based on current knowledge of the most critical sector impacts, further analysis has been undertaken to consider how soon the impacts could happen (proximity), the level of confidence in the evidence used to judge the impacts, and the responses that may be required. Finally, any further information of relevance, such as differences between, or within, marine plan areas, as well as other pressures resulting from anthropogenic activity has been considered.

Unless otherwise stated, understanding of climate change impacts has been based on the UKCP09 climate projections (Lowe *at al*., 2009), the MCCIP Report Cards (MCCIP, 2013; 2012), the UK Climate Change Risk Assessment (2012), Charting Progress 2: The State of UK Seas (UKMMAS, 2010), Met Office reports (2014a, 2014b), MMO evidence documents (MMO, 2012a; 2013a-h; 2014) and individual sectors/organisations reporting on climate change impacts for the Adaptation Reporting Power, e.g. for the Ports and Shipping sector (ABP, 2010) and London Luton Airport (London Luton Airport, 2011). Expert opinion has been applied to the information from these sources to make the assessments.

3.1.1 Stage 1: Identification of the main sector activities that climate change will have an effect upon

A list of the main sectors operating in the East and South marine plan areas was compiled using existing MMO literature (MMO, 2012a; 2013a-h; 2014) and the key climate change drivers and their potential impact on these sectors were elucidated.

The climate change drivers considered were:

- Sea level rise and coastal flooding
- More extreme storms and waves
- Air or sea temperature rise
- Ocean acidification
- Changes in terrestrial inputs (e.g. fluvial flows and flooding)
- Changes to ocean currents

It should also be noted that expert judgement and use of secondary data will inevitably introduce a degree of subjectivity, and that further detailed studies would be required to assess interacting or cumulative risks and their potential complexity (including complex indirect effects that remain unknown at this time).

3.1.2 Stage 2: Risk assessment matrix

The risk matrix described below is based upon a standard risk methodology, comparing probability against impact. The categories used are broadly based upon those outlined in the MMO risk methodology framework (MMO, 2012b), but here a simpler 3x3 matrix (Table 1) adapted for impacts and benefits is used, which is more appropriate for climate change assessments, given the uncertainties involved when ascribing “probability" to future marine climate change impacts.

The categories for “probability” are as follows:

- Low (1) = Unlikely to occur
- Medium (2) = About as likely to occur as not to occur[15]
- High (3) = Likely to occur.

The categories used for “impact” (both positive and negative) are as follows:

[15] The language used for “medium” probability (i.e. about as likely as not to occur) is based on the mid-point used by the Intergovernmental Panel on Climate Change (IPCC).

- Low (1) = Little or no impact/benefit
- Medium (2) = Some potential impacts, but containable (negative) or some potential benefits (positive)
- High (3) = Major potential impacts (negative) or major potential benefits (positive).

Scores are expressed as negative numbers (i.e. where impact is assessed as detrimental / negative) or positive (where impact is assessed as beneficial / positive). For simplicity, positive and negative scores are given equal weighting in the assessment.

Table 1: Risk and benefit matrix scoring.

		Impact		
		Low = 1	Medium = 2	High = 3
Probability of Risk	High = -3	-3	-6	-9
	Medium = -2	-2	-4	-6
	Low = -1	-1	-2	-3
Probability of Benefit	Low = +1	+1	+2	+3
	Medium = +2	+2	+4	+6
	High = +3	+3	+6	+9

Low risk = green, Medium risk = yellow and High risk = red. All benefits = blue. Risk/benefit score is derived by multiplying the impact and probability scores.

The results of a detailed matrix scoring for each sector and climate change variable is presented in Annex 1.

3.1.3 Stage 3: Further analysis of highest scoring risks / benefits

The highest scoring impacts, both positive and negative (i.e. those scoring at least +/- 6) were subjected to further assessment to explore the nature of the risk in more detail (e.g. temporal proximity of the risk, confidence in climate data and assessment) and suggest what responses may be required. The categories used to further analyse high scoring risks and benefits are explained in Table 2.

3.1.4 Stage 4: Further information

For each sector, any further information of relevance to the risk analysis has been assembled as a short piece of commentary text (e.g. on differences between the East and South marine plan areas; localised differences within plan areas or other human pressures).

3.1.5 Stage 5: Overall risk summary

For each sector, a short summary is provided up-front to highlight the key messages (see Table 3).

Table 2: Categories for the further analysis of high scoring risks / benefits.

Climate change impact	Climate change variable and sector impact
Score	Risk score (with probability and impact in brackets)
Proximity	Near = next 20 years Medium = 20-50 years Long = more than 50 years
Confidence	Very low = based on variable, and / or contrasting expert judgement. Low = based on few, incomplete and / or inconclusive impact studies. Medium = based on expert interpretation of a number of (potentially conflicting) impact studies. High = based on a number of impact studies that give a broadly consistent picture and give some consideration to uncertainty. Very high = based on many impact studies that give a coherent picture and have explored uncertainty as far as the evidence allows.
Effects on sector	What are the implications, both positive and negative
Recommended Next Steps	e.g. new or updated marine plan policies from the MMO

Table 3: Assessment of activities and main climate change risks that could cause a potential impact and/or benefit for sectors and activities in the East and South marine plan areas.

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Oil and gas industry	East Inshore and Offshore	More frequent extreme storms and waves, sea level rise and changes in ocean currents affecting: • Safety of working on, and travelling to, offshore sites • Structural integrity of infrastructure • Scour around seabed structures • Construction of offshore sites.	
Offshore wind	East Inshore and Offshore	More frequent extreme storms and waves affecting: • Efficiency of turbines • Structural integrity of infrastructure • Safety of working on, and travelling to, offshore sites • Scour around seabed structures • Construction of offshore sites. Sea level rise, more extreme storms and waves, and changes to fluvial inputs causing: • Inundation of interconnection nodes at the coast.	More frequent extreme storms may increase the energy generated from wind turbines if operating limits are not exceeded.

Potential spatial effects of climate change in the South and East marine plan areas

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Tidal stream / wave energy	East and South Inshore and Offshore	Sea level rise, more frequent extreme storms and waves, and changes in ocean currents affecting: • Efficiency • Site integrity • Safety of working on, and travelling to, offshore sites. Sea level rise, more extreme storms and waves, and changes to fluvial inputs causing: • Inundation of interconnection nodes at the coast.	More frequent extreme storms may increase the energy generated if operating limits are not exceeded.
Carbon capture and storage	East Inshore and Offshore	Sea level rise and more frequent extreme storms and waves affecting: • Integrity of storage sites • Safety of working on, and travelling to, offshore sites.	

Potential spatial effects of climate change in the South and East marine plan areas

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Ports / shipping	East and South Inshore and Offshore	Sea level rise, more frequent extreme storms and waves, fluvial flooding and changes in ocean currents affecting: • Sedimentation, increasing need for dredging to keep channels clear (covered in "dredging/disposal" sector) • Flooding of port facilities and access roads • Disruption to shipping (including passenger ferries) • Safety of ships at sea • Loss of cargo.	Sea level rise and coastal flooding could reduce the need for dredging to keep channels clear in some areas (covered in "dredging/disposal" sector). Air and sea temperature rise may cause an opening of Arctic sea routes and so save shipping costs.
Dredging / disposal	East and South Inshore and Offshore	More frequent extreme storms and waves and an increase in fluvial inputs affecting: • Efficiency of operation (such as the positioning of suction dredgers) • Increased need for and cost of dredging • Safety at disposal and dredge sites • Need for re-mapping of sites.	More frequent extreme storms, waves and an increase in fluvial inputs will increase the need for dredging. This could be of benefit to the dredging industry.
Aggregates	East and South Inshore and Offshore	More frequent extreme storms and waves affecting: • Safety during operations • Efficiency of operations (such as positioning of suction dredgers).	Sea level rise and coastal flooding causing an increase in demand for aggregates for building and maintaining sea defences.

Potential spatial effects of climate change in the South and East marine plan areas

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Cables / pipelines	East and South Inshore and Offshore	More frequent extreme storms and waves, and changes in ocean currents affecting: • Scour around buried pipelines / cables • Damage to pipelines / cables • Safety concerns when laying new pipelines / cables.	
Fisheries	East and South Inshore and Offshore	Sea temperature rise, ocean acidification, changes in fluvial flows (particularly in estuarine nursery grounds) and ocean currents causing negative changes: • A decrease in abundance, survival and growth of some exploitable fish species • An increase in abundance, survival and growth of non-native pest species. More frequent extreme storms and waves affecting: • Safety of fishing vessels • Negative impacts may be exacerbated by low oxygen conditions, and presence of pollutants and marine contaminants.	Sea temperature rise causing beneficial changes affecting: • Abundance, survival and growth of some exploitable fish and shellfish species • Abundance, survival and growth of exploitable non-native species.

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Aquaculture (dominated by shellfish aquaculture in these areas)	East and South Inshore and Offshore	Sea temperature rise and changes in fluvial inputs increasing: • Frequency of occurrence and concentration of marine pathogens or harmful algal blooms in shellfish leading to economic losses or human health implications. • Occurrence of nuisance invasive species fouling gear or affecting shellfish growth. Sea level rise and more frequent extreme storms and waves affecting: • Site and facility infrastructure • Loss of suitable intertidal habitat for aquaculture. Ocean acidification and sea temperature rise negatively affecting shellfish growth and reproduction.	Sea temperature rise creating conditions for culture of previously unexploited species. Sea temperature rise and changes in fluvial inputs potentially reducing some marine pathogens affecting shellfish (depending on their environmental tolerances).

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Tourism and recreation	Mainly South Inshore, but also East Inshore	Sea level rise, more frequent extreme storms and waves, sea temperature rise, and changes to fluvial inputs affecting: • Ecotourism (access to sites in bad weather, decrease in some bird species populations) • Safety of recreational fisheries during bad weather • Coastal tourism during bad weather • Integrity of coastal tourism infrastructure • Loss or degradation of beaches • Decrease in suitable conditions for scuba diving • Decrease in bathing water quality during storms and operation of combined sewer overflows.	Air and sea temperature rise creating benefits through: • Increased ecotourism • Increased recreational fishing • Increased coastal tourism • Improved conditions for scuba diving. More extreme storms and waves, air and sea temperature rise and coastal flooding creating benefits through: • Increased opportunities for some water sports such as sailing and surfing.

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Inshore and offshore protected areas	East and South Inshore and Offshore	Sea level rise and coastal flooding, more frequent extreme storms and waves, air and sea temperature rise and fluvial inputs affecting: • Loss of coastal habitats and the need for compensatory habitats • The links within ecological networks • Habitat integrity such as re-suspension of soft substrates and reduced growth of reef species • Breeding success of marine organisms at onshore and offshore sites • Breeding success of birds and marine mammals at onshore sites.	Sea temperature rise and changes to ocean currents potentially improving the links within ecological networks.
Power stations	East and South Inshore	Sea temperature rise increasing the ecological effects of cooling water discharges. Sea level rise, more frequent extreme storms and waves, and fluvial flooding affecting: • Site integrity • Safety • Economic losses due to temporary shut downs or failure.	
Waste water	East and South Inshore	Fluvial inputs and flooding affecting: • Operation of combined sewer overflows, in turn affecting water quality.	

Potential spatial effects of climate change in the South and East marine plan areas

Sector	Marine plan areas most affected based on the location of the activity	Potential risks	Potential benefits
Defence	East and South Inshore and Offshore	Sea level rise, more frequent extreme storms and waves and fluvial flooding affecting: • Coastal site integrity • Safety of military operations at sea (and air).	

3.2 Risk assessment results

The risk matrix analysis for all sector impacts (see Annex 1) resulted in ten high scoring risks and five high scoring benefits. Further analysis of the high scoring risks and benefits is provided below, split out by sector.

3.2.1 Ports and shipping

Overall summary

The ports and shipping sector is likely to be affected by negative climate change impacts on port and shipping infrastructure, with consequences for insurance but also potential benefits through opening up of northern sea routes.

Table 4: Highest scoring risks for ports and shipping due to impact of climate change

Climate change impact	Sea level rise and flooding leading to inundation of port facilities (ABP, 2010; Wright, 2013)
Score	-6 *(medium probability and high impact)*
Proximity	Medium
Confidence	Low
Effects on sector	Damage to site infrastructure and vessels. Cutting off access routes. Damage to Vessel Monitoring Systems (VMS). Safety concerns. Increased insurance costs.
Recommended Next Steps	Guidance on local (site specific) sea level rise risk and site assessments.

Table 5: Highest scoring benefits for ports and shipping due to impact of climate change

Climate change impact	Warmer air and sea temperature leading to opening of northern sea routes (Wright, 2013)
Score	+6 *(high probability and medium impact)*
Proximity	Medium
Confidence	Low
Effects on sector	Opportunity to save on shipping costs and regionally to expand port operations.
Recommended Next Steps	Feasibility studies into use of northern sea routes, and which UK ports would profit the most. Need to consider environmental implications.

Further information
Ports and harbours may be affected by a number of climate change factors including sea temperature change, sea level rise and storminess. A combination of sea level rise and changes in storminess may decrease the safety/stability of ships and also safety of people on and around the harbours. Ships may need to stay in harbour for longer periods of time if severe storms occur, incurring costs to the shipping industry. Port and harbour infrastructure and terrestrial access routes may flood, preventing personnel from getting to site. The highest skew surge for the East Inshore Marine Plan Area is projected to be along the Yorkshire and Lincolnshire coasts, affecting the ports of Hull (Immingham and Grimsby), and the south Suffolk coast, affecting the ports of Felixstowe and Harwich. In the South Inshore Marine Plan Area, the skew surge is highest in the Solent region where there are many ports and harbours (in particular Southampton). Sea temperature rise may negatively affect ports and harbours by allowing the spread of non-native fouling species which can reduce the efficiency of ships, foul harbour infrastructure and be costly to remove. This is likely to occur first in the South Inshore Marine Plan Area as fouling species arrive in the UK from the continent and move their way north along the coasts as sea temperature rises. Fouling organisms that are brought to the harbours in ballast water which are currently unable to survive discharge into existing sea temperatures, may be able to survive under increased sea temperatures.

There may be benefits if sea temperature rise allows more ships to use Arctic shipping routes, shortening ship journeys and saving costs. These new routes may benefit the East Inshore container ports and harbours more than the South Inshore ports, as ships would enter the North Sea from the north. As these new shipping routes become used more frequently, it will become clear which UK ports will most benefit. Work to assess the likely future needs for enhanced port capacity associated with northern shipping routes is already underway at ABPmer (ABPmer, 2007).

3.2.2 Aggregates

Overall summary
The aggregates industry would be affected by any increase in storms and waves that could disrupt operations at sea, although the extent of such disruption is unclear at this time. As a direct consequence of climate change impacts at the coast, there is likely to be an increased need for extraction of marine aggregates for use in coastal defence works.

Further information
As the proportion of coastline defended is greater in the East Inshore Marine Plan Area, and this region already plays host to many active aggregate extraction licences, it might be expected that increased activity will be a greater feature in this region compared to the South Inshore and Offshore Marine Plan Areas. If sea level rise leads to an increased need for marine aggregates for use in coastal defence works, one aspect to consider will be in relation to the supply of sufficient quantities within the existing areas or the need to explore if the resource will be available in new areas.

Table 6: Highest scoring benefits for aggregates due to impact of climate change

Climate change impact	Sea level rise leading to an increased need for marine aggregates for use in coastal defence works (Pinnegar *et al.,* 2012)
Score	+6 (high probability and medium impact)
Proximity	Near
Confidence	Low
Effects on sector	Economic benefits to the industry
Recommended Next Steps	Consideration given to where expansion in the industry is most desirable.

3.2.3 Fisheries

Overall summary

There is now a substantial body of research on marine climate change impacts with regards to fisheries, the last few years witnessing as many papers published as in the previous twenty (Pinnegar *et al.*, 2013). It is expected that climate change will have significant impacts on commercial species, with traditional stocks declining but new fisheries becoming more commercially viable. In relation to the EU Common Fisheries Policy (CFP), to date there is not information on how climate change will be accommodated. One clear avenue will be to continue to revise the yearly total allowable catches (TACs) and quotas, such that these reflect the status of the underlying stocks and hence prevailing environmental conditions. Other policy options for fisheries in response to climate change are discussed in detail in the Defra Economics of Climate Resilience report on sea fisheries (Defra, 2012).

Table 7: Highest scoring risks for fisheries due to impact of climate change

Climate change impact	Sea temperature rise leading to food web impacts on abundance and distribution of species (Pinnegar *et al.,* 2013)
Score	+6 (high probability and medium impact)
Proximity	Near
Confidence	High
Effects on sector	Changes to fish distributions on fishing grounds. Impacts on quotas. Loss of income for fisherman targeting traditional species.
Recommended Next Steps	Consult with Inshore fisheries and conservation authorities (IFCAs) on alternative fishing opportunities.

Table 8: Highest scoring benefits for fisheries due to impact of climate change

Climate change impact	Sea temperature rise leading to food web impacts on abundance and distribution of species (Pinnegar *et al.*, 2013)
Score	+6 *(*high probability and medium impact*)*
Proximity	Near
Confidence	High
Effects on sector	Impacts on quotas for new commercial species. **Opportunities for fisherman targeting new species such as bass and anchovy. However, this may require** changes to vessels and gear to target new species.
Recommended Next Steps	Consult with IFCAs on alternative fishing opportunities. Research into socio-economic impacts of climate change on the industry.

Further information

The South marine plan areas are likely to witness increases in abundance of anchovy, red mullet, sea bass and John Dory among other species, which will bring new opportunities for fisheries. In contrast the East marine plan areas could see a decrease in yields of some traditional target species such as cod, which may affect job opportunities, with increased need to import food from further afield.

On the Dogger Bank particularly, in the northeast of the East Offshore Marine Plan Area, there is heavy fishing activity due to the large numbers of fish, which may be affected by a combination of sea temperature rise and the wind farm developments. The highest sea temperature rise in areas of fishing activity is projected to be in the mid-eastern section (around the Outer Silver Pit), and the southern tip (off Goodwin Sands) of the East Offshore Marine Plan Area and so these areas may see the greatest change in fish distributions. Additionally, in the East Inshore and Offshore areas there are important spawning (e.g. plaice, sand eels and sole) and nursery areas (e.g. cod, herring, sole and whiting) that may be affected. Sea surface temperature changes could have implications for spawning and reproduction of fish. There may be some fish migration from these inshore sites to areas which can offer shelter and food resources (e.g. offshore wind farms and marine protected areas). There are fewer proposed wind farms in the South marine plan areas and so fewer anticipated conflicts with fisheries. With sea temperature rise, the distribution of fishing activities may change through “autonomous adaptation” (see section 5). The proposed Rampion wind farm, off the coast near Brighton has considerable overlap with current fishing activities and so there may be some conflict if fishing activities become excluded from this area.

3.2.4 Aquaculture

Overall summary

The aquaculture sector in England is dominated by shellfish, which may be considered to be more susceptible to climate change than the more controlled environments of finfish aquaculture sites (Callaway et al., 2012). Risks are primarily associated with disease vectors and nuisance species, many of which are expected to increase with climate change, including some with human health implications. However, to a lesser degree, other pathogens and harmful algal blooms (HABs) relying on colder conditions could become rarer. Some aquaculture species that cannot currently be farmed in the UK could start to feature in coming decades as a result of climate change creating more favourable conditions.

Table 9: Highest scoring risks for aquaculture due to impact of climate change

Climate change impact	Sea temperature rise *leading* to disease and infections (Inc. sea lice and marine pathogens affecting human health such as Norovirus and Vibrios) (MCCIP, 2012; Gubbins *et al.,* 2013)
Score	-6 *(*high probability and medium impact*)*
Proximity	Medium
Confidence	Low
Effects on sector	Loss of income. Shellfishery closures driven by Shellfish Waters directive[16]. Human health implications (e.g. shellfish poisoning Vibrios and Norovirus). Disease control and shellfish depuration costs. Insurance risk and loss of reputation.
Recommended Next Steps	Impact studies on health implications of disease and infections. Site inspections. Consideration of site location in relation to sewer overflows and rivers.

[16] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:376:0014:0020:EN:PDF (accessed on 09/12/2015)

Climate change impact	Sea temperature rise leading to an increase in nuisance species (e.g. non-natives/ HABs/ jellyfish blooms) (MCCIP, 2012; Gubbins *et al.*, 2013)
Score	-6 *(*high probability and medium impact*)*
Proximity	Medium
Confidence	Low
Effects on sector	Costs associated with clearing fouling organisms. Detrimental impacts on cultured species, e.g. reductions in growth. Temporary fishery closures due to harmful algal blooms.
Recommended Next Steps	Monitoring of blooms and research into prediction techniques. Consideration of anti-fouling in design of site structures.

Climate change impact	Ocean acidification leading to impacts on fish/shellfish reproduction and growth (MCCIP, 2012; Gubbins *et al.*, 2013)
Score	-6 *(*high probability and medium impact*)*
Proximity	Long
Confidence	Low
Effects on sector	Loss of income or closure of sites for mussel farms.
Recommended Next Steps	Monitoring of pH around coastal sites. Impact studies on culture sites.

Further information
Sea surface temperature may cause negative impacts for some species, but there may also be benefits for the aquaculture industry. Higher sea temperatures may create conditions suitable for culture of valuable shellfish species which require higher temperatures such as Pacific oyster (Jones *et al*. 2013b). Higher temperatures may also allow existing aquaculture species to grow at a faster rate. Sea temperature rise may reduce the number of cold water pathogens present in shellfish waters (for example the harmful algal bloom species *Karenia mikimotoi*) but combined with more extreme terrestrial run-off from rivers and storm overflows could create beneficial conditions for other pathogens such as Vibrios and Norovirus ,. Higher temperatures can also create conditions for non-native invasive species to survive and spread.

Non-native invasive species can increase the fouling of aquaculture beds/equipment and reduce the growth of native shellfish, beyond that caused by native species, although some non-native species such as Pacific oyster are themselves exploitable. Marine pathogens and fouling organisms can have economic consequences for the aquaculture industry. The maps in Annex 2 show areas of highest projected sea temperature change and where these benefits and risks may be seen the most. In the East Inshore Marine Plan Area, there are aquaculture sites around The Wash, the North Norfolk coast, and the South Coast of Suffolk which may become affected by higher temperatures. The more southerly sites of the East Inshore Marine Plan Area around Suffolk may see non-native fouling organisms sooner than in Norfolk and Lincolnshire as new non-native species move across the English Channel and along the coast from the south of the country. In the South Inshore Marine Plan Area there are numerous aquaculture sites from Chichester Harbour to the west of the marine plan area. These may all experience changes in sea temperature affecting the sites, and these areas could be the first in the country to see new non-native fouling species which arrive from the continent and there may be a need to adopt additional mitigation measures (e.g. some antifouling coatings, more frequent maintenance, and measures to protect local resident fauna).

Additionally, effects on aquaculture could be driven by ocean acidification. Changes to pH (see **Error! Reference source not found.** and **Error! Reference source not found.** for the South and East marine plan areas) are anticipated all around the UK although there is considerable spatial and temporal variability (**Error! Reference source not found.**). Carbon dioxide concentrations in seawater are higher during the productive seasons (spring and summer) (Portner et al. 2014) and hence pH is lower, largely driven by plankton respiration, bacterial degradation and thermal stratification By contrast surface seawater pH is elevated by inputs of more alkaline freshwater in the winter and autumn across most areas, when there is also much less spatial variability.

With regard to future projections, Blackford and Gilbert (2007) provided model outputs (Figure 20) of ocean acidification in the North Sea assuming a number of different scenarios of increased fluxes of atmospheric CO_2 into the marine system for the time horizon 2050 and 2100. Assuming an increase in CO_2 up to 500ppm by 2050, then this could result in a 0.1 pH unit change over much of the area over the next 50 years, and a total acidification of 0.5 pH units below pre-industrial levels at atmospheric CO_2 concentrations of 1000ppm by 2100. The simulations suggest that by 2050 some areas of the North Sea will be experiencing a pH range completely distinct from current levels. The current maps for surface and bottom water pH show considerable variability in time and in space, with lower pH (more acidic) waters in the south of the North Sea compared to the north during summer, but also marked differences between surface and bottom waters. pH varies considerably throughout the year (not illustrated) and this is influenced by precipitation and run-off from land. Some coastal areas of the UK already experience a one pH unit variation over the course of the year and thus any shellfish living in such conditions would presumably be able to tolerate some long-term change in the future (Figure 21).

3.2.5 Tourism and recreation

Overall summary

Coastal tourism would be expected to be highly sensitive to changes in climate. Benefits may be realised in terms of increased visitor numbers and increased participation in marine leisure activities as a result of an increase in temperature, but infrastructure may be damaged by climate change impacts such as more frequent flooding and storms. Information about visitors to the coast tends to focus on specific towns and resorts. Limited research is available on the impacts of climate change on a national and regional level, despite the clear implications that a changing climate has for the industry. MMO evidence (MMO, 2013g) suggests that tourism at the coast is expected to increase in the near future, focussed especially on daytrips and shorter breaks rather than long holidays but the impact of climate change on this trend is unclear.

Figure 20: Monthly mean surface pH values for (left to right) January, April and June and simulations of 2000 (atmospheric CO_2=375ppm), 2050 (500ppm), 2100 (700ppm) and the 2100 worst case scenario (1000ppm) (Extracted from Blackford and Gilbert, 2007).

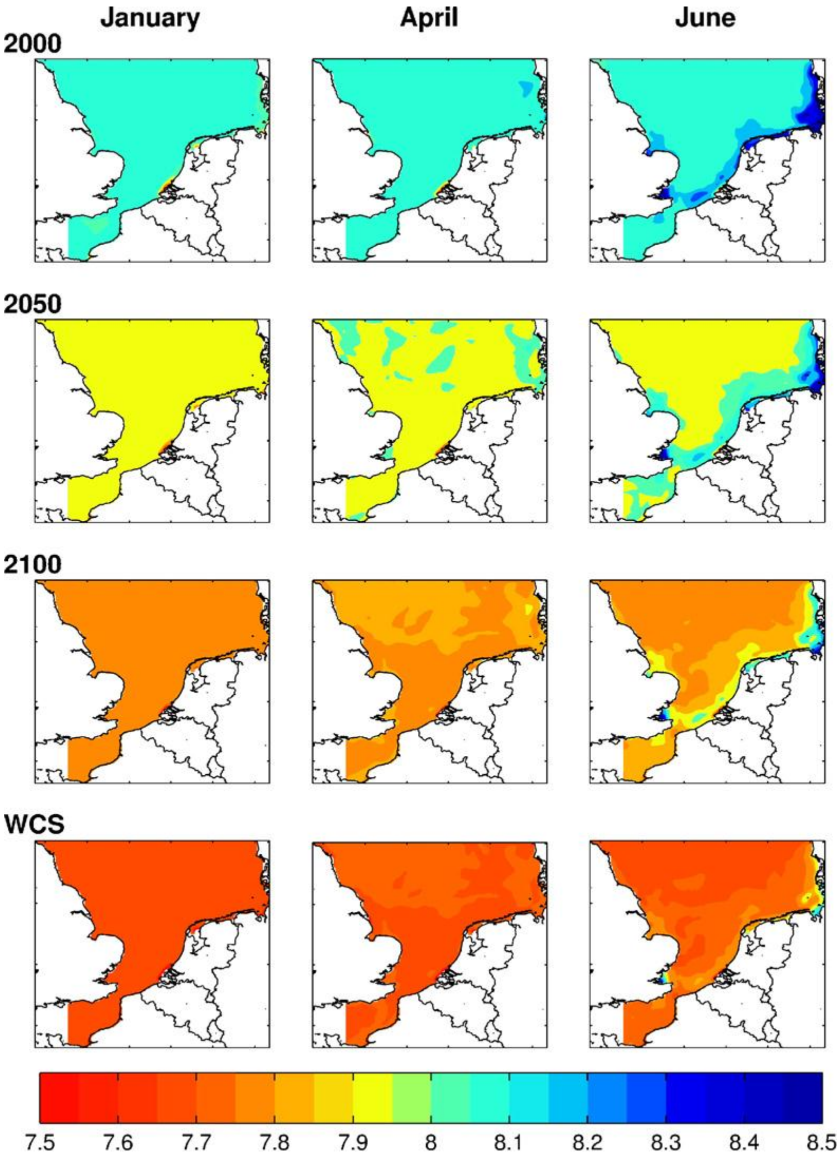


Figure 21: Present day pH for surface (left) and bottom waters (right) in the North Sea during July and August 2011 (Greenwood, et al., unpublished).

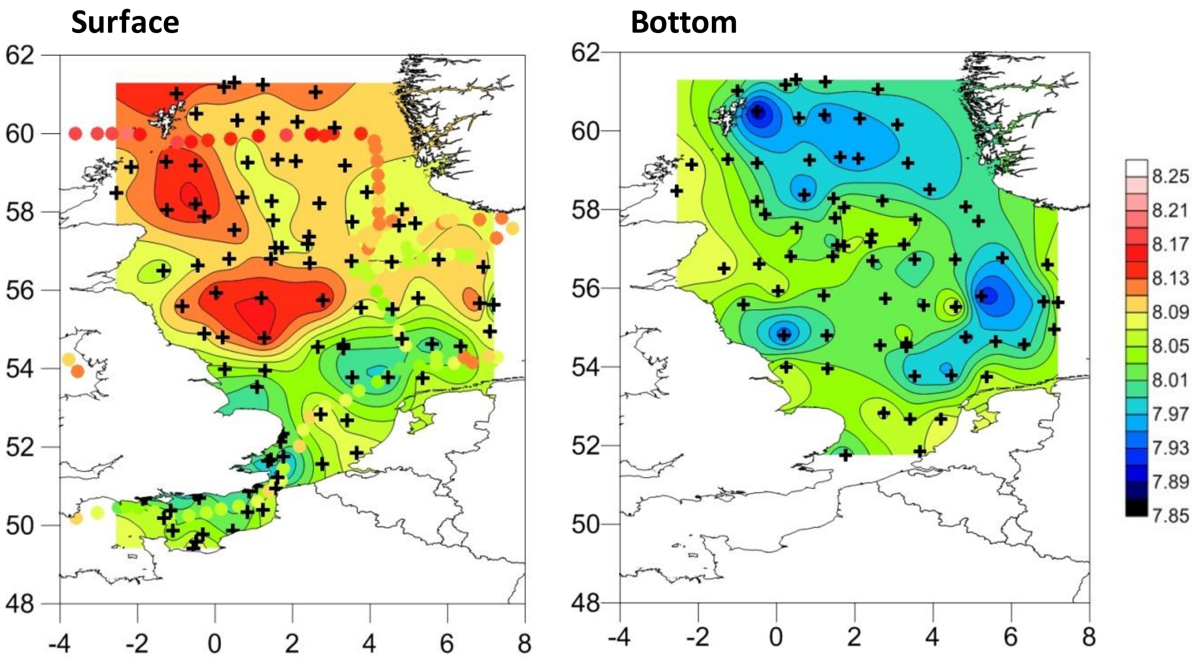


Table 10: Highest scoring risks for tourism and recreation due to impact of climate change

Climate change impact	Sea level rise and flooding leading to impacts on coastal tourism infrastructure, including marinas (Baglee *et al.,* 2012; Simpson *et al*., 2013).
Score	-9 (high probability and high impact)
Proximity	Medium
Confidence	High
Effects on sector	Damage to wide range of infrastructure and closure of facilities. Increased insurance and reputational costs. Increase in safety issues
Recommended Next Steps	Consideration of future climate change in the design standards for coastal infrastructure by the appropriate organisations.

Table 11: Highest scoring benefits for tourism and recreation due to impact of climate change

Climate change impact	Sea temperature rise leading to an increase in recreational fishing (Baglee *et al*., 2012; MCCIP, 2012)
Score	+6 (high probability and medium impact)
Proximity	Medium
Confidence	Medium
Effects on sector	Increased income, directly to the industry, as well as for support services such as local hotels.
Recommended Next Steps	Participate in sea angling projects / surveys with Defra to determine which species/localities may benefit from climate change.

Climate change impact	Air and sea temperature rise leading to an increase in visitors (Baglee *et al.,* 2012; Simpson *et al.,* 2013)
Score	+6 (high probability and medium impact)
Proximity	Medium
Confidence	Low
Effects on sector	Increased income from both domestic and overseas visitors. Employment opportunities.
Recommended Next Steps	Examination of how opportunities for coastal businesses and local regeneration could be assisted.

Further information
Coastal tourism and marine recreation developments are particularly important in the South Inshore Marine Plan Area, which is expected to witness some growth in the near future. Changes to sea surface temperatures in spring, summer and autumn are likely to have a positive effect on the numbers of people using the coast and so boost coastal economy. There may be a need to up-date and enhance existing facilities, to encourage coastal tourism.

In the summer, higher sea temperatures may attract more visitors to the coast for beach holidays, rather than them travelling abroad. This could have an added benefit of helping to reduce carbon emissions from overseas flights and could help boost the UK economy as a whole. In the spring, sea temperatures may warm sooner, and in autumn, the sea temperatures may stay higher for longer, and so extending the tourist season. The maps in Annex 2 show areas where this may be the case for the East Inshore and South Inshore Marine Plan Areas. In the east, the North Norfolk coast is projected to see the greatest sea temperature rise and so may have more visitors to the region. In the South Inshore Marine Plan Area, sea temperature rise is quite uniform across the area and so it is expected that the whole coast will benefit from increased coastal tourism.

3.2.6 Inshore and offshore protected areas

Overall summary

The impacts of sea level rise on coastal habitats are expected to be significant and compensatory habitats may be required to offset any losses. Impacts on coastal protected sites are already being felt (Gillingham, 2013).

Table 12: Highest scoring risks for inshore and offshore protected areas due to impact of climate change

Climate change impact	Sea level rise and flooding leading to habitat loss and need for compensatory habitats (Brown *et al*., 2012)
Score	-9 (high probability and high impact)
Proximity	Near
Confidence	Medium
Effects on sector	Loss of coastal habitats for a range of protected species. Where protected there will be a need for compensatory habitats. Economic losses due to reduction in visitors.
Recommended Next Steps	Consideration of where compensatory habitats should be located. Consideration of appropriate land management techniques (e.g. managed re-alignment).

Further information

Currently “coastal squeeze” is particularly apparent in the East and South Inshore Marine Plan Area, which is heavily protected by hard sea defences. Loss of coastal habitat will be a challenge in the face of EU directives which aim for no net loss of intertidal habitats, especially as rates of sea level rise, and coastal squeeze accelerate. A large number of inshore and offshore Marine Protected Areas (MPAs) (existing, recommended and proposed) are present throughout all marine planning areas but there are distinct concentrations of protected sites along the south Devon coast, between the Humber Estuary and North Norfolk and offshore in the English Channel.

3.2.7 Power stations

Overall summary

Many power stations are located at the coast, drawing on the cooling water that the marine environment provides. Sea level rise and coastal or fluvial flooding could have significant impacts on power production if stations are inundated, or suffer low water levels in estuaries (drought). Site integrity is of critical importance, especially when the lifespan of certain installations are considered. For example, the life cycle of commissioning, building and de-commissioning nuclear power stations can extend beyond one hundred years, meaning preparedness for sea level rise and flooding is of particular importance. The temperature of seawater would also be important in terms of the efficiency of cooling (less efficient if temperatures increase).

Furthermore several power stations (eg the Torness nuclear power station in East Lothian, Scotland in June 2011[17]) have been forced to shut down temporarily in recent years due to a proliferation of jellyfish or seaweed that clogs intakes and has been linked to warmer temperatures.

Table 13: Highest scoring risks for power stations due to impact of climate change

Climate change impact	Sea level rise and flooding leading to impacts on power station site integrity (including nuclear) (EDF 2011; Wadey *et al.*, 2013)
Score	-6 *(*medium probability and high impact*)*
Proximity	Long
Confidence	Medium
Effects on sector	Shutdown of sites/reactor leading to loss of income and long term loss of electricity generation. Safety threats to human life. Insurance and reputational costs.
Recommended Next Steps	Consideration of safety limits for extreme sea levels and consideration of the timescales over which these limits need to be reviewed. Review of safety procedures in the event of an emergency. Review of contingency plans for loss of energy production.

Further information
Both the South and East Inshore Marine Plan Areas include nuclear power plants (at Dungeness in the south and Sizewell in the east), both situated towards the south east of the UK. Significant investment into developing the Sizewell site is underway and consideration is being given to long term climate change impacts at the site (EDF, 2011). Other directly-cooled coastal power stations (gas or oil fired) in the region include those at Cowes (gas), Fawley (oil), Great Yarmouth (gas) and Shoreham (gas).

[17] www.bbc.co.uk/news/uk-scotland-13981189 (accessed on 09/12/2015)

3.2.8 Waste water management

Overall summary

Changes in rainfall are likely to have an impact on the delivery of waste water to the marine environment, including from the operation of combined sewer overflows (CSOs). Releases from CSOs are anticipated to occur more frequently in the future with more intense rainfall events, releasing untreated waste water into the marine environment. This could be a significant issue particularly in the summer when wastes are less diluted and also bathing waters are being used by more people.

Table 14: Highest scoring risks for waste water materials due to impact of climate change

Climate change impact	Changes in terrestrial inputs (e.g. fluvial flows and flooding) leading to impacts from combined sewer overflows (Baker-Austin *et al.*, 2013; Sheahan *et al.*, 2013)
Score	-6 (high probability and medium impact)
Proximity	Near
Confidence	Medium
Effects on sector	Pollution and failure to comply with Water Framework Directive standards. Risks to aquatic and human health. Closure of shellfish and bathing sites.
Recommended Next Steps	Consideration of threat from CSOs with water authorities and provision of storm water storage. Consider risk thresholds for bathing and shellfish waters.

Further information

There are approximately 22,000 CSOs discharging into rivers and the sea around the UK, including at least 500 direct onto beaches. However, it is difficult to determine which locations within the East Inshore or South Inshore Marine Plan Areas would be most affected by discharging CSOs in the future.

3.2.9 Defence

Overall summary

Defence sites and activities in both plan areas are likely to be affected by climate change, either through direct impacts on the site for example through sea level rise and inundation (e.g. at Portsmouth in the South Inshore Marine Plan Area), or through impacts on military exercises.

Table 15: Highest scoring risks for defence due to impact of climate change

Climate change impact	Sea level rise and flooding leading to impacts on the structural integrity of defence sites
Score	-6 (medium probability and high impact)
Proximity	Medium
Confidence	Medium
Effects on sector	Flooding of sites. Damage to high value equipment and machinery. Closure of sites. Reputational damage. Temporary suspension of military training.
Recommended Next Steps	Review of safety limits and coastal defences at key sites and consider the timescales over which these need to be reviewed. Review of safety procedures in the event of an emergency. Review of contingency plans for emergencies.

Further information

As well as Portsmouth on the South Coast, the Royal Navy has shore-based training establishments or barracks at Fareham and Gosport in Hampshire, Poole in Dorset, Lympstone and Dartmouth in Devon.

4. Conflicts between sectors

This section provides an overview of the interactions across sectors, as well as considering current and potential future conflicts. It takes into account information presented earlier in this report on the climate change information that has been compiled and mapped as well as the results from the risk assessment. At the time of writing there was not sufficient available evidence of the future planned activities over the different marine plan areas, therefore the location of current activities has been used as a starting point to assess future conflicts. Plan areas have been used alongside general information of the different sectors to provide some spatial information. Consultation with industries and sectors would be required to fully understand the future conflicts likely to arise through changing use patterns.

This section and the maps presented in Annex 2 have only considered the sectors which are thought to be most at risk and show the overlap between activities and the climate change variables themselves. Maps are provided for the East Inshore and Offshore, and South Inshore and Offshore Marine Plan Areas, and the climate variables for the marine projections only use the medium emissions scenario), which have been used to illustrate changes/sensitivities (e.g. bathing seasons) for the two marine plan areas. For skew surge, different return periods (timescales for the predictions) are included, providing information about the frequency of severe storms of different levels of impact. In some cases the assessment covers a wide range of activities and the likely expected effects from climate change.

4.1 Annual sea surface temperature, fishing areas and wind farms

Relevant map from Annex 2:

- Recent fishing hotspots and wind farm areas as potential sanctuaries with annual mean sea surface temperature change projections.

Sea surface temperature may cause a conflict between fishing areas and wind farms as changes in productivity, food webs and spawning success will alter fish distributions, in turn affecting the areas targeted for fishing. Wind farms typically need to exclude fishing vessels from certain areas for reasons of safety and insurance. . The maps in Annex 2 evidenced some overlap between current fishing grounds and proposed wind farms. Potentially, the additional structures might attract fish and this overlap may increase further in the future if fish stocks move in response to changes in temperature. This may be the case in the East Offshore Marine Plan Area where there is much overlap already between the 2013 fishing grounds and proposed wind farms as well as in the South marine plan area, where fishing activity is an important industry. For example plaice seem to be moving offshore in the North Sea towards the Dogger Bank (Van Keeken *et al*. 2007) in recent years, where many large windfarms are now planned in the UK sector.

It is complicated to predict how fishing activity may be affected in the future by climate change. Additionally, one of the largest concerns for the fishing industry is the uncertainty and the changes that may result from Common Fisheries Policy reform as well as the potential introduction of new MPA management measurements which are also likely to affect the fishing industry. Whilst fish displacement/relocation is a key concern for the fisheries industry, there are other non-climate related issues associated with growth in other sectors (e.g. offshore wind farms, aggregate extraction, ferry routes, MPA measures) that are of concern as well as change within the fisheries sector itself such as gear conflicts (e.g. Lyme Bay).

Fisheries may be affected by secondary climate change impacts such as expanding tourism activities in active fishing ports . Whereas the effects associated with expanded aggregate extraction include dredging in the vicinity of herring spawning grounds, especially in the East Offshore Marine Plan Area requiring management measures to avoid additional impact on this industry.

4.2 Annual sea surface temperature, aquaculture sites and bathing waters

Relevant maps from Annex 2:

- Monitored bathing and aquaculture sites with spring mean sea surface temperature change projections
- Monitored bathing and aquaculture sites with summer mean sea surface temperature change projections
- Monitored bathing and aquaculture sites with autumn mean sea surface temperature change projections.

Changes to sea surface temperatures in spring, summer and autumn are likely to have a positive effect on the numbers of people using bathing waters and tourist resorts, and so boost coastal economies. There may be a need to update and enhance facilities, which in turn will be likely to encourage further coastal tourism in some areas.

Climate change is expected to both affect the South and East marine plan areas, although some identified conflicts will be:

- Issues associated to coastal/beach erosion at some sites, which could affect areas dedicated to tourism and particularly issues associated with safety and attractiveness (e.g. Isle of Wight and Hastings).
- Some seaside areas are already in decline and will need significant investment to improve their acceptability in the future (e.g. Great Yarmouth).
- Expansion of port and harbour facilities may mean that areas of recreational or wildlife value have to be sacrificed.
- Areas set aside for nature conservation (compensatory habitats) as a result of national and international legislation could mean that tourism has little space to expand.

- Consenting of wind farms, tidal energy schemes and port development could affect tourism in particular areas (e.g. Navitus Bay off Bournemouth, Rampion off Brighton and St Catherine's Point, Isle of Wight).

- The condition of the marine environment will also have to be taken into account, especially with regards to water quality as this is important for recreation and tourism (bathing sites).

When considering interactions with aquaculture, the main sites are located within the South and East Inshore Marine Plan Areas (MMO, 2013h). Water quality is of high importance to the aquaculture industry, as poorer water conditions impact species growth and increase the risk of disease transmission (both to humans and in shellfish).

It is also important to consider interactions between aquaculture, tourism and recreational activities (e.g. boating or yacht clubs), as most aquaculture developments are situated in estuaries, which are also used for recreational activities in the South and East marine plan areas, e.g. the Blackwater and Crouch estuaries in the East and Chichester or Poole Harbours in the South. The tourism sector may also benefit due to an increase in sea surface temperature, and any related longer periods of warm weather for tourists to visit the coast and estuaries. Tourists may wish to take advantage of prolonged warm weather periods, which may result in co-location opportunities for aquaculture whereby aquaculture developments could allow companies to open some of their sites for tours and educational visits. Non-native species have been introduced to the UK and spread by shipping, aquaculture and recreational boating alike. Hence these two sectors can also interact in a variety of direct and indirect ways.

There may be other sectors (e.g. maintenance and capital dredging, port and shipping activities or fisheries) that could also co-exist in areas where aquaculture takes place. There may be some conflicts associated to these areas as they compete for space as well as other considerations such as water contamination by viruses, bacteria or contaminants, and issues associated with ballast water which can introduce non-native species. A number of opportunities are being assessed by The Crown Estate in relation to co-location of aquaculture and for example capture fisheries. As these two activities share similar needs for land infrastructure and workforce skills, this could allow for positive interaction. Another potential opportunity for the aquaculture sector is to share infrastructure with offshore wind farms if the environmental conditions are suitable. The culture of mussels is a clear example, were there has been some consideration of biological and economic feasibility (MMO, 2013d). Some areas being considered by the Shellfish Association of Great Britain are in Wales (North Hoyle Wind Farm), but also in the South Marine Plan area where the shellfish industry propose to create the UK’s first large scale offshore rope culture mussel farm in Lyme Bay (MMO, 2013h).

Another area where there could be opportunities as a result of climate change is the marine biofuel (cultivation of macro-algae) sector whereby seaweeds are grown for burning or bio-digestion in power stations. Also higher temperatures could provide additional opportunities for farming novel species (e.g. trout, sea bream and sea bass). This will require investment as well as adjustment of existing technology or skills.

4.3 Sea level rise, storminess, bathing waters, aquaculture sites and disposal sites

Relevant maps from Annex 2:

- Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2020
- Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2040
- Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2060
- Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2080
- Monitored bathing sites, aquaculture locations and open disposal sites with 2 year return level skew storm surge trend
- Monitored bathing sites, aquaculture locations and open disposal sites with 10 year return level skew storm surge trend
- Monitored bathing sites, aquaculture locations and open disposal sites with 20 year return level skew storm surge trend
- Monitored bathing sites, aquaculture locations and open disposal sites with 50 year return level skew storm surge trend.

Sea level rise and storminess may have negative consequences for aquaculture, bathing waters and disposal sites. In the East and South Inshore plan areas, water quality in shellfish and bathing waters could be reduced following flooding or storm events when pathogens and contaminants are washed into the sea from land. Aquaculture infrastructure may be damaged by storms, and access to aquaculture sites may be restricted or become unsafe. The use of bathing waters during stormy weather is likely to be reduced, with negative consequences on the local economy, and storms could also cause potential damage to tourist infrastructure. Also, sea level rise could reduce the area of beach in some locations, and storminess could change the beach profile making it more or less appealing to tourists. The maps show that sea level rise is projected to be similar around the coast of the East and South Inshore Areas; however the skew surge is projected to be highest around the Yorkshire, Lincolnshire and Suffolk coasts in the East, and higher along all of the South Inshore Marine Plan Area but particularly around the Solent. There may be conflict between aquaculture and bathing waters as aquaculture sites expand or increase in number and move nearer bathing areas. Some aquaculture and bathing water sites are already in close proximity in The Wash in the East Inshore area, and around the Solent in the South Inshore Area where this may become a problem.

In the East Inshore and Offshore and South Inshore Marine Plan Areas, contaminated sediment disposal sites may be affected by storminess. Storms could affect the safety and efficiency of operation, and the availability of suitable weather in which to operate could be reduced. It is possible that sea temperature rise and ocean acidification may also affect the potential impact disposal sites, because they could affect the behaviour/bioavailability of substances in the marine environment (heavy metals, Tributyl tin, Polychlorinated biphenyls, etc.). For example, some chemicals which are known to be safe in the current pH and temperature may start to break down or exhibit increased toxicity under future conditions (Roberts *et al*., 2013). This may be a particular issue in areas which have historic legacy contamination from industrial activities such as fly ash disposal and colliery mining. Storminess could also cause re-suspension of substances at disposal sites, and so their position may need reconsidering if this is the case, particularly if they are close to bathing beaches, fishing grounds or aquaculture sites such as around the Isle of Wight and Bournemouth in the South Inshore Marine Plan Area, and near Spurn Head and the entrance to the Wash in the East Inshore Marine Plan Area. There may be increased demand for capital dredging (e.g. arising from port expansion) due to larger ships (e.g. bulk and container ships) and hence a need for deep navigation channels. One of the potential side effects may be negative consequences for ecosystem function and biodiversity and the footprint of such effects may have to be mitigated and managed accordingly through licensing permits.

4.4 Annual sea surface temperature, sea level rise, storm surge and ports and harbours

Relevant maps from Annex 2:

- Ports, harbours and mooring / warping locations with annual mean sea surface temperature change projections
- Commercial and recreational shipping infrastructure with 2 year return level skew storm surge trend
- Commercial and recreational shipping infrastructure with 10 year return level skew storm surge trend
- Commercial and recreational shipping infrastructure with 20 year return level skew storm surge trend
- Commercial and recreational shipping infrastructure with 50 year return level skew storm surge trend
- Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2020
- Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2040
- Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2060
- Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2080.

As identified in Section 3 of this report, climate change and in particular impacts of storminess and sea level could have a number of consequences for UK port and harbours. An estimated 95% (by volume) of all goods and products arrive in the UK by sea and to date, the ports sector contributes around 17,286 full time equivalent jobs (FTEs) to the UK economy (MMO, 2013f). In the South marine plan areas there are a number of significant English Channel ports including Dover and Southampton (supplying freight, passenger, leisure and fishing industries). There are also a wide range of smaller harbours which host leisure and fishing activities. The majority of the largest port developments are located in the East marine plan areas (Felixstowe, Harwich, London Gateway, Immingham, etc.). Hence any change in climatic conditions could have serious consequences for the UK economy.

When assessing future conflicts with other sectors, at the time of writing, there are the two proposed Round 3 offshore wind farms developments (Navitus Bay and Rampion) in the South marine plan areas which are still awaiting government consent, but could greatly interact with shipping traffic in the Channel. Similarly, major wind farm developments along the Essex and Suffolk coast (such as Greater Gabbard, Gunfleet Sands) could interact with traffic from Felixstowe and Harwich. The development of port capacity in different areas will depend on the importance of different sectors locally. For example, the expansion of facilities to handle marine aggregates could occur at Immingham whereas maintenance and construction of offshore turbines for the renewable energy sector is becoming an increasing part of activity in many ports (e.g. Great Yarmouth and Lowestoft).

4.5 Temperature, pH, fishing areas, aquaculture sites and onshore and offshore protected areas

Relevant map from Annex 2:

- Fishing hotspots, aquaculture sites and marine protected areas with annual mean sea surface temperature change projections.

Ocean acidification could have a negative impact upon shellfisheries and the shellfish aquaculture industry. Aquaculture companies may have to move to waters with tolerable pH in the mid to long-term, perhaps moving out of the traditional East Inshore and South Inshore Marine Plan Areas or moving to onshore facilities where water intakes can be regulated.

Research is ongoing to monitor pH and produce projections of future values around the UK, but quality controlled data layers of pH are not currently available for incorporation in the MMO Marine Planning Portal. For the purpose of this report we have used the modelled dataset Blackford and Gilbert (2007) (Figure 20) and an observed but unpublished dataset of current conditions (Figure 21 taken from Greenwood *et al*., *pers comm*.), mainly to illustrate ongoing work but also to set the context of the present spatial variability. These data sets do not allow full coverage of the East and South marine plan areas, but do illustrate “state of the art” techniques as this is the first time that pH is measured and presented over the entire North Sea area.

Onshore and offshore protected sites may also be affected by low pH. Biogenic reefs such as mussel beds and *Sabellaria* reefs may reduce in area or disappear which could in turn affect other species which live in and amongst them. Food chain impacts may be felt by species such as fish and birds, which rely on shellfish as a food source.

5. Climate change adaptation and mitigation and specific recommendations

The seas around the UK have been highlighted as a “hot spot” of marine climate change, having warmed by more than 1ºC over the past 40 years (MCCIP, 2013). This rate of increase is more rapid than almost anywhere else on Earth. The combined changes in storminess and ocean acidity has prompted considerable interest among scientists as well as among policy makers and industry. Aquatic organisms and industries are sensitive to climate change; however, the level of knowledge concerning marine climate change impacts is still limited when compared with terrestrial systems. Through the 2008 UK Climate Change Act, the government is required to conduct a Climate Change Risk Assessment (CCRA) every five years, and this includes the assessment of risks to the marine environment and industries which will improve the evidence base related to climate change impacts.

Adaptation is the process through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails making appropriate adjustments to mitigate the negative effects, or to exploit the positive ones. There are many options available and opportunities to adapt. These range from highly-expensive engineering projects such as increased sea defences or flood protection barriers, to simple behavioural or procedural changes at the individual level, such as encouraging the buying of fish which are more tolerant of increased temperatures or building infrastructure in the most appropriate places. The different categories of adaptation that are most widely cited in the literature include: “reactive” versus “anticipatory” and “planned” versus “autonomous”:

- “Planned” adaptation is the result of a deliberate policy decision, based on the awareness that conditions have changed or are expected to change, and that some form of government intervention is required to maintain a desired state. Such anticipatory adaptation would progress from the top-down approach, through planning, regulation, standards, and investment schemes.
- “Autonomous” adaptation refers to those actions that are taken by individual institutions, companies and communities independently as a result of their perceptions about climate risk. Such autonomous actions may be short-term adjustments and are often considered as a reactive or bottom-up approach.

Marine planning has a role to play in planned adaptation by providing policies which reduce the negative impacts of climate change on marine industries and which maximise the opportunities which climate change can bring. In the coming years and decades autonomous adaptation driven by industry will take shape, as more detailed projections become available and climatic changes are realised. The marine plans and climate related policies will need to respond to new information and be more explicit about what is expected in the future (where, when and what) as well as what outcomes are desired.

Under the auspices of the Defra-funded "Marine Climate Change Adaptation Action Plan" project (MACCAP[18]), Cefas mapped-out a set of risks and opportunities arising from anticipated climate change, as well as "autonomous" and "planned" responses that could help address these impacts (Cefas, 2013). A starting list of 75 high-level maritime climate change risks was considered and 373 'planned' and 284 "autonomous" options/interventions were mapped-out. These were not spatially explicit but they largely serve to illustrate the range of options that the government or industries could adopt in the face of emerging threats. Some insights and actions elucidated as part of this process eventually were taken up in the UK National Adaptation Plan (NAP) that was published by Defra in July 2013.

"Planned" adaptation options include:

- Monitoring and surveillance
- Forecasting and computer modelling
- Research and development (mechanisms and processes)
- New legislation, regulation and policy
- Engineering solutions
- Issuing "codes of best practice"
- Market-oriented initiatives
- Public awareness campaigns
- Emergency response and planning.

The majority of these options are not related to marine planning, but are applicable to Defra or the wider government. However those relevant to marine planning, or to the wider MMO and government but of benefit to marine planning, have been considered below.

5.1 Overall recommendations for consideration by MMO and its partners

It is recommended that MMO and Defra assume a leading role in encouraging climate adaptation in the East and South marine plan areas, to ensure that the obligations under the 2008 Climate Change Act and the 2011 Marine Policy Statement are fully achieved. Marine plans are to be reviewed every three and six years. This provides a window of opportunity to take account of newly generated evidence from different sources such as experiments, monitoring and computer modelling (Birchenough *et al.*, 2013b) and in particular insights from the UK Marine Climate Change Impact Partnership (MCCIP). This partnership has helped to elucidate the most pressing impacts resulting from climate change around the UK and Ireland.

Section 5.3 provides more detailed climate change adaptation and mitigation recommendations for MMO and for government as a whole, across the East and South marine plan areas. It is important to note that not all of the recommendations

18 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17901&FromSearch=Y&Publisher=1&SearchText=maccap&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description [accessed 06/03/14]

concern marine plans *per se,* some provide further information on the regulation of activities in the marine environment, or on measures that government should take to help industries adapt to anticipated future climate change. As these adaptations will affect marine industries they are indirectly linked to marine planning.

5.2 Overall recommendations for marine planning

A key recommendation from this report is that marine plans take account of the information already available "off the shelf" from UKCP09 and other sources, and this report is a first step in this direction. The maps within this report can be used when developing marine plans to identify the locations where major environmental changes are anticipated and where vulnerable industries are already located. As discussed earlier in this report, the UKCP09 sea surface temperature projections only include outputs for one model run, one emissions scenario (medium emissions) and one future time-slice that is far in the future and beyond the usual business planning horizon for most marine industries.

A clear recommendation, especially before the next tranche of marine plans are developed, would be to draw upon new scenario outputs that will become available as a result of the Defra MINERVA[19] project, in the next few months. An attempt is currently underway under MINERVA, at the Met Office (working with Cefas), to develop outputs from 11 different climate model formulations (although still assuming a medium emissions scenario), thereby offering insight into uncertainty and robustness of projections, but also outputs for intermediate time-slices (the next 20, 30, 40 years etc.). These will be much more useful for climate change adaptation cycles and marine planning. Given this information, it will be possible to better judge the rate of change, the need for adaptation in specific geographic areas and therefore the necessity for consideration by planning policies.

5.3 Sector Specific Recommendations

5.3.1 Structures[20]

For most of the structures associated with offshore wind farms, oil and gas platforms, ports and sea defences, the main issues when assessing climate change risk are concerned with the site integrity and damage to structures as a result of sea level rise or changes in storminess. Sea defences can become damaged in storms and a range of adaptation strategies are required to protect properties and coastlines including renewing sea defences and for enabling managed retreat. In contrast, some potential benefits of climate change will be associated with warmer air and sea temperatures, which could enable new shipping routes to open up (e.g. adoption of northern routes), which in time might require regional expansion to certain ports, re-

[19] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=19006 [accessed 06/03/14]

[20] This includes ports and shipping, power stations, waste water materials, offshore wind farms, carbon capture and storage and wave and tidal developments.

routing of shipping lanes and traffic separation zones but potentially provide wider economic opportunities.

Marine planning recommendations

As sea defences bear the brunt of storms and waves and it is thought that severity and frequency of storms may change in the future, in the East and the South, it is recommended that planning policies be developed that take account of such anticipated changes to avoid property loss and protect coastlines. Shoreline Management Plans for each area should be used to promote specific policies regarding adaptation options such as managed retreat where appropriate. It is also recommended that EU directives which protect coastal habitats be considered as part of marine planning to ensure that their objectives are met.

Changes in storminess may also mean that more robust sub-sea structures are required at certain localities, to withstand the force of extreme waves and winds or additional scour etc. This could place a requirement on marine planning to provide clear policies that address this, given that these would likely have a more extensive “footprint” on the seabed, for example a shift from tethered designs (or monopoles for wind turbines) to large concrete “gravity base structures”, that would also require sites for eventual decommissioning.

Ports and shipping may be affected by climate change in both the East and South marine plan areas. It is recommended that proactive planning policies relating to changing shipping routes and ship designs be developed in advance, that include consideration of vessel sizes (draught), traffic movements, and a potential requirement for new port facilities or dredged channels. Particular attention should be paid to maintaining shipping channels so that they are less affected by sedimentation in the future and where necessary that alternative routes or protocols are put in place should sedimentation occur as a result of changes in currents and/or storms. It is also recommended that MMO keeps abreast of information regarding the opening up of the northern shipping routes through the Arctic and that marine planning policies are developed when necessary that are related to these new shipping routes including expansion of ports further north in the UK to accommodate polar vessels or reconfigure onshore transport links to transfer goods and products to major cities.

When considering mitigation strategies to reduce carbon emissions for example via offshore wind farms and carbon capture and storage, there are clear UK national priorities, and these will have major consequences for marine planning, mainly in the East Inshore and Offshore Marine Plan Areas. For example the UK government has committed to generating 15% of its energy from renewable sources by 2020 in order to cut carbon emissions, requiring large areas of sea-bed to be turned over to this activity. Marine biofuels might also become important and thus areas might also need to be set aside for this activity, even though unimportant at the moment. It is recommended that marine planning policies pay specific attention to emerging marine renewables and consider co-location of these areas with other activities where suitable. Also it will be necessary to consider locations of inter-connection nodes and sub-sea cables to connect the burgeoning number of offshore power generation sites to networks on land. Such actions will have to be considered in long-term marine plans, even if it will be many years before structures or inter-connections are actually required on the sea bed. A recommendation to keep marine planning policies up to date, is that MMO engage in regular "horizon scanning" exercises with The Crown Estate and industry stakeholders to determine what new activities might arise. Already brand new port facilities have needed to be developed "from scratch" in the UK to service the burgeoning offshore renewable sector. An example includes the Port of Mostyn Breakwater development in North Wales or the Outer Harbour development in Great Yarmouth.

Additional recommendations for consideration by MMO and its partners

A recommendation for the wider MMO is to consider a combination of "planned" (statutory) and "autonomous" (industry-led) adaptation measures. Government intervention as well as commercial and individual input will all be required to ensure that identified climate change risks are fully addressed. Government intervention may include measures such as enhanced sea defences, better surveillance, monitoring and forecasting infrastructure, better early warning systems, "guides of best practice" whereas commercial and individual input may include measures such as more robust ship and structure designs and more comprehensive insurance..

Suggested adaptation actions, arising from the MACCAP project included:

- Avoidance of losses to property and coastal infrastructure:
    - Expand the current network of tide-gauges and Waveney buoys around the UK to monitor changes in sea level and storminess.
    - Commission locally-relevant projections of sea level rise from climate models (or storm surge return periods).
    - Shoreline Management Plan – Environment Agency to define a strategy deciding areas that will require hard defences, and those that won't be protected.
    - Government incentives to encourage industry or households to move away from high risk areas.
    - Planning requirements to limit onshore developments in high flood risk areas.
    - Establish early warning systems and regulations for safe transport conditions.
    - Commission research trials into new wave-power technologies.

- Avoidance of damage to offshore turbines or oil rigs and/or maintenance issues:
    - Continued support for Wavenet[21] – wave monitoring and early warning.
    - Better real-time weather forecasting/downscaling.
    - Review and update of health and safety requirements for oil and gas rigs and wind turbines.
    - Statutory risk assessment and computer modelling as part of the consents process of changes in scour conditions around structures.

[21] http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/wavenet.aspx [accessed 06/03/14]

  - Update and revision of licensing conditions for cables, pipelines and structures to address potential impacts on scour.
  - Requirement to update contingency and preventive plans for accidents.
  - Statutory limits on operating envelopes for service vessels/helicopters (i.e. a requirement to stay ashore if too rough).

- Avoidance of disruption to ports and damage to shipping:
  - Improved storm forecasting at the local scale of relevance to individual port / harbour locations.
  - Statutory safety limits on port / harbour infrastructure design/operation.
  - Construction of more resilient port facilities and transport links.
  - Limits on ship design/operation.
  - Re-mapping of the seabed at regular intervals to address changes in sedimentation of navigation channels.
  - Improve accident response services (e.g. availability of emergency tugs).
  - Scoping reports on cost-benefits of opening new shipping routes for UK trade and feasibility of using such routes. Identifying the consequences for UK ports and harbours.

In the case of ports, MMO could provide signposting to existing guidance for new and existing developers to ensure that structures comply with modern design standards to cope with sea level rise and to avoid inundation as well as the adoption of low carbon construction materials. A “cradle to grave” carbon budget should become a requirement of Environmental Impact Assessments. For example, in the East Inshore Marine Plan Area it is envisaged that changes resulting from sea level rise and storminess along the Yorkshire and Lincolnshire coasts, will affect the ports of Hull and Immingham, and the south Suffolk coast, affecting the ports of Felixstowe and Harwich. In the South Inshore Marine Plan Area, the skew surge is highest in the Solent region where there are many ports and harbours. MMO may have a role to play to ensure these port developments remain fit for purpose, which could be managed through marine plans policies or where this is not the case, that other sites are identified. Changes in storm patterns may also require the construction of new breakwaters, offshore reefs and groynes to protect port infrastructure at some sites, and this would need to be taken into consideration in marine plans.

5.3.2 Aggregates and dredging

Marine aggregate extraction provides around a fifth of all the sand and gravel used in England and Wales. A direct consequence of sea level rise and change in storminess will be an increase in the need for marine aggregates for coastal defence works. It is likely that increased marine aggregate extraction will be mainly concentrated in the East marine plan areas, although aggregate licences currently also exist in the area around the Isle of Wight and Hastings. Marine sands and gravel are currently dredged from 70 production licence areas located off the coast of England and Wales. In the future, there may be a need to source material further offshore (potentially in deeper waters) and therefore in a harsher environment.

With government support for the construction of nine more offshore wind farm zones and construction moving into deeper water, the use of gravity base foundations is likely to grow. Each gravity base foundation requires 1,000m^3 of concrete and a further 2,000m^3 of sand for ballast fill once installed, hence demand for marine aggregate materials could be significant in the future. Additionally, climate change may have a tendency to increase coastal erosion thereby increasing risk of breaching of dunes and inundation by the sea, necessitating extensive beach replenishment.

Any change in storminess or wave heights could have a significant impact on the aggregate extraction and dredging sectors, given that suction dredgers (which dominate the industry) rely upon calm conditions for accurate positioning of the suction head and for safe operation. There are currently a number of 10 to 15 year aggregate extraction licenses in place off the Humber, East Coast, and in the Eastern English Channel, off the South Coast and southwest. It is important to assess if climate change will affect these regions and there may be a need to search for additional areas. Changes in currents or circulation patterns could impact upon dispersal of the sediment plume that typically results from dredging/aggregate extraction, also the recovery time of the sea bed (sediment infill) following passage of a dredging vessel.

Marine planning recommendations

It is recommended that marine plans consider what new areas might be needed in the near to medium term for marine aggregate extraction and for disposal of dredged material. If storminess were to increase (this is highly uncertain), it may be necessary to open up new sites in more sheltered waters, or to set aside larger areas – acknowledging difficulties in precise dredge operation. Some of the potential changes identified will be as a result of storminess and sea level rise that could affect both the East and South marine plans.

Changes in sediment regimes or re-suspension caused by dredging and disposal could have knock-on consequences for other marine sectors, such as recreation, fishing, aquaculture and nature conservation that might be negatively affected. In considering new areas for dredging or disposal, it is recommended that marine planning takes into account these potential conflicts.

Additional recommendations for consideration by MMO and its partners

It is recommended that the MMO work with the Environment Agency, the Crown Estate and the British Marine Aggregate Producers Association (BMAPA) to map out trends in future demand, and also requirements/plans for coastal defence.

There may be expected changes in sediment transport, which could lead to increased siltation of harbours (also see the section on ports, above), inlets and channels (CEDA, 2012) necessitating an expansion of dredging activities. One option would be for the MMO to work with industry to assess the observed changes and allow the industry to prepare a “contingency” plan, involving surveillance, pre-defined actions and dredging schedules to keep channels open as necessary (i.e. for the MMO to assist with “autonomous” adaptation).

Adaptation actions identified by the MACCAP project included:

Need for increase in marine aggregates for sea defences:

- Review licensing of marine dredging sites around UK and EIA requirements.
- Provide locally-relevant projections of sea level rise from climate models (or storm surge return periods).
- Review coastal management plans.
- Assess water quality effects (including light and water clarity at extraction sites).
- Expand the current network of tide gauges around the UK to monitor changes in sea level.

Reduced access to offshore aggregate resources (sand and gravel):

- Review the potential impacts of changes to storms / waves and calm weather windows on aggregate extraction.
- Statutory limits or codes of practice on operating envelopes for vessels (a requirement to stay ashore if too rough).
- Better real-time weather forecasting/downscaling.
- Review licensing of marine dredging sites around UK.

5.3.3 Fisheries

With regard to fisheries, the main effect predicted to result from climate change is a significant impact on the distribution of species and hence availability of commercial fish resources to fishermen. However, as traditional stocks decline or move away from UK waters other opportunities could arise because new commercial species expand and become commercially exploitable for the first time. This topic has been discussed in detail in the 2013 Economics of Climate Resilience (ECR) report (Defra, 2012) on sea fisheries. This report included an account of institutional and logistical barriers to adaptation in the UK fish catching sector, and also highlighted the need for government-led actions, including some of relevance to the MMO, such as making adjustments to quota allocation or introduction of closed areas to protect spawning populations.

Marine planning recommendations

Anticipated future range shifts for commercial and conservation species are described in the ECR report (Defra, 2012) and were derived from analyses by Jones *et al*. (2012, 2013a, 2013b). A clear recommendation, when developing or revising marine plans would be to consult these sources and to discuss the robustness of individual predictions with the report authors. At each review of the marine plans, a search for current research should be undertaken to ensure that the most up-to-date evidence with the highest confidence is used. This is important for all sectors, not only fisheries, however much scientific research is currently being undertaken on ecosystems and fisheries, and so the evidence base is likely to change markedly between each marine planning cycle. Changes in the distribution of species will result in changes in the distribution of fishing vessels and potentially their interactions with other users of the marine environment. For example, a recent shift in the distribution of plaice towards the Dogger Bank in the central North Sea as a result of climate change (van Keeken *et al*. 2007), may result in increased competition between the commercial beam trawl fleet and planned offshore wind farms or marine protected areas in this region.

Additional considerations might include the need for better facilities (identified spatial locations) for fishing vessels to tie up during stormy weather. During the harsh winter storms of 2013/2014 many South Coast fishermen were unable to go to sea for many months, necessitating sufficient capacity within harbours and possibly highlighting a need for new breakwaters and sheltered berths to protect vulnerable assets (and requiring consideration in spatial plans).

Additional recommendations for consideration by MMO and its partners The UK fishing industry includes operators of vessels of varying adaptive capacity and capability. The ability of some segments within the sector to adapt is more constrained than others, notably small vessels face constraints on their ability to travel distances to reach their favoured fish stock, the time they are able to spend at sea and their access to the rights to catch particular species. The wider MMO has a role to play alongside the fishing industry as it undertakes key “autonomous” adaptation actions. These are likely to include:

- Enabling boats to travel further to fish for current species, if stocks move away from UK ports.
- Diversifying the livelihoods of port communities, this may include recreational fishing where popular angling species become locally more abundant (e.g. sea bass).
- Changing gear types to fish for different species, if new or more profitable opportunities to fish different species are available.
- Developing routes to export markets to match the changes in catch. These trade-flows may involve countries (such as those in southern Europe) which currently eat the fish stocks which become more abundant the UK EEZ.
- Stimulating domestic demand for a broader range of species, through joined up retailer and media campaigns.

Key barriers to autonomous action identified in the ECR report include:

- The capacity of vessels to travel (distance and time at sea); a barrier for smaller inshore fleets.
- The cost of investing in new nets and gear where it may be required for a particular species (although there is some funding available through industry grants).
- The speed of the sector to adapt is constrained by the process of setting quotas for particular species. This process is lengthy and backward looking so there is a risk that quota allocations restrict fishing activity where stocks are increasing or changing their distribution.
- Quota allocations are based on historic levels of catch and therefore can create incentives for maladaptation. Particularly for species not under quota, where their emerging abundance creates expectations of future quota restrictions (a race to establish a “track record”).

- A strong domestic consumer preference for a limited range of species is a major constraint inhibiting the ability of UK suppliers to benefit from potential opportunities.

The MCCIP Annual Report Card supporting document on fisheries (Pinnegar *et al*., 2013) identified that some commercial and recreational fisheries have already responded to climate change in recent years. As a result of sea surface temperature increase, fishing patterns will likely be modified in all of the East and South marine plan areas. A further recommendation that the MMO might consider could be to encourage the commissioning of computer modelling work that attempts to predict the future distribution of fishing vessels as a consequence of changing fish distributions or spatial management measures (this work could cover all of the East and South marine plan areas). A number of techniques are available to characterise the behaviour of fishing vessels in time and space. Models have been used to predict the response of the English beam trawl fleet following introduction of a spatial fishery closure in 2001 (see Tidd *et al*., 2012; Hutton *et al*., 2004), and also to predict the response of the English scallop trawl fleet in the Channel to changes in aggregate extraction and shipping traffic. These tools could be used to predict spatial conflicts in the future, for example to determine whether particular fishing fleets will likely move into areas designated for other activities, a key focus of marine spatial planning.

5.3.4 Aquaculture

The need to ensure adequate supplies of seafood for human consumption has driven rapid development of the shellfish and fin-fish aquaculture sectors worldwide. In England many different marine species are farmed, the most dominant being oysters and mussels (but also clam *Venerupis semi-decussata* and cockle). In England and Wales, marine aquaculture generates a total of ~20,521 tonnes of seafood per year (Callaway *et al*., 2012). At the moment, salmon aquaculture is not an important component, unlike in Scotland.

Shellfish aquaculture has been considered more vulnerable to climate change in comparison with finfish aquaculture. In the case of bivalve farming (e.g. oysters and mussels etc.), a specific issue is associated with seawater temperature, given that most UK aquaculture relies on supplies of wild spat (larvae) for stock replenishment. Strong relationships have been identified between shellfish recruitment and seawater temperature around the UK (e.g. Diederich *et al*., 2005; Shephard *et al*., 2010). In addition most existing aquaculture facilities rely upon adequate quantities of plankton for food.

A major climate-related threat to shellfish aquaculture production in the UK could be ocean acidification. Although poorly understood, experimental studies and meta-analyses in the past few years have revealed that certain shellfish taxa are very sensitive to changes in pH (Kroeker *et al.*, 2013; Wittman and Portner, 2013), but also that UK waters exhibit marked spatial variability in pH, such that some shellfish populations are already exposed to fairly extreme conditions on a regular basis. It is thought that oysters are more sensitive to low pH than mussels, and that crustaceans are less vulnerable than molluscs. Aquaculture sites (mostly oyster culture) existing on the East Coast of England currently occur in regions that are anticipated to witness a 3°C rise in seawater temperature and a 0.5 pH unit decline in ocean acidity by 2100. Oysters are known to be very sensitive to these two parameters and thus existing aquaculture sites may become inhospitable and perhaps untenable in a few decades time.

Callaway *et al.* (2012) produced a comprehensive review of the possible climate change impacts on UK aquaculture in the future. Some of the main concerns were in relation to sea-level rise, precipitation, pollution and temperature changes which could disturb the conditions to which cultivated organisms are adapted, or could cause additional stresses and pressures such as the proliferation of pathogens (as described in earlier sections of this report).

Marine planning recommendations

As some species and areas are at risk from climate change, it is recommended that the marine planning process takes into account that particular aquaculture sites may become inhospitable in the future, and hence planners and industry might need to seek alternative localities. For oysters described above, it may be necessary to consider locations for future development (perhaps offshore as part a co-location project alongside a dedicated area for offshore wind farms). It may be necessary to bring aquaculture onto land, in order to adopt tighter controls on water conditions to avoid negative consequences. It is recommended that some of these considerations be addressed in the East Inshore and Offshore Marine Plans, where most of these activities currently take place. Similar actions have needed to be taken to protect oyster culture along the Oregon coasts of North America, given that low pH (high acidity) waters are occasionally found near the coast and have led to reproduction failures of oyster in this region (Gruber *et al*., 2012).

Alongside the effects that location of facilities may have on cultured species, it is recommended that marine planning considers the need for new localities for aquaculture where pathogen loads may be lower in the future, or which may be more sheltered from storms.

By contrast new opportunities may arise as conditions become habitable for certain warm-water species for the first time. For example new areas could open for Pacific oyster cultivation on the East Coast where this was not possible before (see Jones *et al*., 2013b). A recommendation allied to that suggested for fisheries is that the MMO examine outputs from recent bio climate envelope modelling studies (e.g. Jones *et al*. 2013b), to try to determine which sites might be suitable for which aquaculture species (and those that will be unsuitable) in the near future.

It is recommended that if there is drive from industry to develop aquaculture of new species, sufficient space is set aside in marine plans to accommodate these new developments. In September 2013 Cefas, together with the British Trout Association (BTA) and The Crown Estate issued a call for experienced aquaculture operators to tender for a demonstration project in coastal waters off southwest England, involving net-pen production of rainbow trout. This type of marine fin-fish aquaculture will be completely new in England and Wales, but could place additional demands on the marine planning system if successful.

Extensive programmes of research are currently underway in the UK aimed at clarifying the likely consequences of ocean acidification. Notably, the UK Ocean Acidification Research Programme (UKOA) sponsored by the Natural Environment Research Council, Defra and the Department of Energy and Climate Change is due to be completed in 2014 and will deliver significant insights of relevance to the UK aquaculture industry (also see the Defra project "Placing Ocean Acidification in a wider Fisheries Context"). A recommendation to the MMO will be to re-visit marine plans, once this new information is available, and in particular to examine spatial outputs/projections from the computer modelling and monitoring components of these programmes, including the insight into spatial variability as well as the magnitude and speed of the emerging changes.

Additional recommendations for consideration by MMO and its partners

The MMO may wish to consider a range of "planned" and "autonomous" interventions in response to anticipated climate change impacts on the aquaculture sector. A clear suggestion would be for the MMO to work with the local aquaculture industry and the Environment Agency (who undertake regular surveys in England and Wales to monitor nutrients, temperature, pH changes and the presence of pathogens and harmful algal bloom species) and develop early warning maps/systems to inform industry of potential problems in key areas. Consideration of potential climate change effects for aquaculture will have to be considered in the East and South marine plans, as there are already numerous aquaculture sites. There may also be opportunities for the MMO to engage with national strategies for the aquaculture sector and to encourage the suitable sighting of future facilities.

Adaptation actions requiring government intervention, identified within the MACCAP project included:

- Changes in species that can be successfully raised in aquaculture:

    - Provision of climate projections at scale relevant to aquaculture developments.
    - Consideration (licensing and planning) of new aquaculture sites where conditions are more conducive to growth and/or production.
    - Monitor changes in ocean pH and temperature around the UK coast.
    - Research into resilience of shellfish species (to pH and warmer temperatures).
    - Research into fin-fish species that could potentially be farmed in the UK (e.g. sea bass, trout and gilthead sea bream).

- Altered balance between pathogens/pests and commercial aquaculture species:

    - Greater monitoring and real-time risk assessment to determine pathogen load.
    - Consideration (licensing) of new aquaculture sites where pathogen loads may be lower.
    - Jellyfish surveillance programmes at relevant localities to determine where and when jellyfish could present a problem.

    - Increased testing for warm-water/exotic pathogens.

- Damage to aquaculture sites – changes in storm frequency, wave height etc.:

    - Better real-time forecasts.
    - Restriction of development in sites that are likely to be heavily affected by storms (re-location to more sheltered sites).
    - Requirements placed on developers as part of the consents process, to ensure the use of robust structures/protocols.

5.3.5 Tourism and recreation

Impacts of climate change and sea level rise on tourism and recreation was a major feature of the 2012 UK CCRA sector report on “Business” (Baglee *et al*., 2012). Within the CCRA, monetary losses due to tourist assets at risk from flooding were characterised and were primarily concerned with the number of UK beaches projected to be affected by sea level rise and also the negative consequences of climate change in terms of inundated tourist infrastructure. The CCRA Business sector report suggested that the estimated loss of UK beach area could be substantial over the course of the next century, and that areas in the south and east will be most adversely affected. Many tourist visitor attractions and facilities are at risk of flooding and this risk is likely to increase.

By contrast, the Business sector report also highlighted the potential positive impacts of climate change on the UK tourism industry. An attempt was made to quantify the expansion of tourist destinations in the UK, since warmer weather is likely to attract visitors to coastal locations, extending the tourist season beyond its traditional months and opening up new destinations (i.e. a positive effect on the industry rather than a negative one). Benefits have also been identified in the risk analysis carried out in this report as it is envisaged that sea temperature rises will lead to an increase in recreational activities (e.g. water sports and recreational fishing), although more intense rainfall events and increased storms could also deter tourists.

Marine planning recommendations

In terms of marine spatial planning, owing to the increased demand for access to the coast, it is recommended that consideration be made to setting aside new areas for recreational activities or tourism-related infrastructure. This might include new harbour facilities or zones dedicated to sailing and surfing. Particular developments that might need to be accommodated in marine plans could be the installation of surfing reefs such as the one constructed off Bournemouth in 2009. This reef was built from large sand-filled geo-textile containers, with a total volume of 13,000m^3. The intention was that the reef would double the number of good surfing days and it was hoped this would generate 10,000 visits per year. In 2012 a similar development was instigated off Borth, near Aberystwyth. Given warmer seawater temperatures and perhaps a change in wave climate in the future, developments of this type could become more commonplace and thus it might be worth the MMO commissioning research to determine where such developments might be practicable

Other full immersion water sports might become more popular in the future as a result of warmer temperatures, for example scuba-diving. A trend in recent years has been to deliberately sink ships and other attractions with the intention of attracting divers and this has included the installation of HMS Scylla a Leander-class frigate of the Royal Navy off Whitsand Bay, Cornwall in 2004. Presumably the deliberate sinking of any artificial structure such as wrecks or reefs on the seabed would need to be considered in marine plans in the future. The only other example so far in the UK is the Glen Strathallan a British ship originally built as a trawler and scuttled in 1970 within Plymouth Sound as a diver training site.

Of the MACCAP recommendations for enhancing the benefits to the UK tourism industry, two can be related to marine planning. It is recommended that marine planning considers encouraging the relocating, or creating new bathing beaches away from areas where pollution run-off may make the waters unsafe. It is also recommended that marine planning considers the potential locations of, and implications of building, new marinas or expanding existing facilities.

Additional recommendations for consideration by MMO and its partners

The tourism industry is likely to adapt as necessary to opportunities created by climate change (i.e. “autonomous adaptation”), but a number of government assisted actions were explored as part of the MACCAP project, including:

- Increase beach recharge schemes, where necessary.
- Establish early- warning systems for flooding and poor bathing water quality.
- Provide locally-relevant projections of sea level rise from climate models (or storm surge return periods).
- Assess impacts of storm events on pollution levels affecting bathing water quality.
- Where necessary re-locate bathing beaches away from areas where pathogens or pollution run-off may become more of a problem (can be considered within marine planning).
- Construct/permit more marinas – improve facilities (in case activity becomes more popular, or existing boats remain in port longer.
- Social and economic research into impacts of climate change on recreational fisheries.
- Regulation of activities in sensitive ecosystems.
- Studies to see how coastal communities can cope with increased pressure on resources (carrying capacity).
- Improved forecasting of surf and sailing conditions or conditions for diving (e.g. visibility).

In February 2014, MCCIP working together with the British Marine Federation (BMF)[22] and the Environment Agency's “Climate Ready” support service[23] published a “report card” on “Climate change and the UK marine leisure industry”. This report provided information on threats and opportunities for the sector, but also

[22] http://www.britishmarine.co.uk/ [accessed 06/03/14]
[23] http://www.environment-agency.gov.uk/research/137559.aspx [accessed 06/03/14]

recommendations for collective and individual actions. These recommendations included:

- Take local sea-level rise into account in any new design work (e.g. how much to increase quay heights).
- Develop a site contingency plan for flooding and ensure staff are trained to respond.
- Ensure site infrastructure is regularly maintained and in good working order to increase resilience to extreme events.
- Sign up to the Environment Agency's flood warning service (England and Wales)[24].
- Develop a long-term strategy based on understanding customer behaviour preferences in response to different weather conditions (e.g. how do numbers vary with temperature and rainfall?).
- Undertake an assessment of the carrying capacity of sites to ensure that increased usage would not have a detrimental impact on existing infrastructure.
- Undertake an energy audit of marinas to reduce carbon footprint, costs and build resilience to future legislation.

5.3.6 Protected Areas

In the United Kingdom marine protected areas come in many different forms and designations, including:

1. Special Areas of Conservation (SACs) under the EU Habitats Directive
2. Special Protected Areas (SPAs) under the EU Birds Directive
3. Spatial closure measures under the EU Common Fisheries Policy (known collectively as "Technical measures" or closure "boxes")
4. Marine Conservation Zones (MCZs) under the UK Marine and Coastal Access Act
5. Nature Conservation MPAs, Demonstration/Research MPAs and Historic MPAs under the Marine (Scotland) Act
6. Sites of Specific Scientific Interest (SSSI)
7. RAMSAR sites under the "Convention on Wetlands of International Importance, especially as Waterfowl Habitat"
8. Closures under various local bylaws including sites set aside to protect juvenile fish (e.g. seabass), or to exclude certain fishing gears (see Rogers 1997 for a summary).

Some of these MPAs are specifically aimed at protecting particular marine species (that may or may not be affected by climate change), whereas others have been established to protect particular habitats or features that will undoubtedly persist in the future, but may play host to a very different assemblage of species.

The majority of the effects of climate change highlighted in this report relate to sea level rise and resulting habitat loss at the coasts. Such habitat loss would create an issue for a wide range of species, and conservation agencies might need to identify

[24] www.environment-agency.gov.uk/homeandleisure/floods [accessed 06/03/14]

compensatory habitats or even to modify the boundaries of some protected sites in response. For some offshore areas there may also be issues associated with an increase of seawater temperature and/or changes in pH conditions. These changes could affect distribution of vulnerable species, and this was a major feature of the study by Jones *et al*. (2013a) who examined changes in habitat suitability for certain commercial and conservation species in selected candidate protected areas around the UK. It is possible that species will shift their distributions outside of the boundaries of closure areas designed to protect them and this has already happened for plaice in the North Sea, that are now largely absent from the “North Sea Plaice Box” established in 1989 to help recover the population (van Keeken *et al*., 2007).

Marine planning recommendations

In December 2014 the MCCIP will publish a “Special Topic Report Card”, specifically focussing on climate change implications for marine protected areas and covering aspects for consideration in support of the EU Marine Strategy Framework Directive (MSFD). Authors are being commissioned to write three detailed review papers and therefore it is recommended that the MMO make use of this information to refine existing marine plans and MPA networks, once the reviews are available. Issues already starting to emerge as part of this process include range changes for benthic species that will take them out of MPAs by the middle of the 21st century; that virtually all closed “boxes” under the EU Common Fisheries Policy will become much less effective in the future; and that biodiversity impacts and ecological changes will not occur at uniform rates across all regions.

With regard to climate change mitigation measures, much has been written about the ability, or otherwise, of natural habitats to act as “sinks” for carbon dioxide (often called “blue carbon”), and hence the merits of protecting such habitats in MPAs. The rate of loss of mangroves, sea grasses and salt marshes, driven mostly by human activities, is estimated to be among the highest of any ecosystem on the planet, prompting international interest in managing them more effectively for their carbon sequestration benefits (Mcleod *et al*., 2011). In the UK, as part of the NERC/Defra Shelf Sea Biogeochemistry Programme (SSB) a new project has been commissioned involving the University of East Anglia, Cefas and the Met Office to investigate the size and value of the natural marine carbon sink and how it might change in the face of different management pressures. Typically “blue carbon” has been considered to apply to coastal habitats (seagrasses, mangroves etc.) but in this project researchers will extend the definition to ‘deep’ storage, such as offshore marine sediments and the deep ocean interior. It is recommended that as part of the marine planning process, the MMO engage with this project, to determine the carbon storage potential of different offshore areas and to consider “trade-offs” in permitting certain areas to be used for development whilst preventing development at sites that are deemed useful/essential for carbon sequestration and long-term storage.

The vulnerability to climate change of particular protected species and habitats may at some point be a required within Environmental Impact Assessments and management plans for designated areas. It is recommended therefore that this information be considered in future marine planning policies as well and that if necessary, the boundaries of protected areas be able to change if they become unsuitable or ineffective due to climate change.

Additional recommendations for consideration by MMO and its partners

In order to better understand the relationship between vulnerable ecosystems and climate change, and so enable more detailed information for marine planning, a recommendation is that the MMO keep up to date with computer modelling work to investigate future distribution shifts in conservation species. As well as the work of Jones *et al*., (2012, 2013), other authors have used similar modelling methodologies to predict future distribution shifts in offshore marine invertebrates (Reiss *et al*., 2011), inter-tidal invertebrates around the UK (Burrows *et al*., 2009) and even seabirds (Huntley *et al*., 2007). In 2013 the European Commission issued guidelines on how to accommodate climate change considerations when designing networks of Natura 2000 sites (European Commission, 2013). Although not specifically written with reference to marine sites, this document aimed to underline benefits from Natura 2000 sites in mitigating the impacts of climate change, reducing vulnerability and increasing resilience, as well as outlining steps of an adaptive management process. The MMO should consult this document and adopt “best practice” with regard to climate change planning adaptation strategies. In such endeavours the MMO will need to work directly with conservation agencies to ensure that the conditions for persistence of species (where possible) remain favourable. There may be a need to consider some alterations to the original designations, their extent and locations, or even the list of “qualifying features”. The MMO will need to engage in further discussions with the relevant government organisations, as some of these designations will have underpinning through national and international legislative agreements (e.g. EU Habitats Directive, EU Marine Strategy Framework Directive, EU Birds Directive etc.).

5.4 Conclusions and future work

This report synthesises the current and most up-to date information available in relation to future climate change impacts in the East and South Inshore and Offshore Marine Plan Areas. One general recommendation is that the MMO seeks opportunities to incorporate new climate change information into plans as it becomes available, to ensure that these plans remain fit for purpose as our understanding of climate processes and the range of activities that must be accommodated develop in the future. The overall risk assessment presented in this report was conducted at a very high level, but it should nonetheless help to indicate the main benefits and risks to marine planning and to the wider MMO. A more detailed, spatially explicit risk assessment could be undertaken given time and resources, and a great deal more evidence will become available once the next CCRA has been completed in 2017.

According to the Marine and Coastal Access Act, marine plans will have to be reviewed at least every three years for progress checking and in more detail every six years. During this review cycle there will be an opportunity for MMO to work alongside partners (e.g. the Environment Agency, the Met Office and Cefas) to input new information and in particular to provide an update on the best available projections and impact information. One potential issue outlined in Townhill *et al*. (2013) is that marine plans will only cover a period of 20 years and yet some marine developments, (e.g. nuclear powers stations and some offshore installations), will be in place for a much longer period of existence, thereby necessitating information about future sea level rise or extreme weather conditions (such as frequency of surge events) 100 or even 200 years into the future. Marine plans will need to have oversight of climate impacts over a range of future time horizons, from the next few years or decades to a century or more, and this will be greatly facilitated by the new Met Office MINERVA datasets (see above) that will be made available in the next few months. In addition, Defra have recently commissioned a new SEPF (Strategic Evidence and Partnership Fund) project involving Cefas and the Met Office to look at “Developing the capability for seasonal to decadal marine prediction”.

There are a small number of issues not covered in this report, for which little detail is available, and these include the arrival and spread of non-native species or outbreak-forming jellyfish, that could pose a threat to maritime activities in certain localities. The potential spread of troublesome non-native marine species (non-indigenous species - NIS) as a consequence of climate change was a key feature in the Marine & Fisheries sector report of the UK CCRA (Marine Metric MA6). In the British Isles, at least 15 marine algae, five diatoms, and 30 marine invertebrates have already been identified as commonplace, and many of these organisms are now spreading as seawater temperatures increase (Cook *et al*., 2013). Marine biological invasions are increasingly being recognised as a threat to native biodiversity, but also to commercial fisheries and to aquaculture. Certain sites in the South Inshore and East Inshore Marine Plan Areas (the most “invaded” parts of the UK), are characterised by very high abundances of non-native species, notably Poole Harbour and the Blackwater Estuary, and this means that these sites are probably now much less suitable for aquaculture production than they once were.

The annual cost of non-native species to “marine-based” industries (e.g., shipping and aquaculture) in the UK is estimated to be £39.9 million, although this is probably an underestimate, as there is little distinction made between native and non-native species during pest control operations. Non-native species are explicitly mentioned in the EU Habitats Directive, the Birds Directives, and the Marine Strategy Framework Directive (descriptor 2), yet, there is little knowledge of climate change influences on the distribution of non-native and invasive species. Outputs from the Defra MINERVA project may be of use in marine planning. Various “bioclimate envelope” modelling techniques are available to project or predict the extent of ‘suitable’ habitat for species, and some of these methodologies will be applied in MINERVA during 2014/15 to define the potential spread of non-natives around the UK. It is **recommended** that the MMO marine planning team keeps up to date on this topic over the coming years, when more information becomes available.

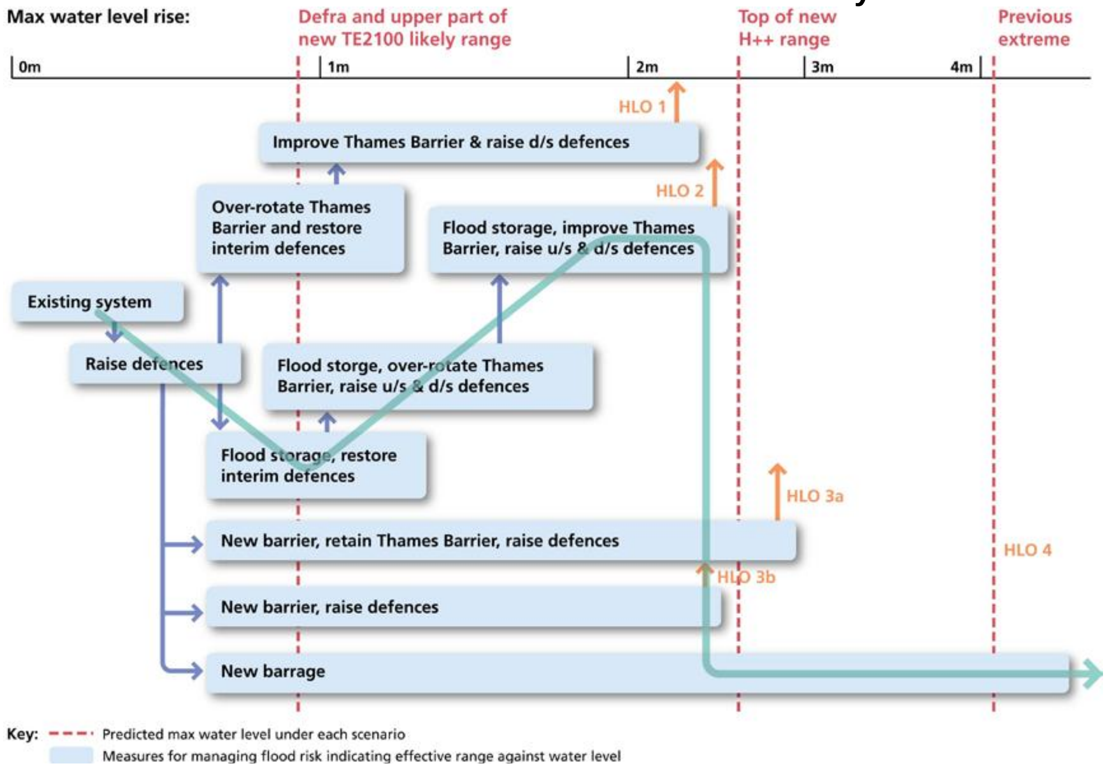
Similarly, jellyfish numbers have increased dramatically in the North and Irish Seas over the past two decades (see Lynam *et al*., 2005, 2011) and this has been ascribed to both climate change but also over fishing. In recent years extreme jellyfish numbers have caused considerable losses of fish in aquaculture facilities (in Shetland) but also a temporary shut-down of the Torness nuclear power station. Jellyfish can pose a major threat to the tourism industry as some species possess a painful sting. So far, very little effort has been dedicated towards modelling the potential proliferation of jellyfish around the UK and hence it is impossible to say whether or not human activities in the East and South Offshore or Inshore Marine Plan Areas could be at risk as a result of this climate-related phenomenon, and hence whether it will be necessary to re-locate activities or installations that are known to be vulnerable. Again, it is recommended that the MMO marine planning team keeps up to date on this topic over the coming years and updates marine plans accordingly as more information becomes available.

In this report we largely consider individual activities in isolation (although see sections 3 and 4 for conflicts between activities). We do not assess in any great detail the issue of co-location and cumulative impacts, even though climate change and the overall suite of activities will occur simultaneously. Several methods based on GIS (Geographical Information Systems) and ecosystem modelling have been investigated which offer the possibility of predicting cumulative effects, on biological receptors. For example, CUMULEO is a spatial modelling tool, implemented in a GIS environment, designed to investigate cumulative effects of human activities in the Dutch EEZ. CUMULEO has been successfully used to investigate effects of offshore wind development on birds, fish, mammals and bottom fauna. The need for further information on cumulative effects to support the evidence base for developing Marine Planning is stated in the Evidence and Issues Report for the East Inshore and East Offshore Marine Plan Areas, and this acknowledges the need to also take account of long-term climate change.

Climate scientists often talk about “adaptive pathways”. This is an approach that has been pioneered in the “Thames Estuary 2100” (Environment Agency, 2009) project and is now viewed as “best practice” with regard to climate change adaptation and ensuring that key infrastructure assets remain protected world-wide. Of particular importance to this approach is identifying thresholds that precipitate action. For example a critical engineering threshold for adaptive measures to be implemented to protect London is one metre above mean sea level. Above this, planners have identified a series of alternative adaptation pathways (Figure 22), some more expensive than others, that are appropriate to cope with the plausible range of sea level rise that is experienced up until 2100. As can be seen from Figure 4, the more extreme the rise in sea level observed (through monitoring and surveillance programmes), the fewer the options available for effective adaptation. The only feasible response if a three metre increase in sea level is observed would be a new (highly expensive) outer barrage to protect London. This approach has also been adopted in the Defra Economics of Climate Resilience project including the fisheries case study.

A longer term recommendation for the MMO would be to consider how this “adaptive” pathways approach might be used within the context of marine spatial planning. It could help to map-out pre-defined action points in response to emerging changes in observed climate parameters, for example the point when it will be necessary to shift the location or prohibit the development of a particular maritime activity such as aquaculture or adapt the boundaries of an MPA. Similarly a threshold concerning the frequency of severe storms might be set such that if exceeded it would precipitate the construction of breakwaters to protect ports or coastal infrastructures and necessitate a change in marine planning.

Figure 22: High-level adaptation options and pathways developed by the TE2100 programme (in the blue boxes) to a range of sea level rise scenarios with different threshold increases for the Thames estuary.



In the present report, climate change information from UKCP09 has been mapped. Clearly, for some factors, the projections available were limited and probably inadequate, therefore as information improves in the future, our ability to make better decisions should also be enhanced. For some areas the risks and benefits were solely identified in the East (Inshore and Offshore), South (Inshore and Offshore) or all of the marine plan areas. In some cases there is sufficient robust information to undertake a full assessment whilst in other cases the information available is currently lacking. Through undertaking consultation with industry and having more spatially and temporally resolved climatic projections (in 2014 for sea temperature rise), a more thorough assessment will become possible, allowing for very local and specific changes in use patterns to be identified and more robust policies developed to facilitate these adaptive responses in the future.

6. Glossary

Acidification: Ocean acidification is the ongoing increase in acidity reflected by a decrease in the pH of the Earth's oceans, caused by the uptake of carbon dioxide from the atmosphere.

Areas of Outstanding Natural Beauty (AONBs): Areas of high scenic quality which have statutory protection in order to conserve and enhance the natural beauty of their landscape.

Blue Flag beaches: Blue Flag is a certification by the Foundation for Environmental Education that a beach or marina meets its standards. The Blue Flag is a prestigious, international award scheme which acts as a guarantee to tourists that a beach or marina they are visiting is one of the best in the world.

Carbon Capture and Storage (CCS): Process of capturing waste carbon dioxide from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere, normally an underground geological formation. The aim is to prevent the release of large quantities of carbon dioxide into the atmosphere. Geological formations are currently considered the most promising sequestration sites It is a potential means of mitigating the contribution of fossil fuel emissions to global warming and ocean acidification.

Carbon dioxide (CO_2): A naturally occurring gas present in the Earth's atmosphere and probably the most important of the greenhouse gases as it is the primary greenhouse gas emitted through human activities and is responsible for 60% of the enhanced greenhouse effect. This greenhouse effect is a natural process by which the atmosphere traps some of the Sun's energy, warming the Earth enough to support life. Human-driven production of greenhouse gases, especially carbon dioxide, appears to be increasing the effect artificially.

Carbon footprint: Greenhouse gas emissions (in particular carbon dioxide and methane) caused by an organization, event, product or person.

Coastal squeeze: Describes what happens to coastal habitats that are trapped between a fixed landward boundary, such as a sea wall and rising sea levels and/or increased storminess. The habitat is effectively "squeezed" between the two forces and diminishes in quantity and or quality.

Co-location activities: Two or more activities within a specific marine area occupying the same spatial footprint, which is considered to be an option to resolve demands on space.

Confidence: The probability that a statement about some random phenomenon of interest is true. A confidence interval indicates the reliability of an estimate.

Emissions scenarios: Describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants. The Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC) published in 2000 produced four different climate change scenarios of how our climate might change following new information about predicted global emissions of greenhouse gases. These scenarios take into account the possible changes in technology and lifestyle over the next 100 years: they are known as **Low** Emissions, **Medium-Low** Emissions, **Medium-High** Emissions and **High** Emissions.

ESRI Geodatabase: Data storage and management framework for ArcGIS. It creates a central data repository for spatial data storage and management.

Exclusive Economic Zone: Seazone prescribed by the United Nations Convention on the Law of the Sea over which a state has special rights over the exploration and use of marine resources, including energy production from water and wind. It stretches from the baseline out to 200 nautical miles from its coast.

Geopark: Unified area with geological heritage of international significance.

Harmful algal blooms (HABs): An algal bloom is a rapid increase or accumulation in the population of algae in an aquatic system. Algal blooms may occur in freshwater as well as marine environment.s Known as red tides, blue-green algae or cyanobacteria, harmful algal blooms have severe impacts on human health, aquatic ecosystems and the economy.

Heritage site: A location designated by the governing body of a township, county, province, state or country as important to the cultural heritage of a community.

Marine aggregates: Marine aggregates are naturally occurring sand and gravels found on the inner continental shelf off the UK coast. Large volumes of marine aggregates have been used and continue to be used in construction projects.

Marine and Coastal Access Act 2009 (MCAA): An Act to make provision in relation to marine functions and activities; to make provision about migratory and freshwater fish; to make provision for and in connection with the establishment of an English coastal walking route and of rights of access to land near the English coast; to enable the making of Assembly Measures in relation to Welsh coastal routes for recreational journeys and rights of access to land near the Welsh coast; to make further provision in relation to Natural England and the Countryside Council for Wales; to make provision in relation to works which are detrimental to navigation; to amend the Harbours Act 1964; and for connected purposes.

Marine Climate Change Impacts Partnership (MCCIP): The United Kingdom Marine Climate Change Impacts Partnership brings together scientists, government, its agencies and non-govermental organisations (NGOs) to provide co-ordinated advice on climate change impacts around our coast and in our seas.

Marine Climate Change Impacts Partnership (MCCIP) report cards: Short reports commissioned and published by the Marine Climate Change Impacts Partnership, they provide the latest updates on our understanding of how climate change is affecting UK seas.

Marine Environmental Data and Information Network (MEDIN) metadata discovery standard: MEDIN is a partnership of UK organisations from the public and private sectors committed to improving access to marine data. The metadata discovery standard sets out a specific format to record details of a dataset so that in the future other people can easily discover datasets that may be of use to them.

Marine Protected Areas (MPAs): Zones of the seas and coasts where wildlife is protected from damage and disturbance through restrictions of human activities.

Mean high water spring tide: The mean high water spring tide is the highest level that spring tides reach on the average over a period of time (often 19 years).

Metadata: File of information which describes how and when and by whom a particular set of data was collected, and how the data is formatted.

National Adaptation Programme (NAP): Sets out what the UK Government, businesses, and society are doing to become more climate ready. The NAP was developed as a response to the UK Climate Change Risk Assessment, which analysed the potential effects of climate change and the risks and opportunities for the UK.

Skew surge: Time independent difference between the maximum observed sea level and the maximum predicted tide. The maximum observed sea level measured by tide gauges is primarily governed by the tidal regime. The difference between the maximum observed sea level and the maximum predicted tide is governed by the wind stress and the local atmospheric pressure, roughly a two thirds to one third split respectively. There is one skew surge value per tidal cycle.

Special Protection Area (SPA): An area of land, water or sea which has been identified as being of international importance for the breeding, feeding, wintering or the migration of rare and vulnerable species of birds found within the European Union. SPAs are European designated sites, classified under the European Wild Birds Directive which affords them enhanced protection.

UK Climate Change Risk Assessment 2012: Government report that outlines some of the most important risks and opportunities, based on their economic, social and environmental consequences, that climate change may present for the UK,until 2100.

UK Climate Projections (UKCP09): A free of charge source of climate information focussed on the UK and designed to help those needing to plan how they will adapt to a changing climate.

UK Marine Policy Statement: The UK Marine Policy Statement has been jointly published by all UK Administrations and adopted by the UK Government, the Scottish Government, the Welsh Assembly Government and the Northern Ireland Executive, the Marine Policy Statement will help achieve the shared UK vision for clean, healthy, safe, productive and biologically diverse oceans and seas. Its aim is to enable an appropriate and consistent approach to marine planning across UK waters, and ensure the sustainable use of marine resources and strategic management of marine activities from renewable energy to nature conservation, fishing, recreation and tourism.

United Nations Convention on the Law of the Sea (UNCLOS): Also called the Law of the Sea Convention or the Law of the Sea treaty, is the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which took place between 1973 and 1982. It defines the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources

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Annex 1 MMO Sectors and Key Impacts

Note: Grey blocks = No direct link between climate change variable and sector impact (e.g. sea level rise on access to oil and gas sites)

Sectors and key impacts	Climate change driver: Sea level rise / coastal flooding	More extreme storms and waves	Air or sea temperature rise	Ocean acidification	Changes in terrestrial inputs (e.g. fluvial flows and flooding)	Ocean currents	Most relevant to East plan areas; South plan areas; all areas
Oil and gas							
Site safety on platforms		-4					East
Access to offshore sites		-4					East
Structural integrity	-2	-4		-2			East
Scour of legs / supports		-4				-2	East
Offshore wind							
Efficiency		-4 +4					East
Structural integrity		-4		-2			East
Access to offshore sites		-4					East
Inundation of inter-connection nodes at the coast	-4	-4			-4		East
Scour of legs / supports/interconnection tables		-4				-2	East
Tidal stream / wave							
Efficiency	-1	-2 +2				-1	Both
Site integrity	-2	-4					Both
Access to offshore sites		-4					Both
Inundation of inter-connection nodes at the coast	-4	-4					Both
Carbon capture and storage							
Integrity of storage sites	-2	-4		-2		-1	East
Site access		-4					East
Ports / shipping							
The need for dredging to keep channels clear	+1	-2				-1	Both
Inundation/flooding of port facilities	-6	-4			-4		Both
Disruption to shipping services (inc passenger ferries)		-4			-4		Both
Loss of cargo		-2					Both
Routes - opening of arctic			+6				Both
Dredge / disposal							
Efficiency of operation (e.g. positioning of suction dredgers)		-4					Both
Increased / reduced need for dredging (e.g. sedimentation)	+1	-2			-2		Both
Disposal site safety		-4					Both
Need for re-mapping		-2			-2		Both
Aggregates							
Extraction safety		-4					Both

Potential spatial effects of climate change in the South and East marine plan areas

Note: Grey blocks = No direct link between climate change variable and sector impact (e.g. sea level rise on access to oil and gas sites)

	Climate change driver						
Sectors and key impacts	**Sea level rise / coastal flooding**	**More extreme storms and waves**	**Air or sea temperature rise**	**Ocean acidification**	**Changes in terrestrial inputs (e.g. fluvial flows and flooding)**	**Ocean currents**	**Most relevant to East plan areas; South plan areas; all areas**
Efficiency of operation (e.g. positioning of suction dredgers)		-4					Both
Demand for more aggregates to protect the coast	+6	+4					Both
Cables / pipelines (telecoms / power etc...)							
Scour around buried cables / pipelines		-4				-2	Both
Damage to existing cables / pipelines		-2		-2		-2	Both
Laying new cables / pipelines		-4					Both
Fisheries							
Food web impacts on abundance and distribution of species			-6 / +6	-4	-2	-4	Both
Fish egg / larvae survival			-4 / +4	-4	-2	-4	Both
Fish / shellfish reproduction and growth			-4 / +4	-4	-2		Both
Pests / disease (inc Non-natives / HABs)			-4 / +2			-4	Both
Safety at sea		-4					Both
Regional productivity							Both
Impacts from pollutants and contaminants		-4	-4		-2		Both
Impacts from de-oxygenation and ph change			-4	-4	-4		Both
Aquaculture							
Disease and infections (inc sea lice and marine pathogens affecting human health such as norovirus and vibrios)			-6 / +4		-4 / +4		Both
Damage to site infrastructure	-4	-4					Both
Loss of habitat for shellfish aquaculture	-3						Both
Nuisance species (e.g. Non-natives / HABs / Jellyfish blooms)			-6				Both
Fish / shellfish reproduction and growth			-4 / +4	-6			Both
Tourism and recreation (including marine leisure activities)							
Eco-tourism (e.g. Birds / marine mammals)	-4	-4	-4 / +4				South
Recreational fisheries		-4	+6				South
Coastal tourism (visitors)		-4	+6		-4		South
Coastal tourism (infrastructure, including marinas)	-6	-4	-4 / +4		-4		South
Boating		-4 / +4	+4				South
Scuba diving, surfing		-4 / +4	+4		-4 / +4		South
Bathing water quality (e.g. Non-natives / algal growth)		-4	-4		-4 / +4		South
Inshore and offshore protected areas							
Habitat loss and need for compensatory habitats	-9	-4			-4		Both
Ecologically coherent networks	-4		-4 / +4			-4 / +4	Both
Breeding success at offshore sites (e.g. Fish)			-4				Both

Potential spatial effects of climate change in the South and East marine plan areas

Note: Grey blocks = No direct link between climate change variable and sector impact (e.g. sea level rise on access to oil and gas sites)

	Climate change driver						
Sectors and key impacts	**Sea level rise / coastal flooding**	**More extreme storms and waves**	**Air or sea temperature rise**	**Ocean acidification**	**Changes in terrestrial inputs (e.g. fluvial flows and flooding)**	**Ocean currents**	**Most relevant to East plan areas; South plan areas; all areas**
Breeding success at onshore sites (e.g. Nesting sites)	-4	-4	-4				Both
Power stations (including Nuclear)							
Cooling water			-3				Both
Site integrity	-9	-4			-4		Both
Waste water materials							
Combined sewer overflows (CSOs)					-6		Both
Defence							
Site integrity (e.g. Bases)	-6	-4			-4		Both
Conditions for military exercises (air and sea)		-4					Both

Annex 2 Climate maps for conflicts between sectors

Maps are presented for the East Inshore and Offshore, and then for the South Inshore and Offshore Marine Plan Areas to support the information presented in earlier sections . The maps shown below are:

- 4.1 - Annual sea surface temperature, fishing areas and wind farms:
  - Recent fishing hotspots and wind farm areas as potential sanctuaries with annual mean sea surface temperature change projections.

- 4.2 - Annual sea surface temperature, aquaculture sites and bathing waters:
  - Monitored bathing and aquaculture sites with spring mean sea surface temperature change projections
  - Monitored bathing and aquaculture sites with summer mean sea surface temperature change projections
  - Monitored bathing and aquaculture sites with autumn mean sea surface temperature change projections.

- 4.3 - Sea level rise, storminess, bathing waters, aquaculture sites, disposal sites:
  - Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2020
  - Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2040
  - Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2060
  - Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2080
  - Monitored bathing sites, aquaculture locations and open disposal sites with 2 year return level skew storm surge trend
  - Monitored bathing sites, aquaculture locations and open disposal sites with 10 year return level skew storm surge trend
  - Monitored bathing sites, aquaculture locations and open disposal sites with 20 year return level skew storm surge trend
  - Monitored bathing sites, aquaculture locations and open disposal sites with 50 year return level skew storm surge trend.

- 4.4 - Annual sea surface temperature, sea level rise, storm surge and ports and harbours:
  - Ports, harbours and mooring/warping locations with annual mean sea surface temperature change projections
  - Commercial and recreational shipping infrastructure with 2 year return level skew storm surge trend
  - Commercial and recreational shipping infrastructure with 10 year return level skew storm surge trend
  - Commercial and recreational shipping infrastructure with 20 year return level skew storm surge trend
  - Commercial and recreational shipping infrastructure with 50 year return level skew storm surge trend

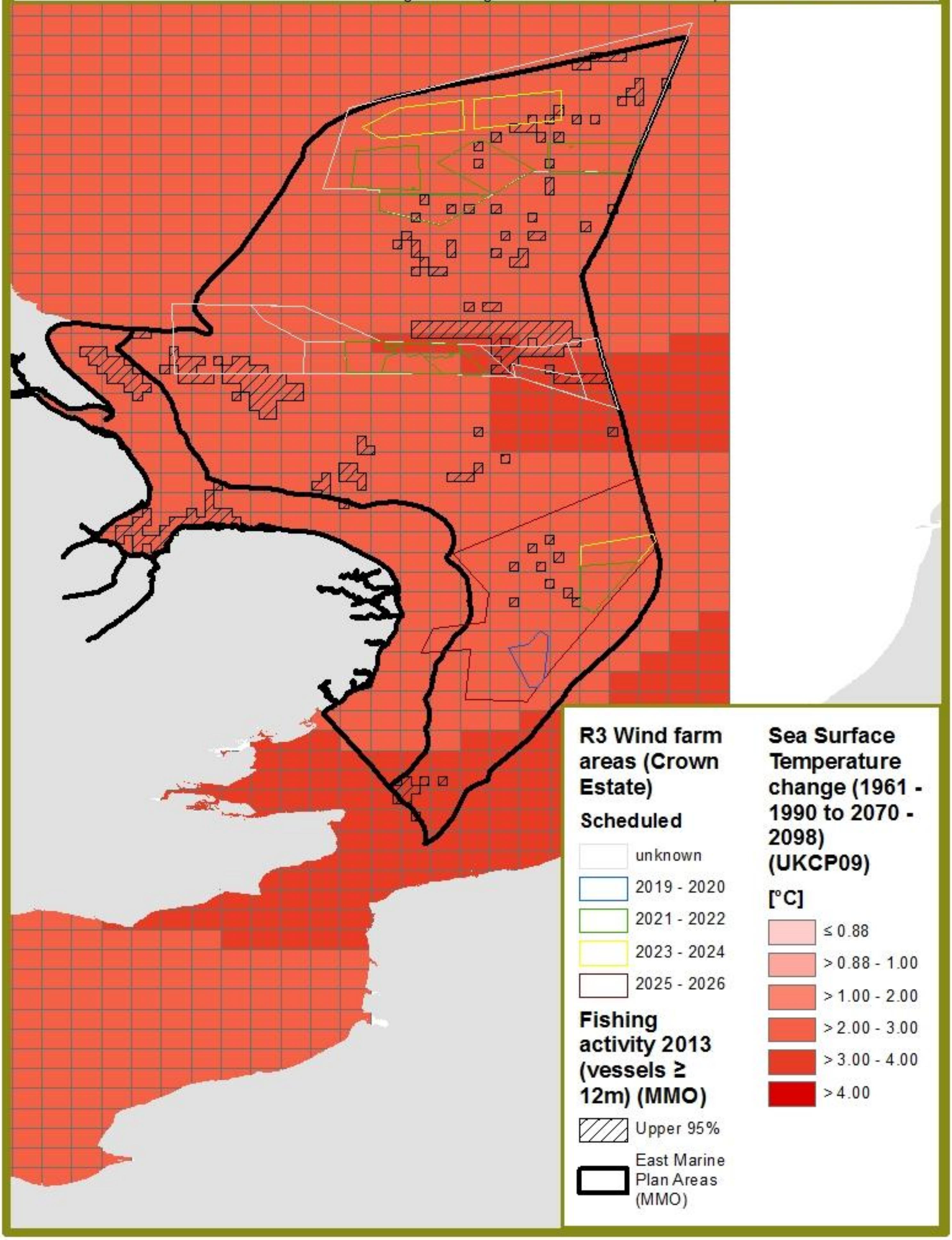
    - Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2020
    - Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2040
    - Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2060
    - Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2080.

- 4.5 – Temperature, pH, fishing areas, aquaculture sites and onshore and offshore protected areas:
    - Fishing hotspots, aquaculture sites and marine protected areas with annual mean sea surface temperature change projections.

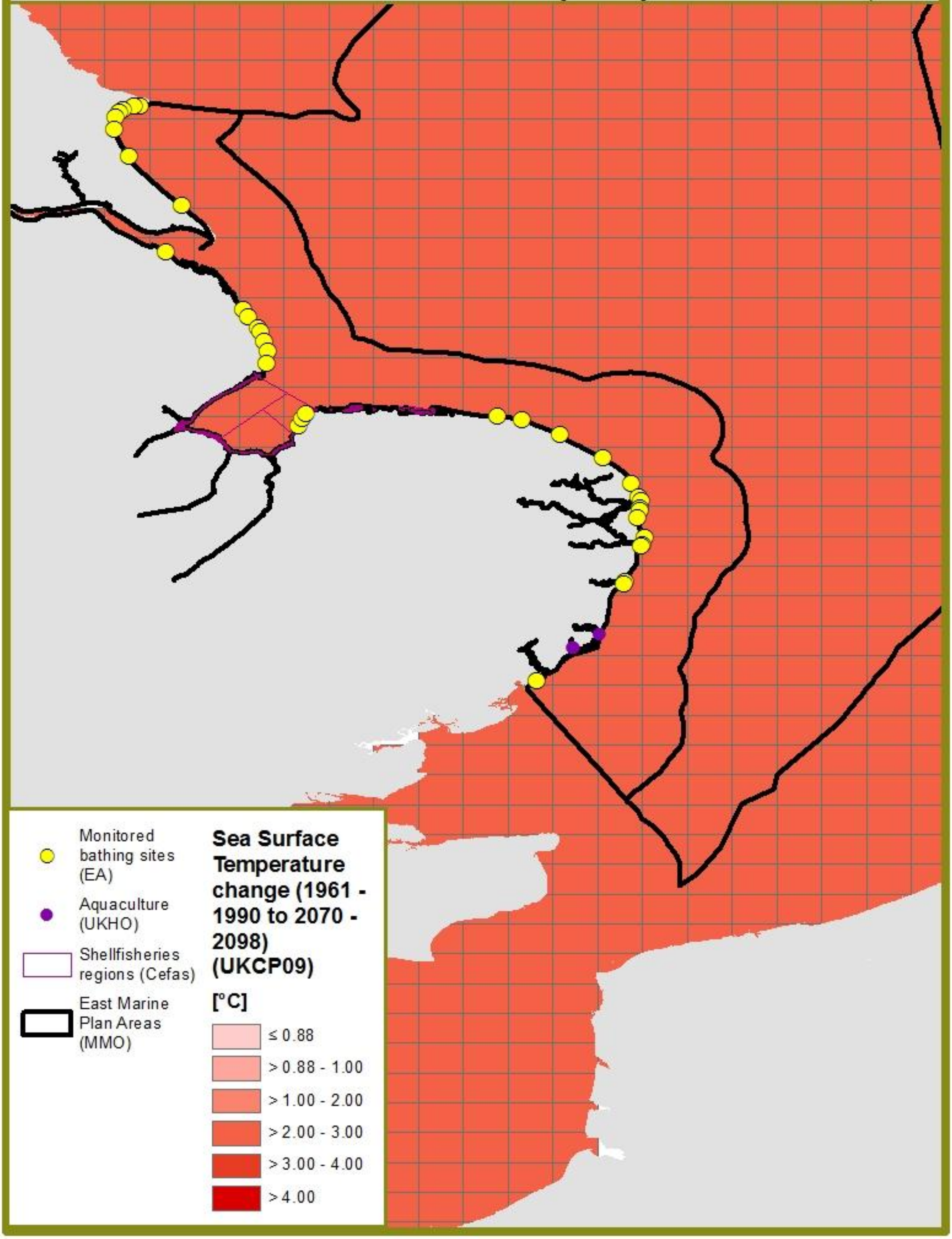
Recent fishing hotspots and wind farm areas as potential fish sanctuaries with annual mean sea surface temperature change projections in the East Marine Plan Areas

Marine Management Organisation

Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, Crown Estate, 4Coffshore.com, MMO and ESRI data.



Monitored bathing sites and aquaculture locations with spring mean sea surface temperature change projections in the East Marine Plan Areas



Marine Management Organisation

Monitored bathing sites and aquaculture locations with summer mean sea surface temperature change projections in the East Marine Plan Areas

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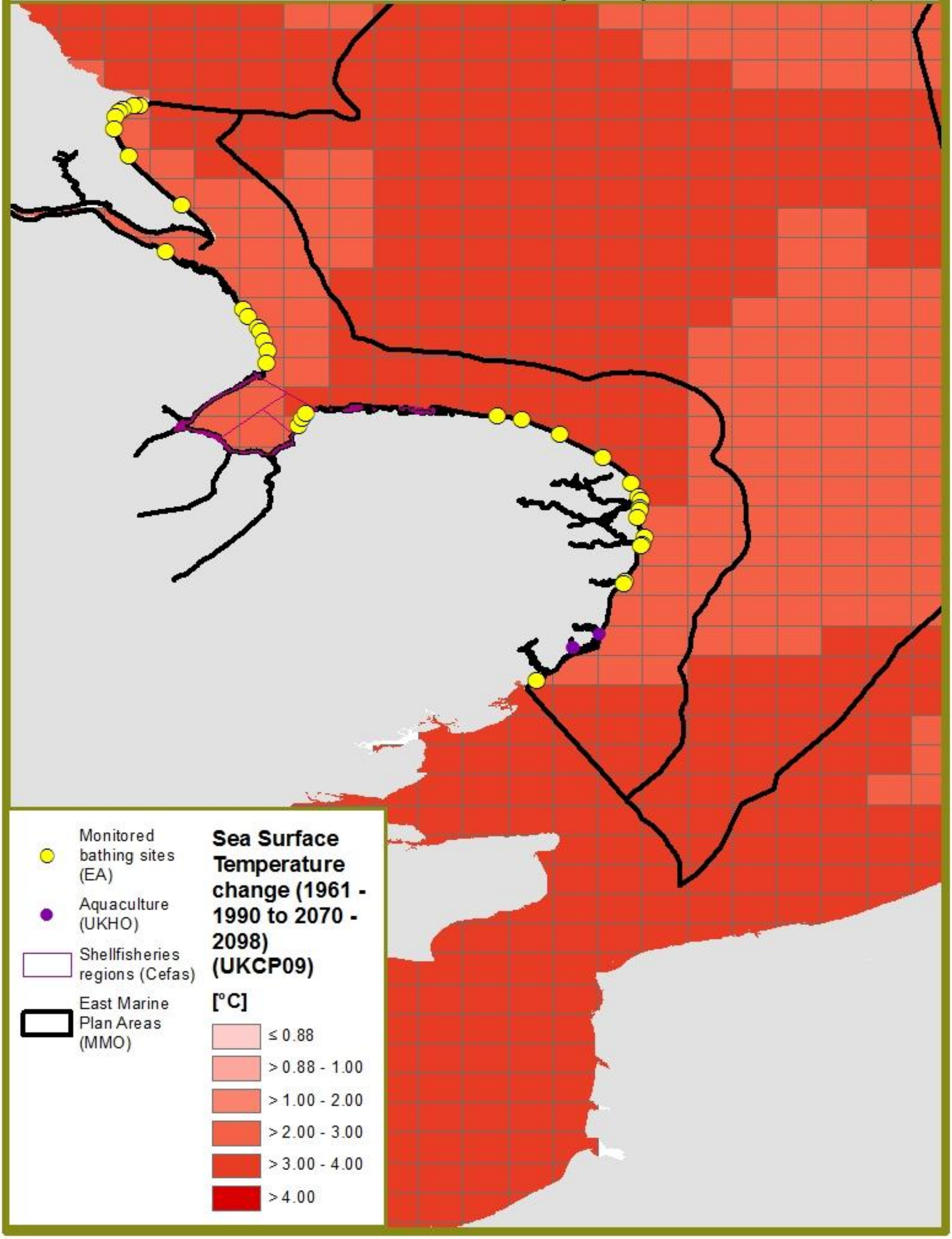

Marine Management Organisation

Monitored bathing sites and aquaculture locations with autumn mean sea surface temperature change projections in the East Marine Plan Areas

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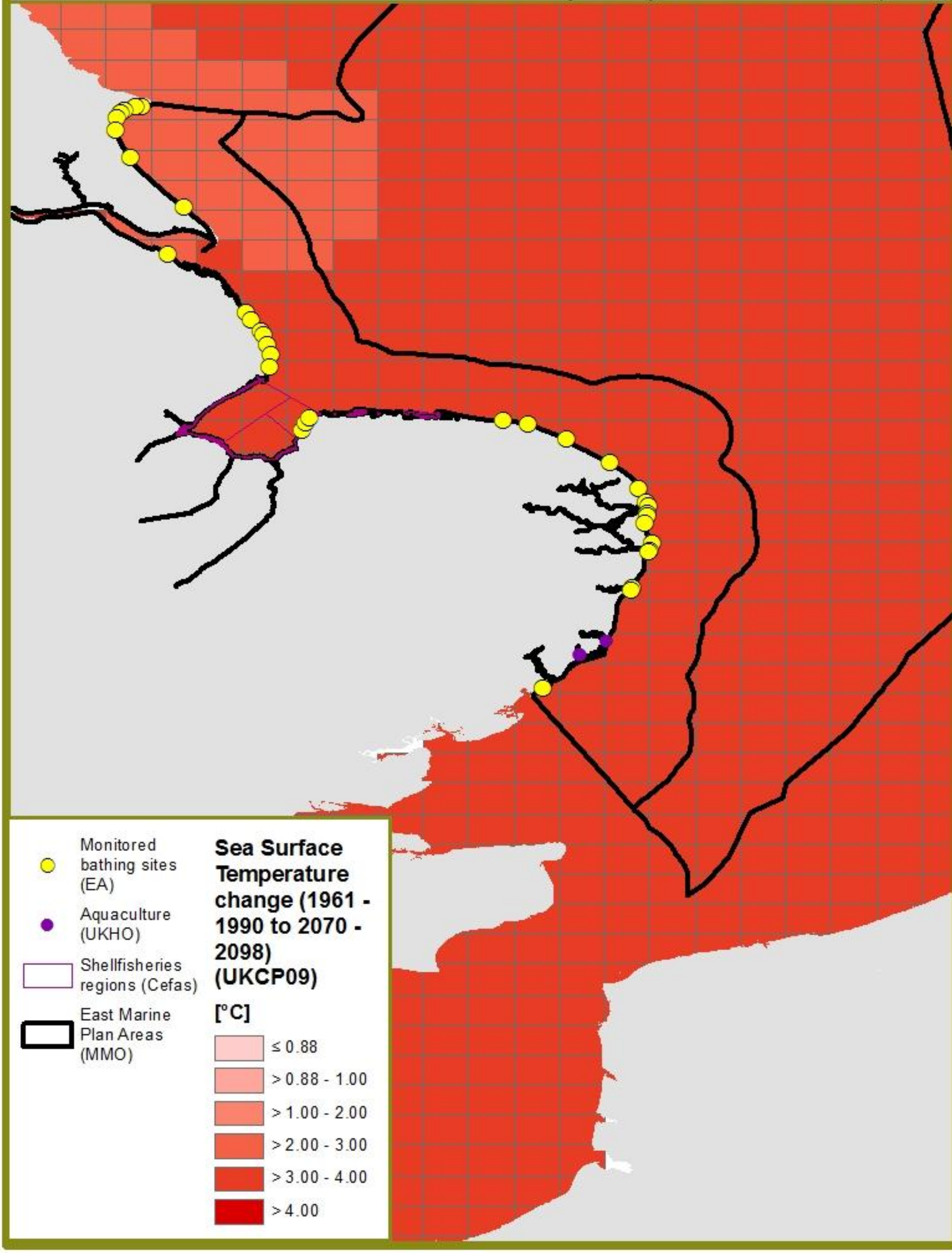

Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2020 in the East Marine Plan Areas

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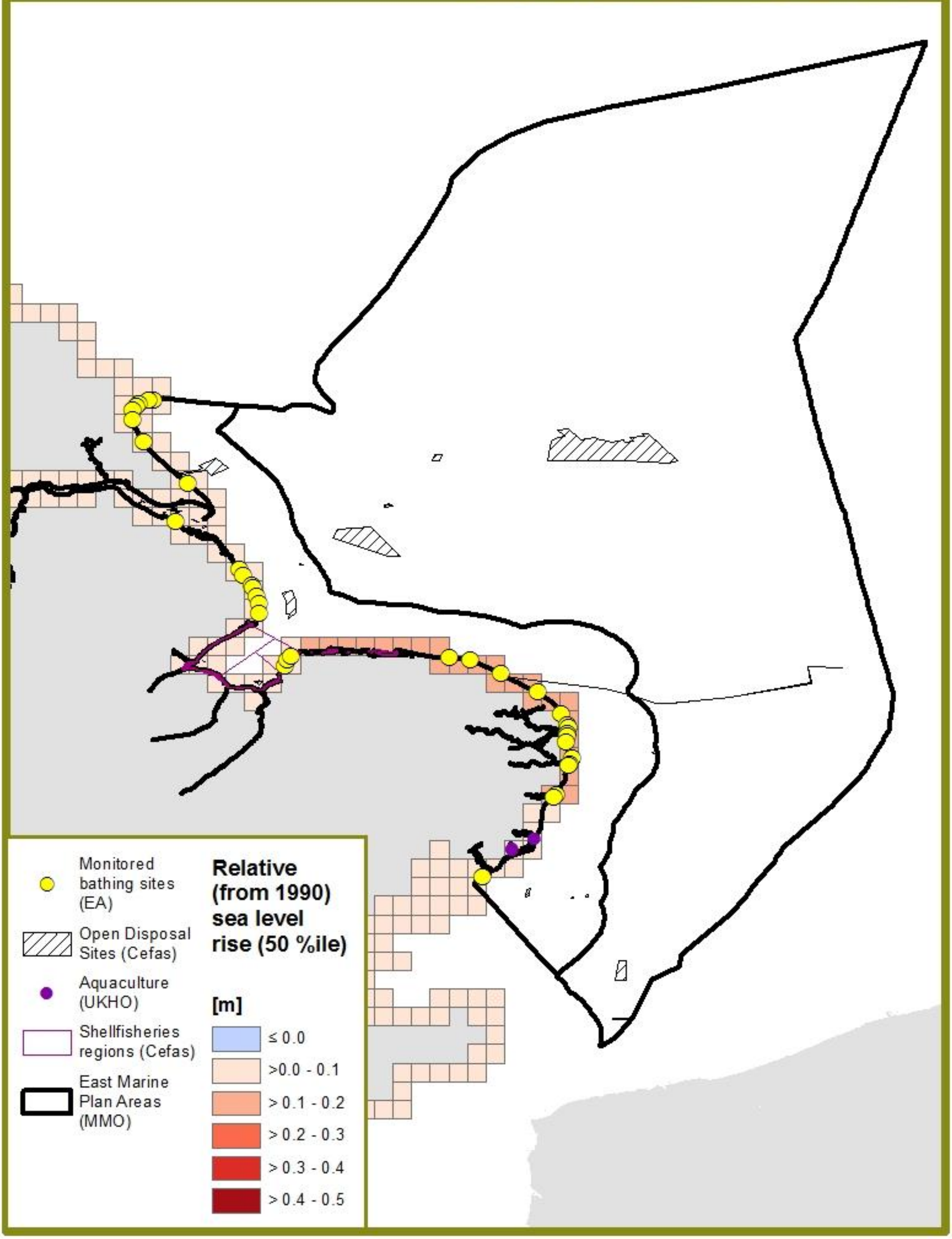

Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2040 in the East Marine Plan Areas

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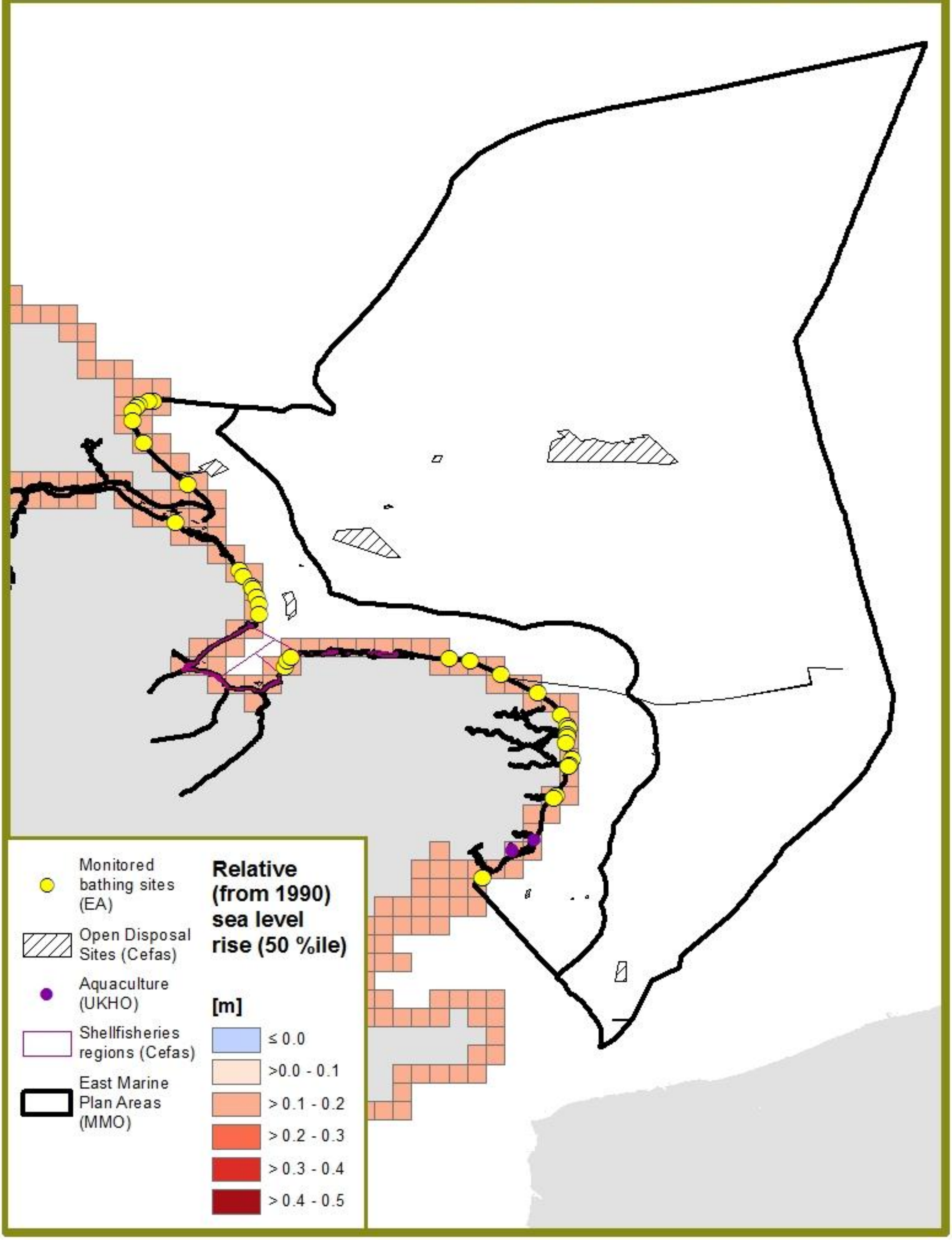

Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2060 in the East Marine Plan Areas

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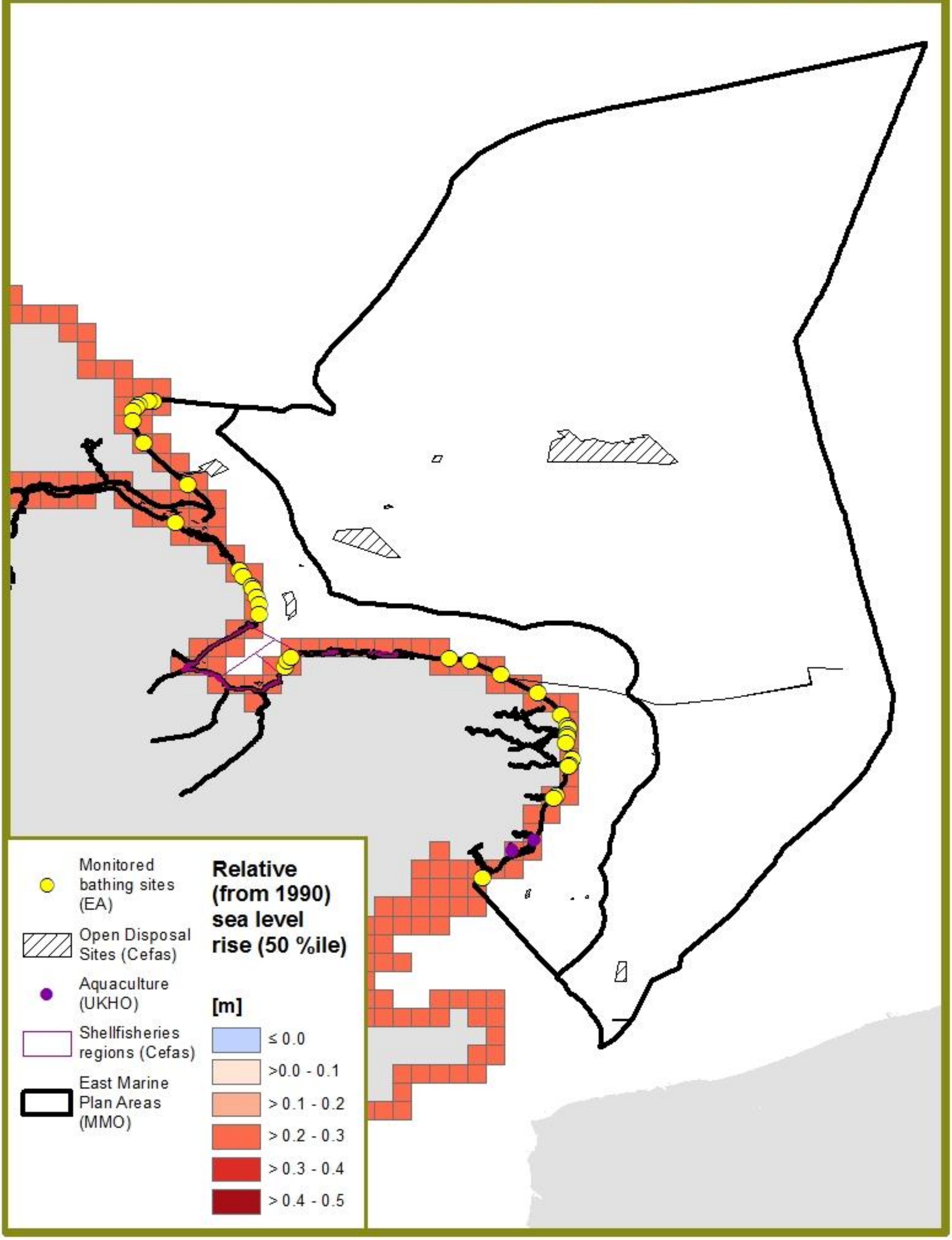

Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with relative sea level rise predicted for 2080 in the East Marine Plan Areas

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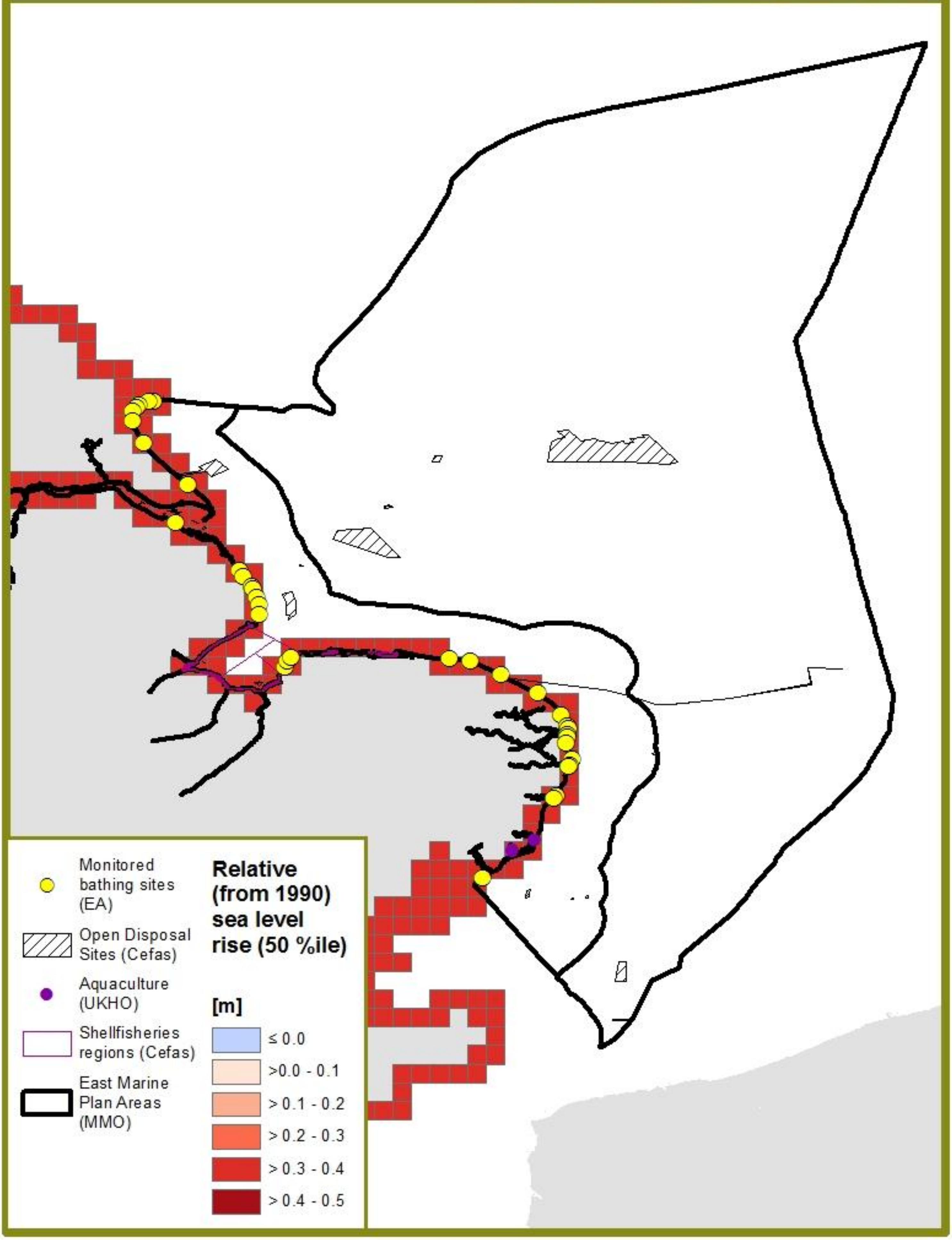
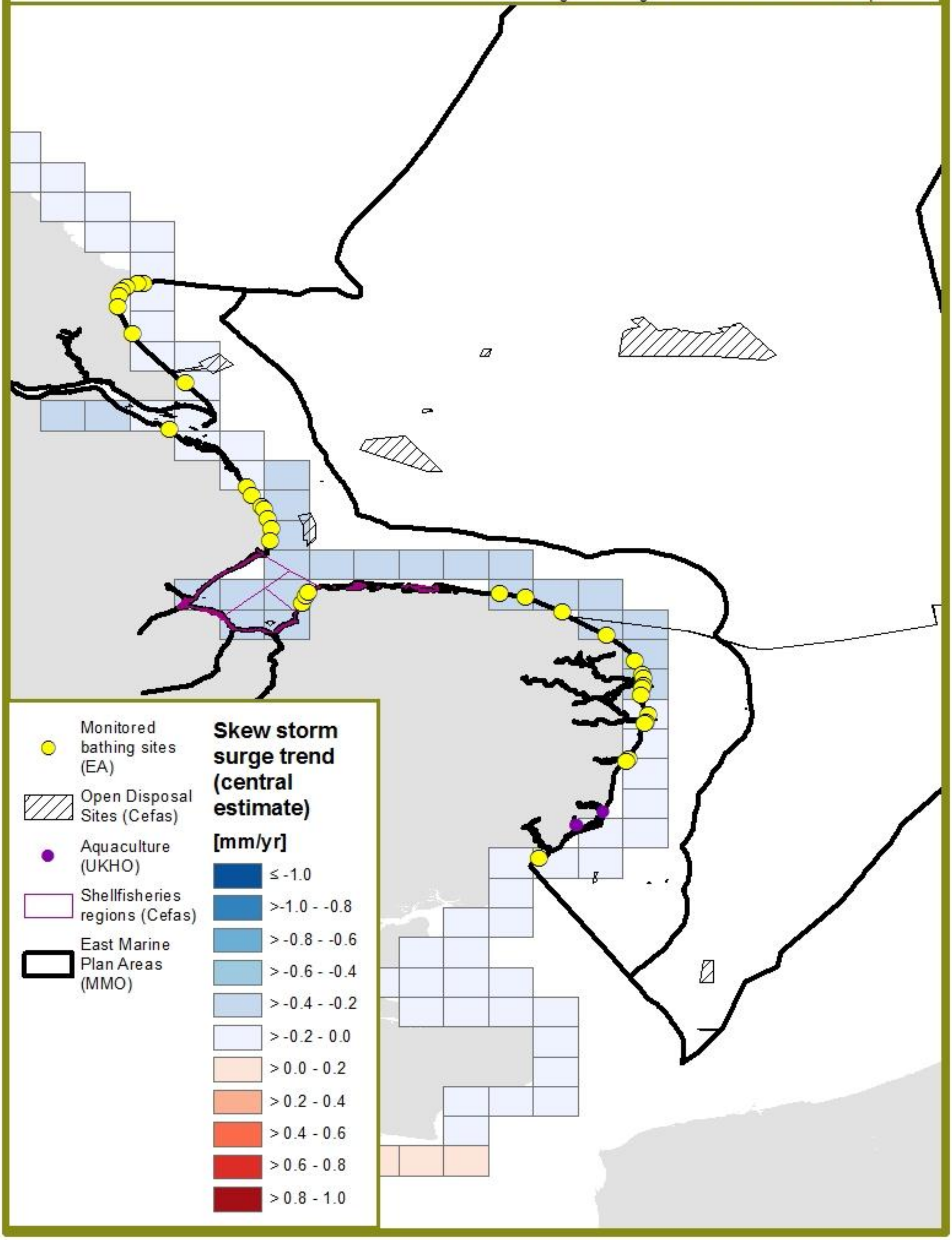


Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with 2 year return level skew storm surge trend in the East Inshore Marine Plan Areas



Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with 10 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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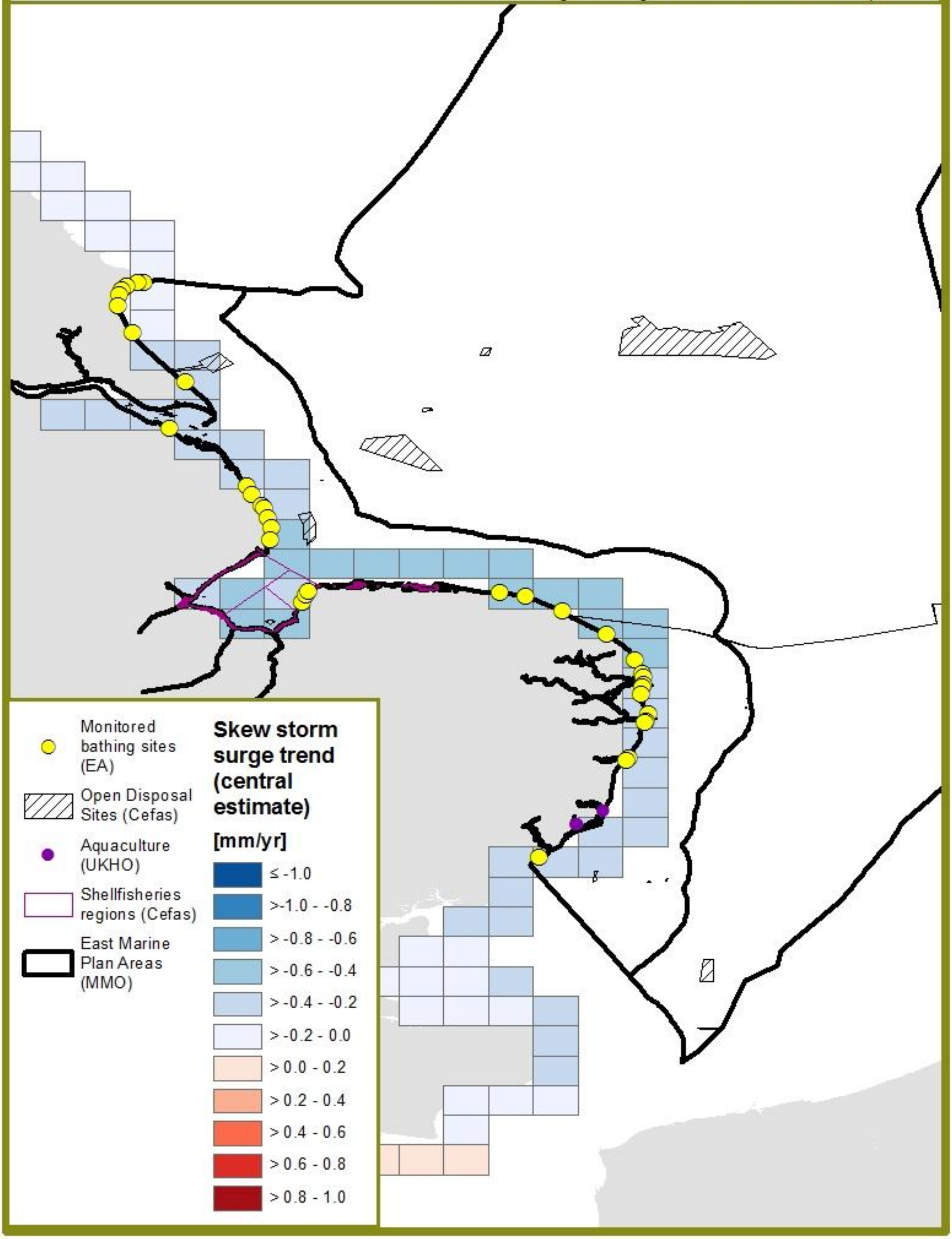

Marine Management Organisation

Monitored bathing sites, aquaculture locations and open disposal sites with 20 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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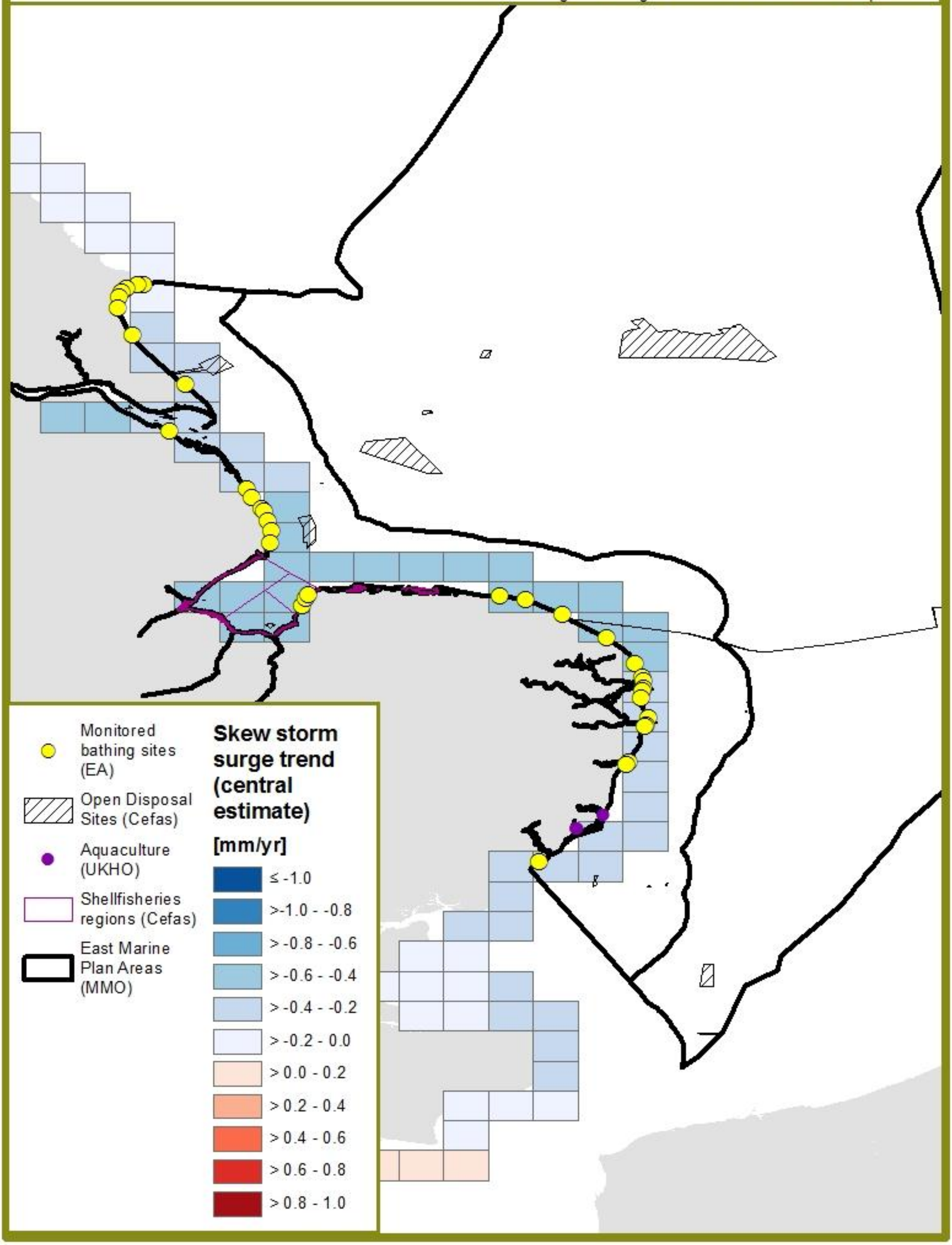

Monitored bathing sites, aquaculture locations and open disposal sites with 50 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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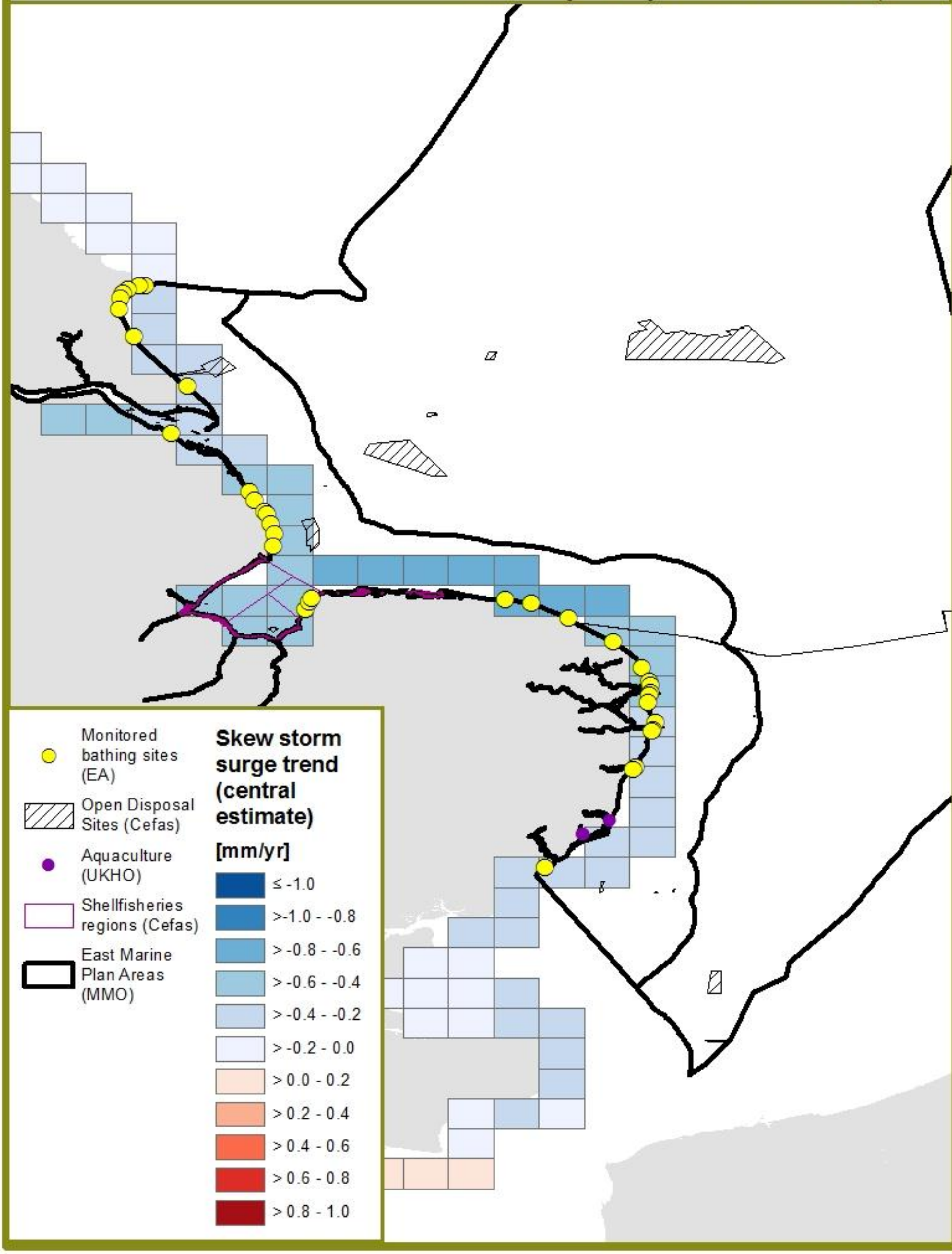

Marine Management Organisation

Harbours, ports and mooring/warping locations with annual mean sea surface temperature change projection in the East Inshore Marine Plan Areas

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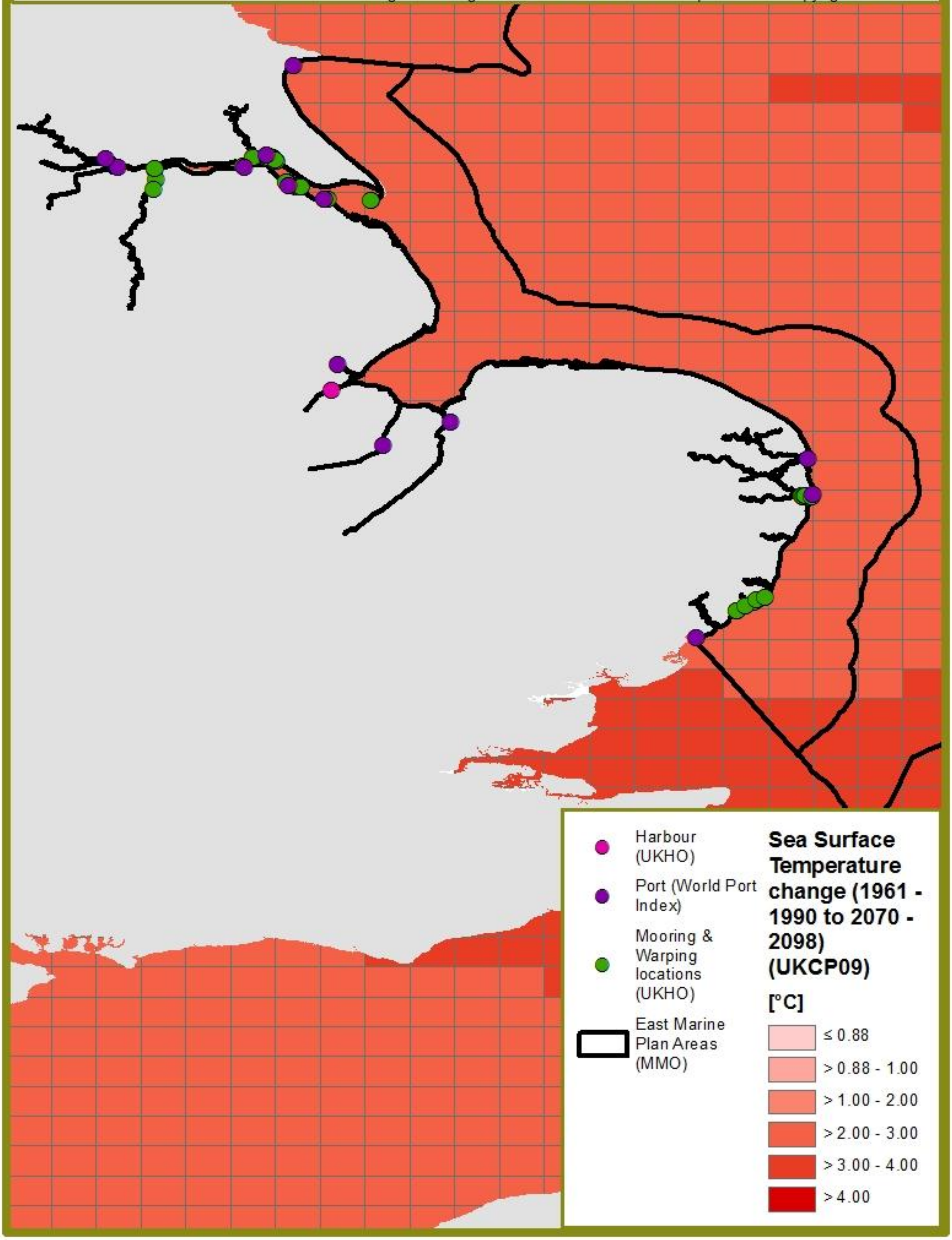

Commercial and recreational shipping infrastructure with 2 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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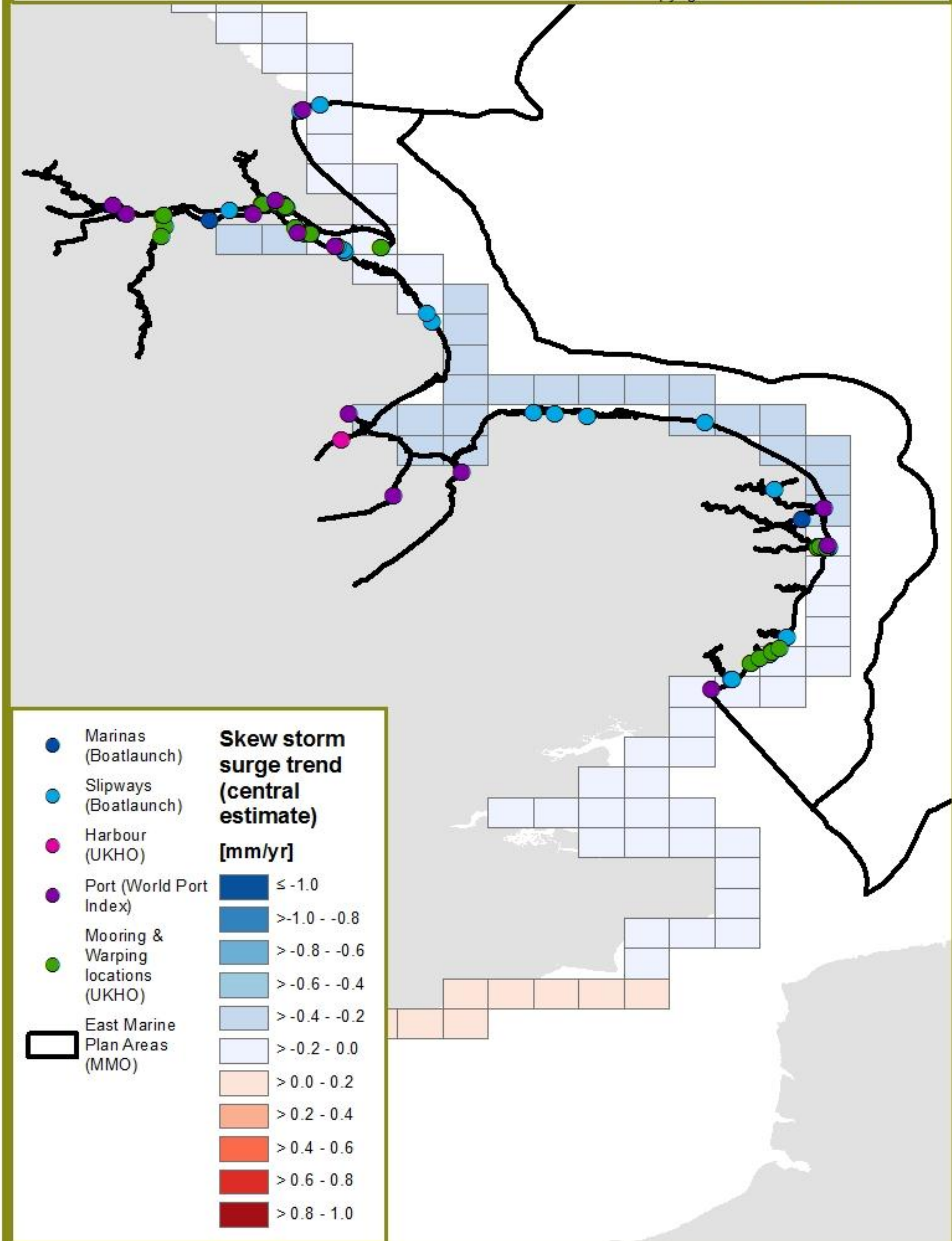

Marine Management Organisation

Commercial and recreational shipping infrastructure with 10 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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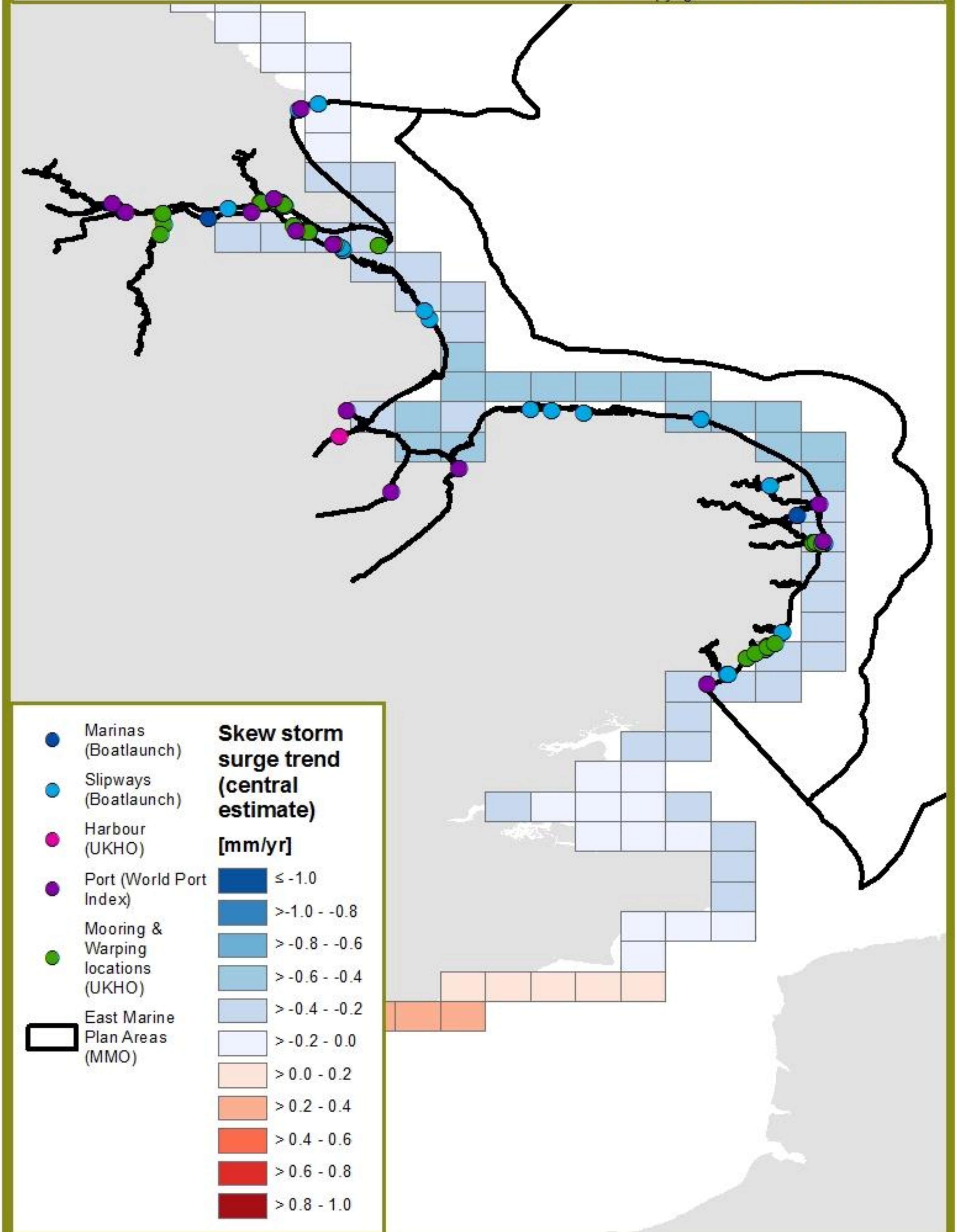

Marine Management Organisation

Commercial and recreational shipping infrastructure with 20 year return level skew storm surge trend in the East Inshore Marine Plan Areas

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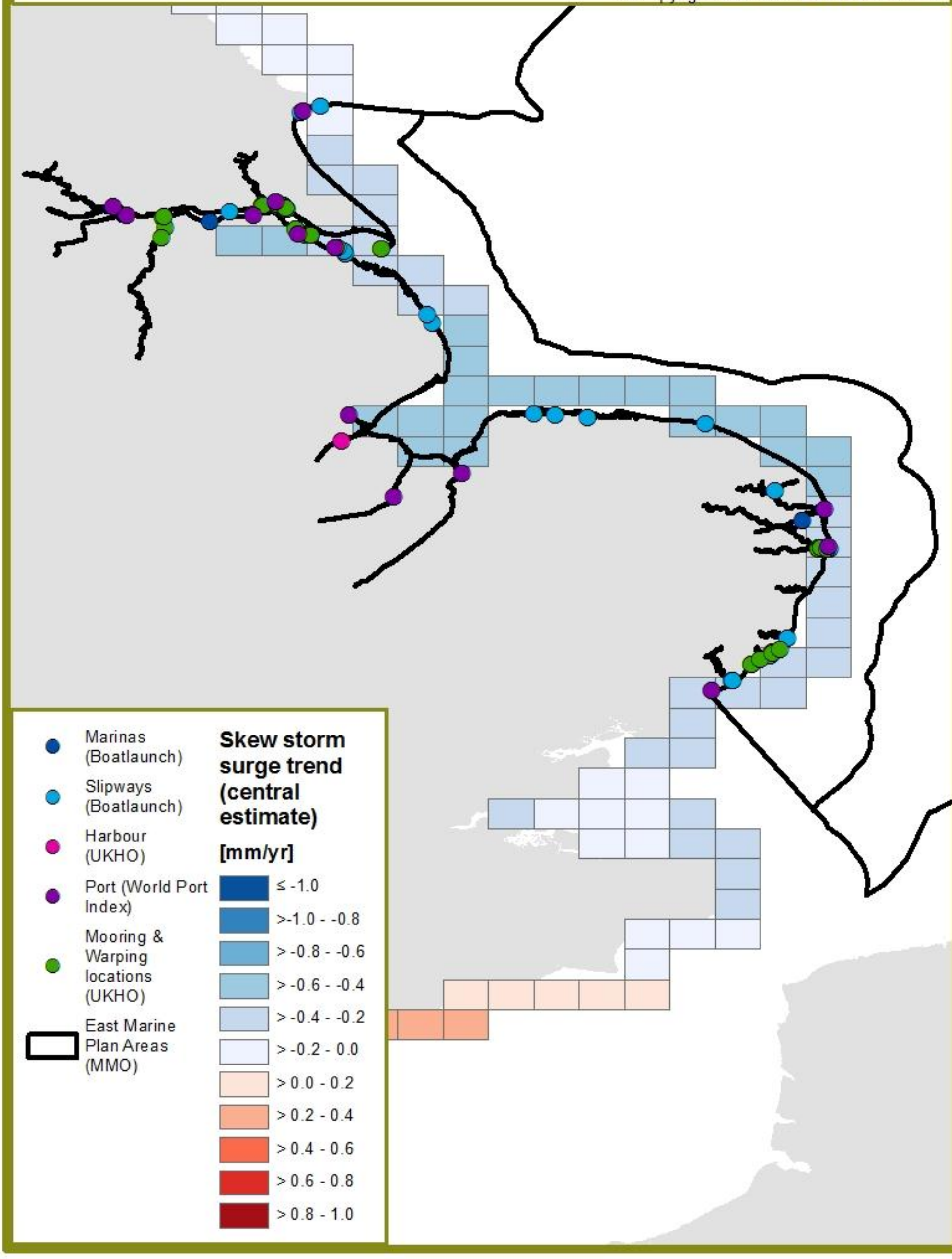

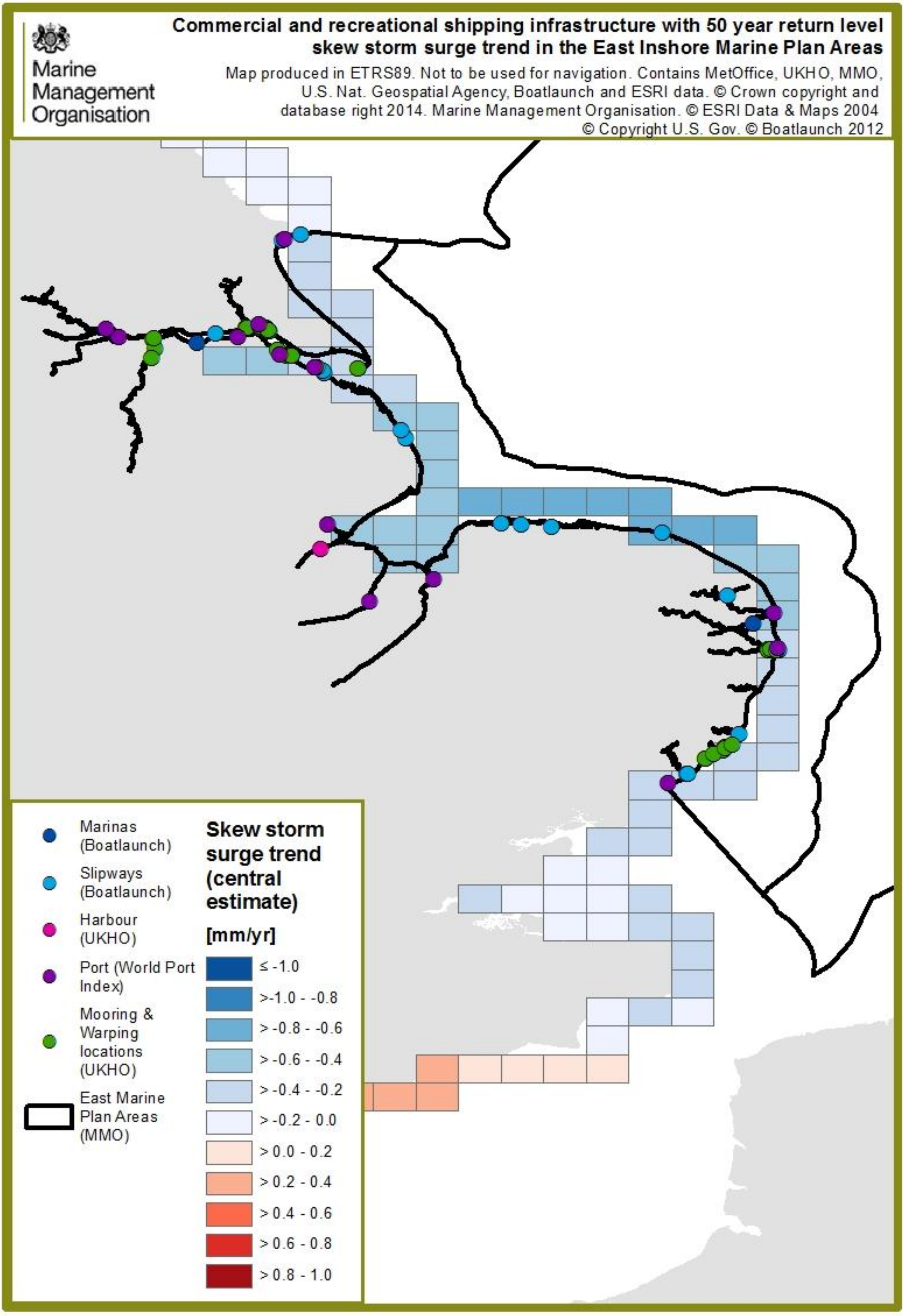
Marine Management Organisation
Commercial and recreational shipping infrastructure with 50 year return level skew storm surge trend in the East Inshore Marine Plan Areas
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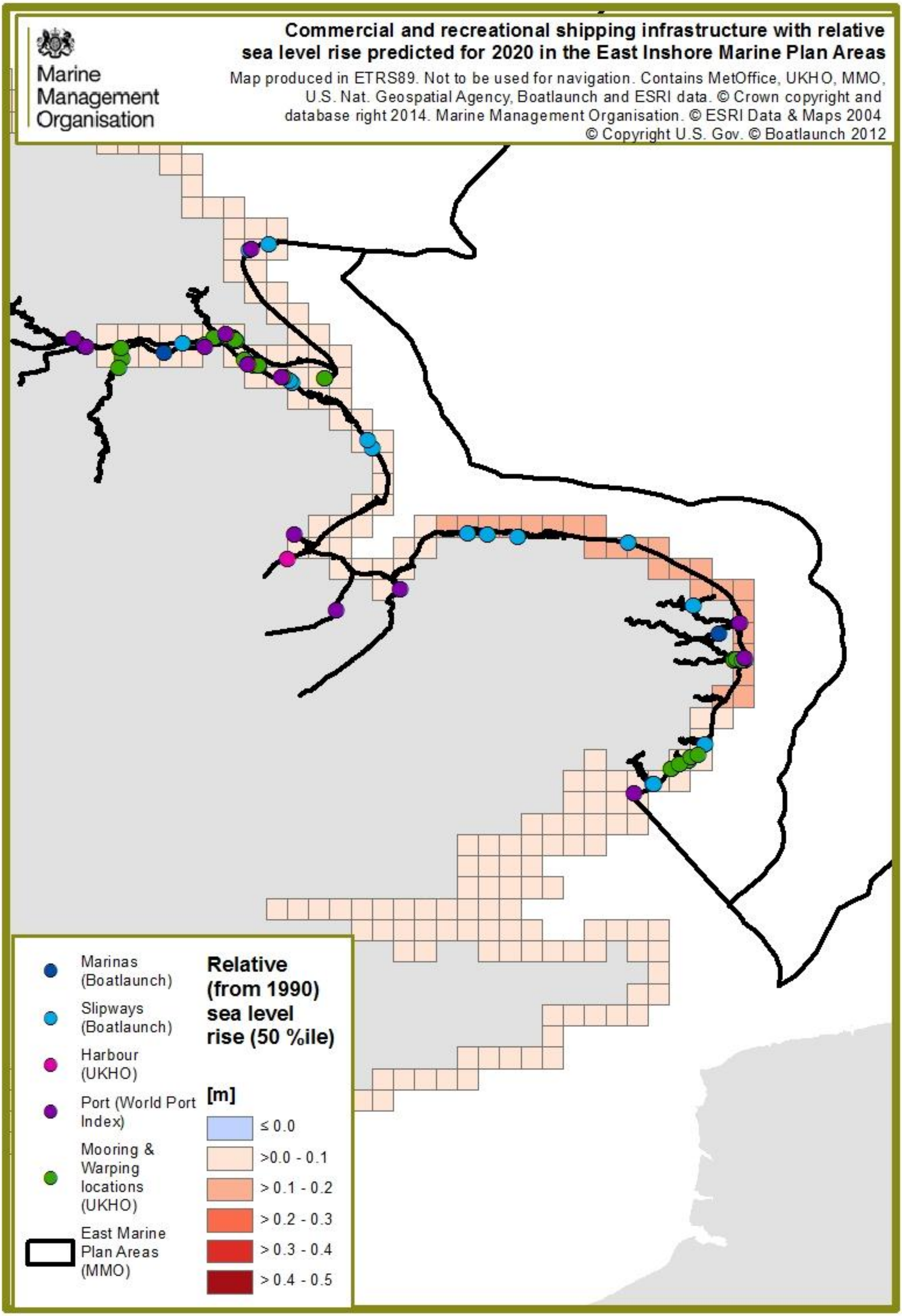
Marinas (Boatlaunch)
Slipways (Boatlaunch)
Harbour (UKHO)
Port (World Port Index)
Mooring & Warping locations (UKHO)
East Marine Plan Areas (MMO)
Skew storm surge trend (central estimate)
[mm/yr]
≤ -1.0
>-1.0 - -0.8
> -0.8 - -0.6
> -0.6 - -0.4
> -0.4 - -0.2
> -0.2 - 0.0
> 0.0 - 0.2
> 0.2 - 0.4
> 0.4 - 0.6
> 0.6 - 0.8
> 0.8 - 1.0


Marine Management Organisation
Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2020 in the East Inshore Marine Plan Areas
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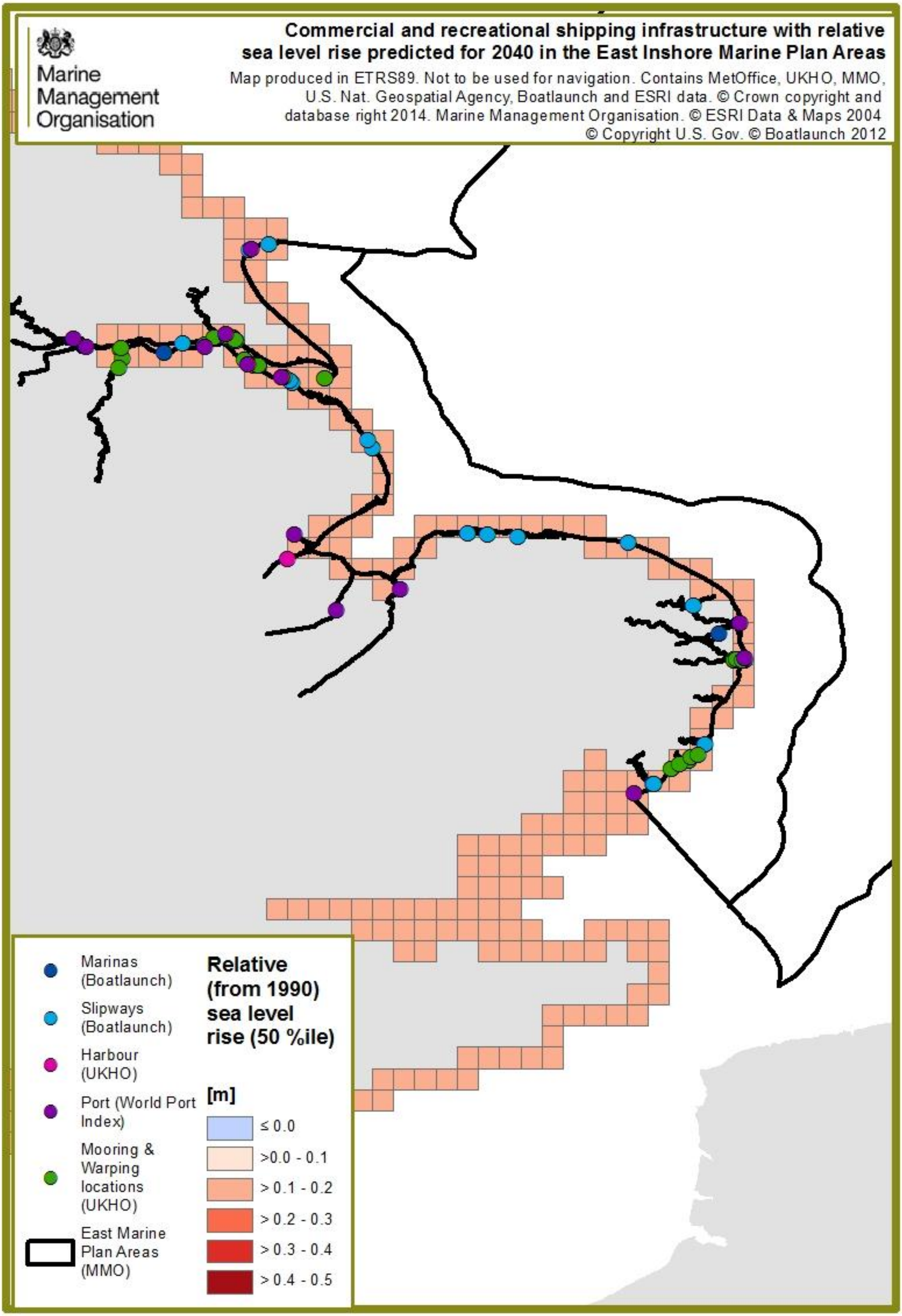
Marinas (Boatlaunch)
Slipways (Boatlaunch)
Harbour (UKHO)
Port (World Port Index)
Mooring & Warping locations (UKHO)
East Marine Plan Areas (MMO)
Relative (from 1990) sea level rise (50 %ile)
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5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Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2040 in the East Inshore Marine Plan Areas
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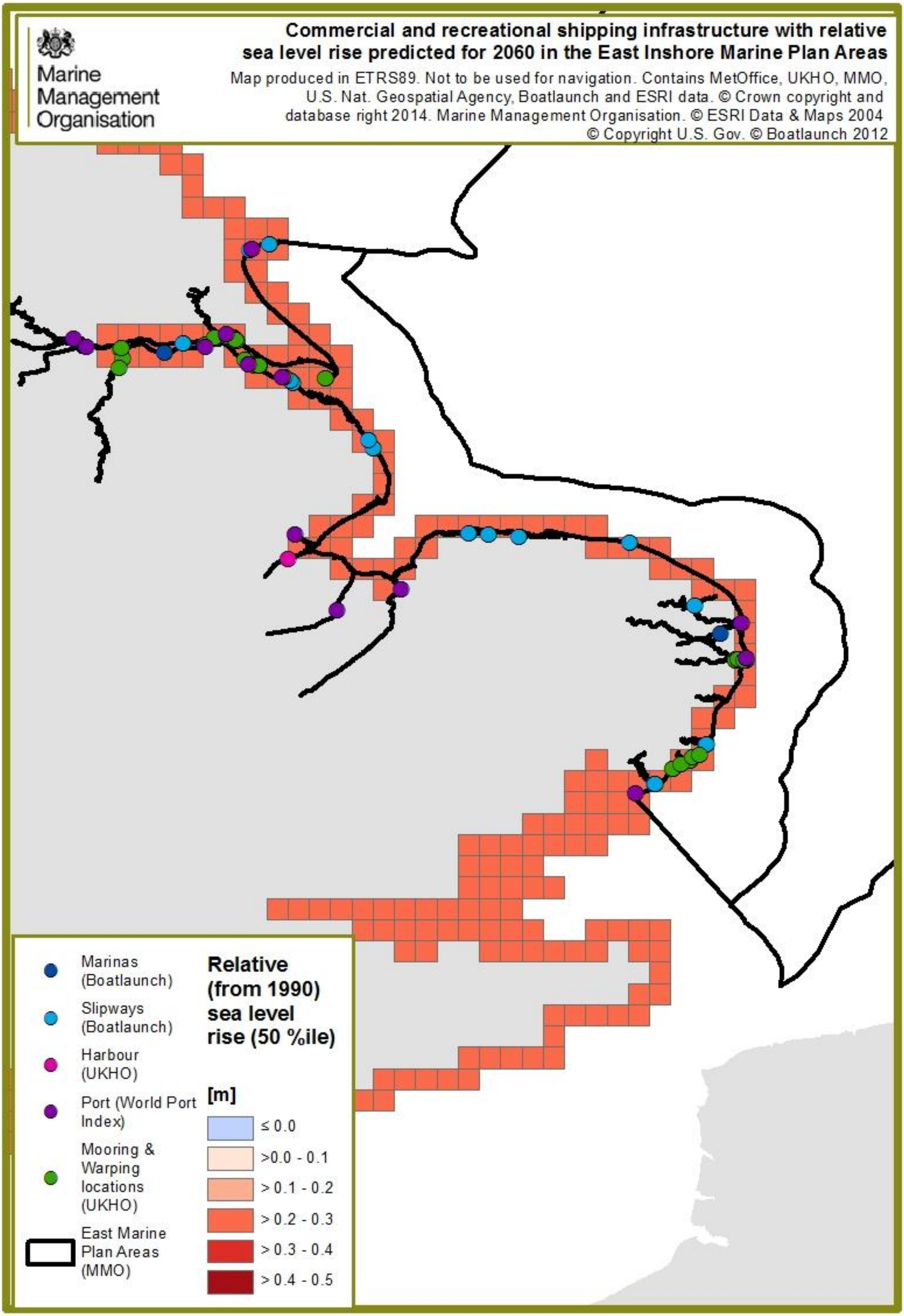
Marinas (Boatlaunch)
Slipways (Boatlaunch)
Harbour (UKHO)
Port (World Port Index)
Mooring & Warping locations (UKHO)
East Marine Plan Areas (MMO)
Relative (from 1990) sea level rise (50 %ile)
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5


Marine Management Organisation
Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2060 in the East Inshore Marine Plan Areas
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Marinas (Boatlaunch)
Slipways (Boatlaunch)
Harbour (UKHO)
Port (World Port Index)
Mooring & Warping locations (UKHO)
East Marine Plan Areas (MMO)
Relative (from 1990) sea level rise (50 %ile)
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5

Commercial and recreational shipping infrastructure with relative sea level rise predicted for 2080 in the East Inshore Marine Plan Areas

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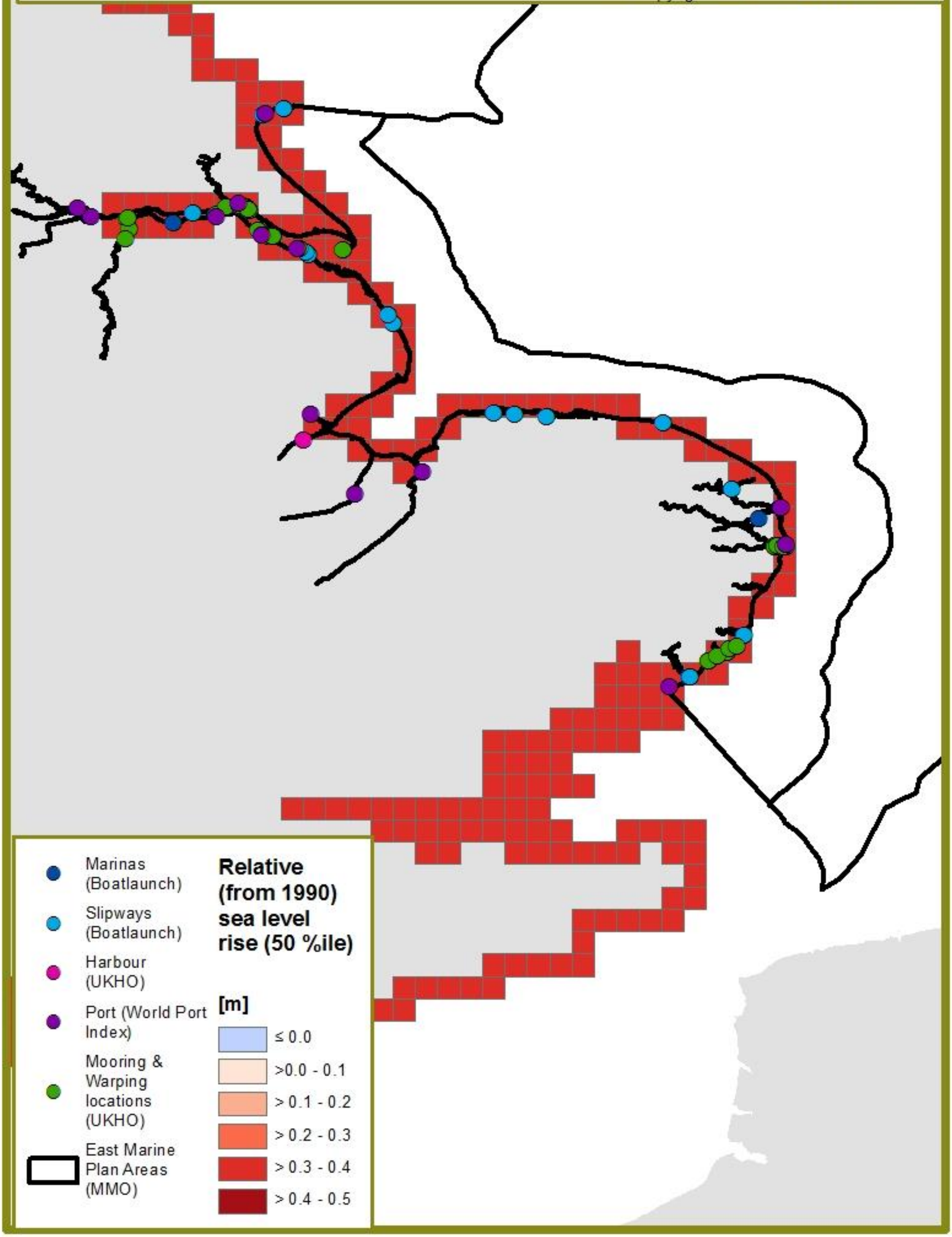
Marine Management Organisation



Fishing hotspots, aquaculture sites and marine protected areas with annual mean sea surface temperature change projection in the East Marine Plan Areas

Marine Management Organisation

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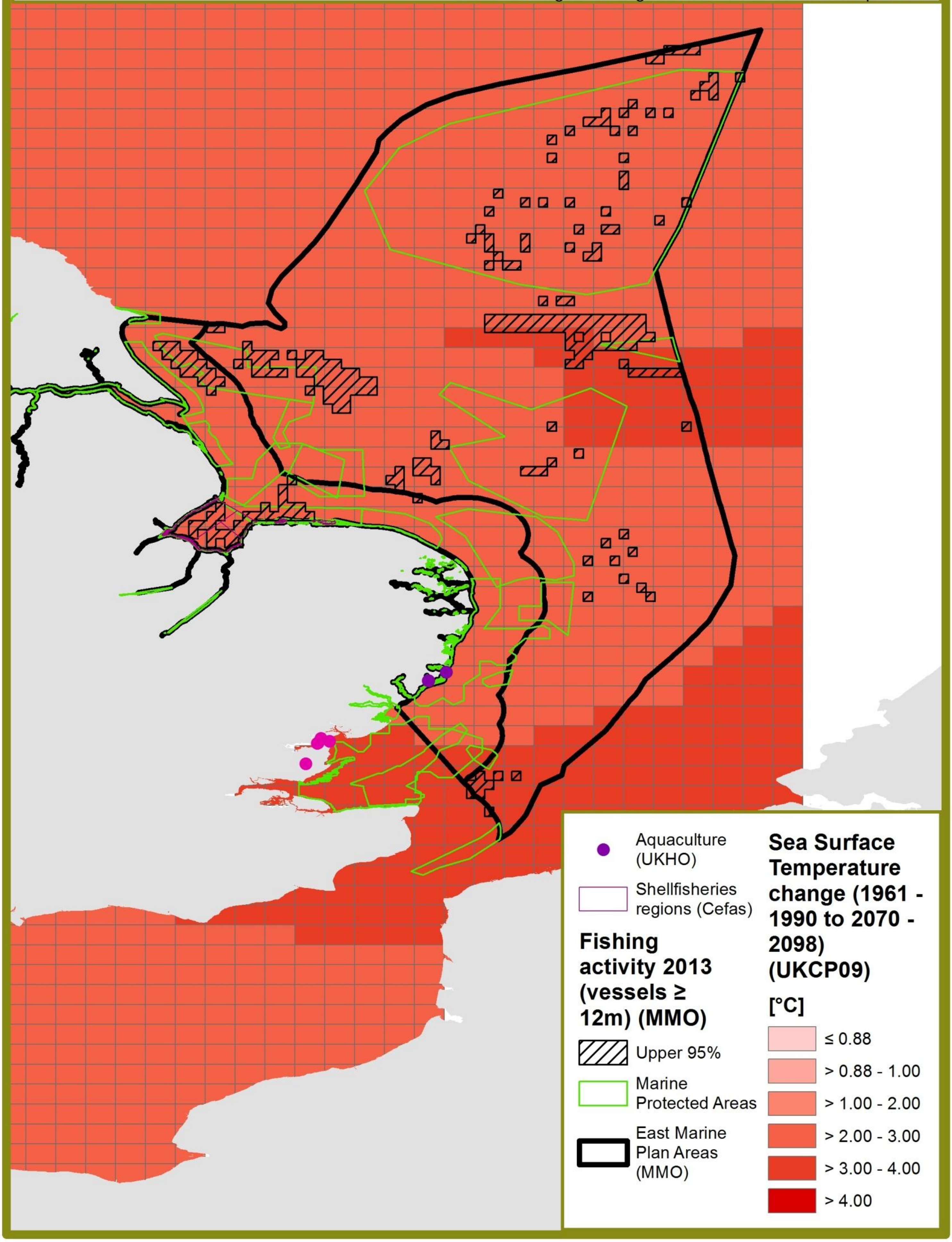
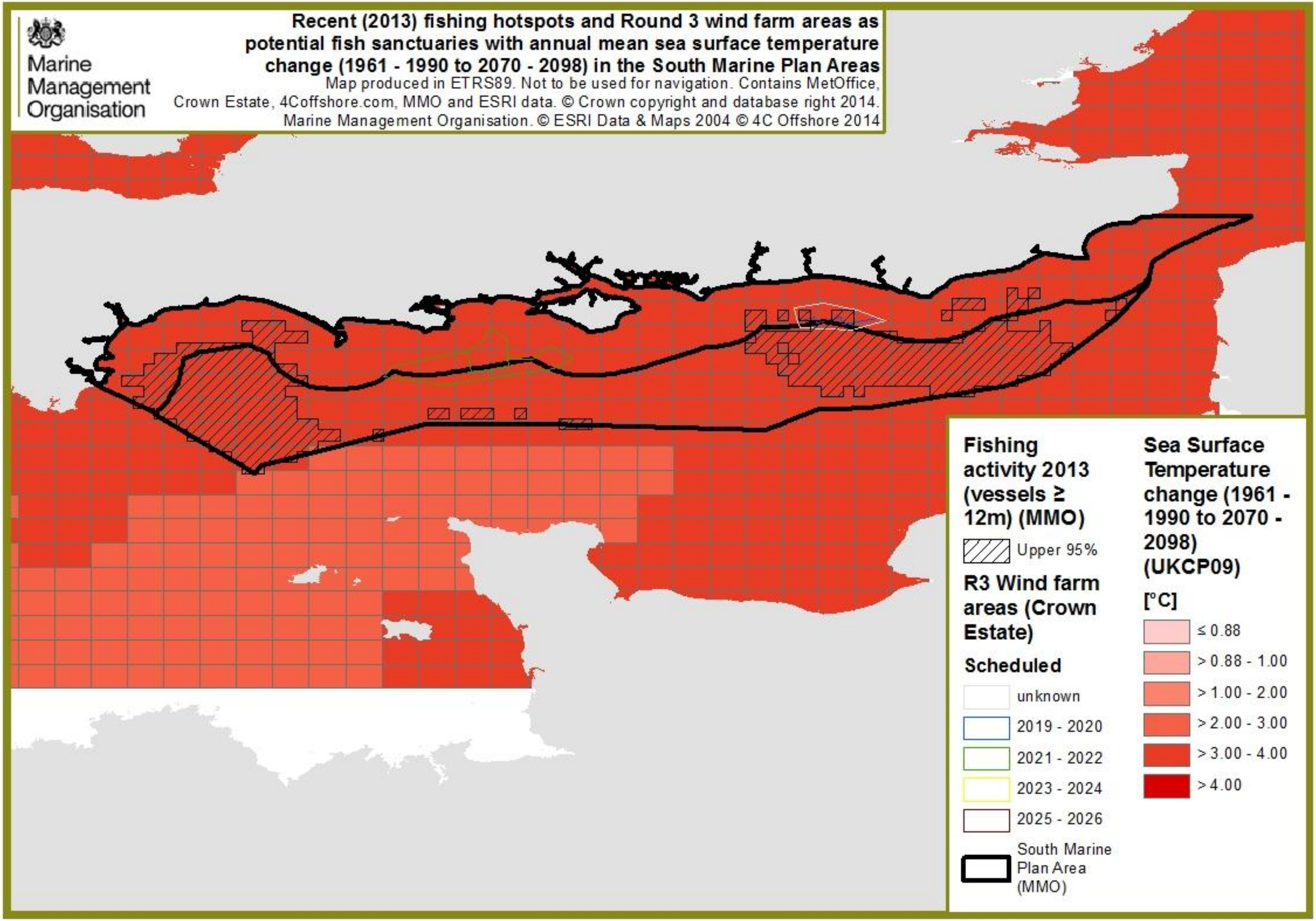
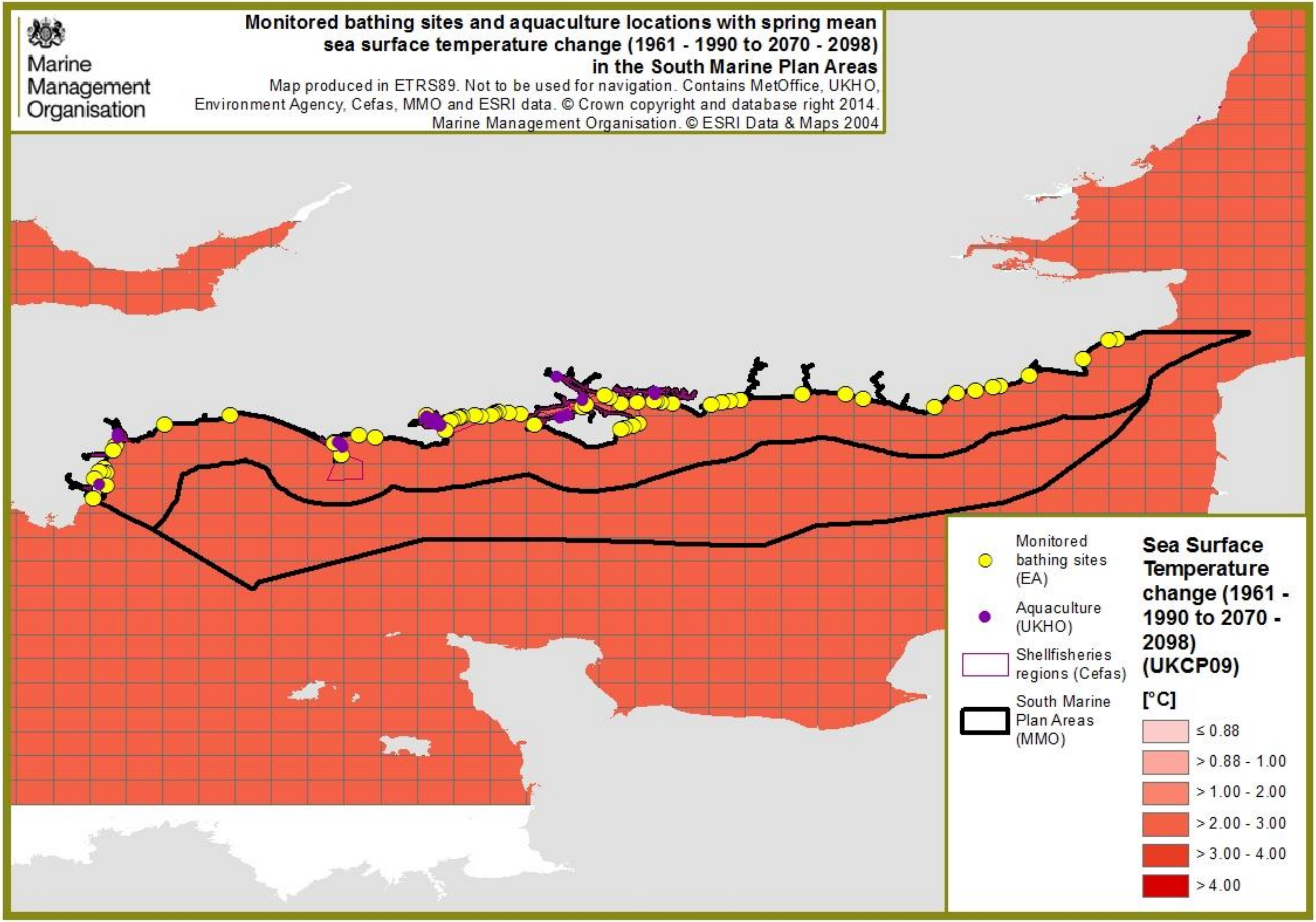
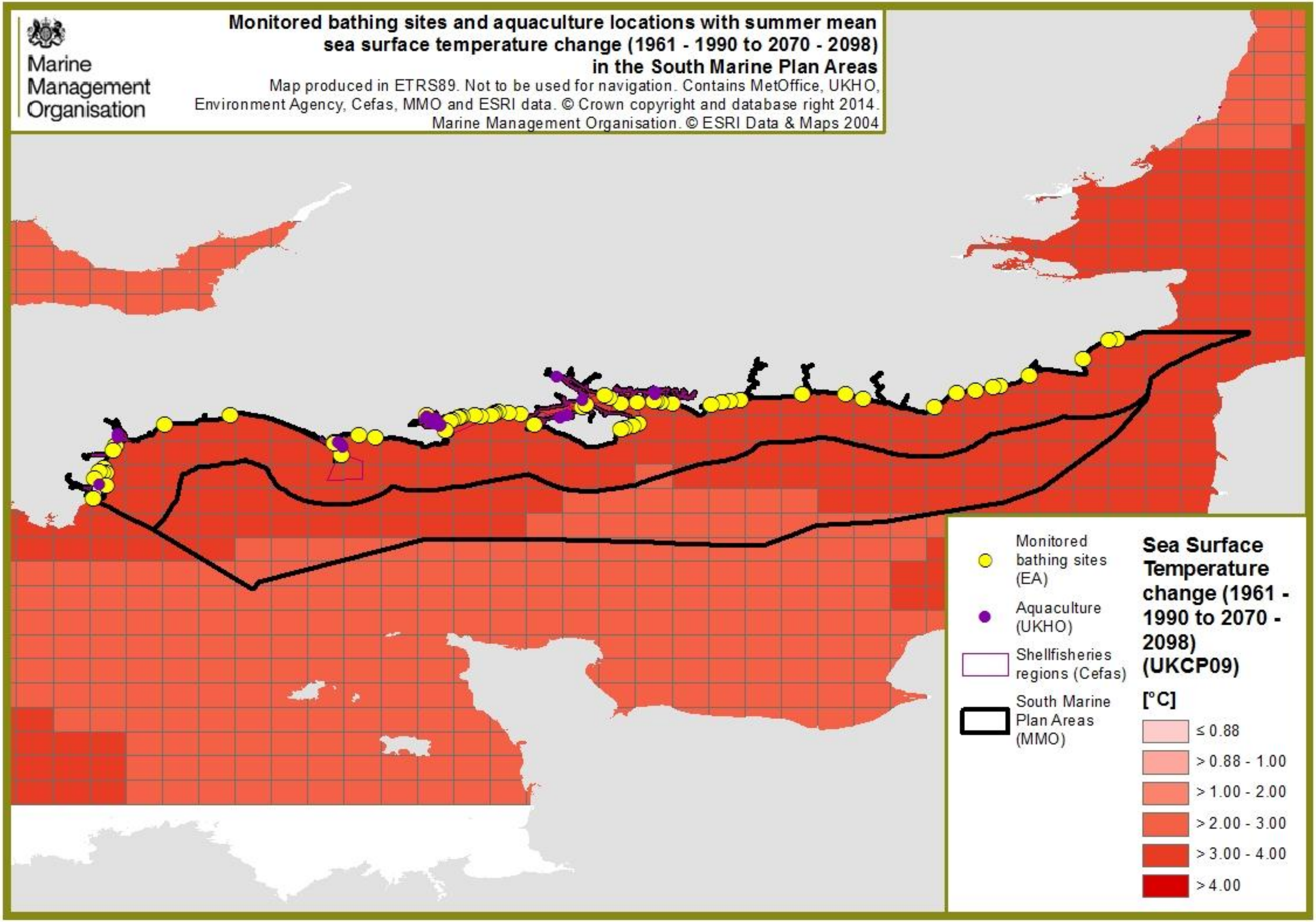
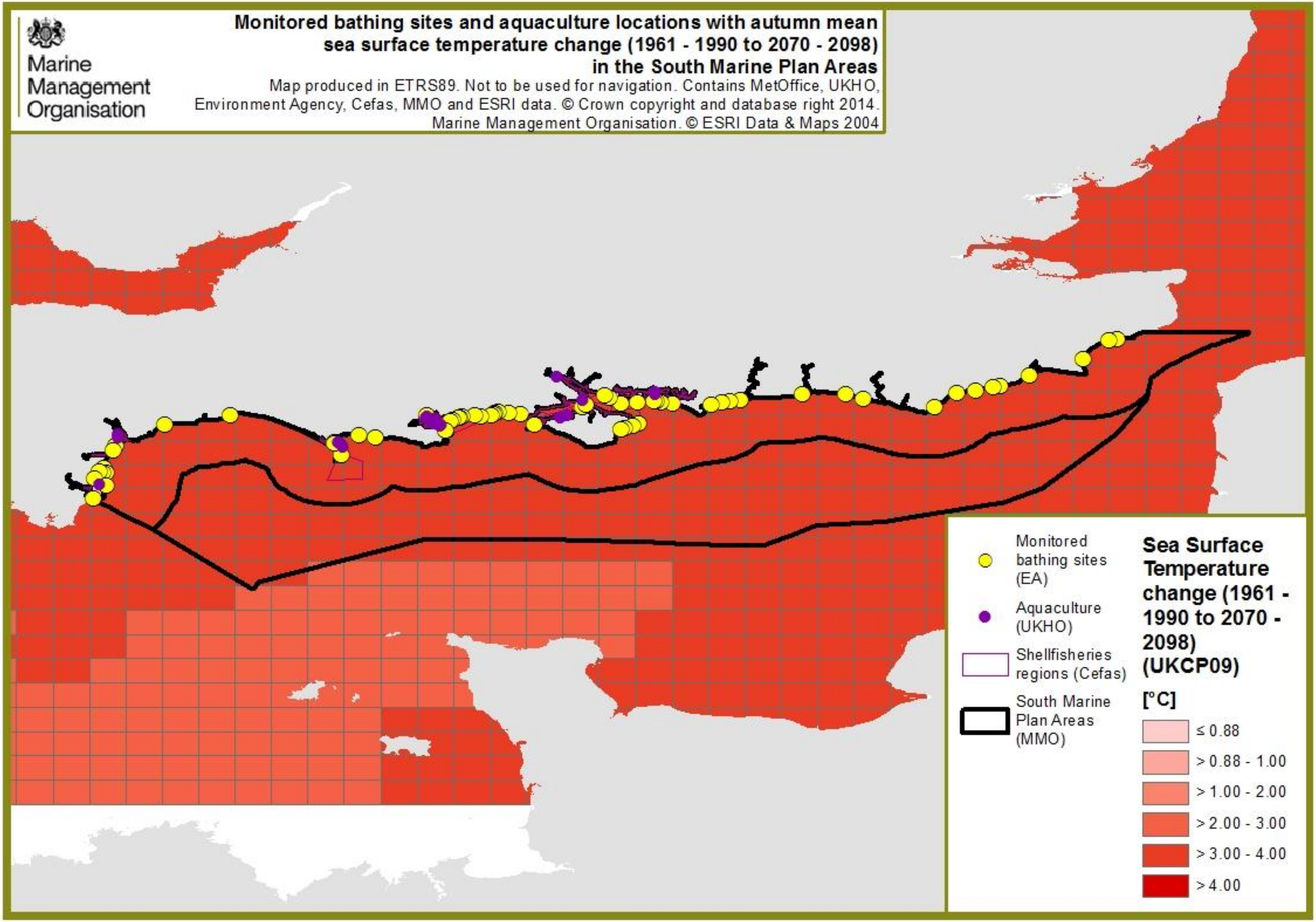
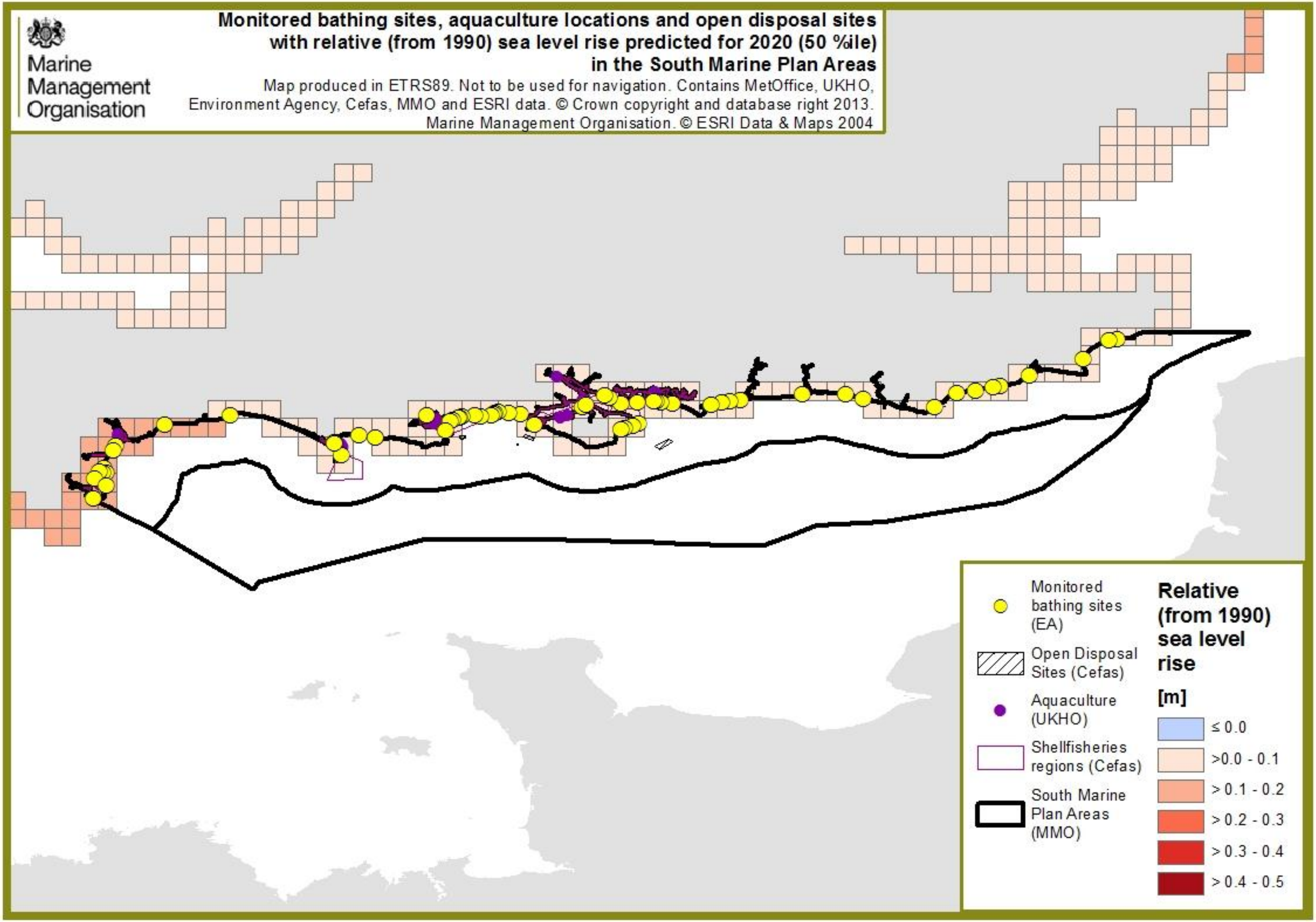



Marine Management Organisation
Recent (2013) fishing hotspots and Round 3 wind farm areas as potential fish sanctuaries with annual mean sea surface temperature change (1961 - 1990 to 2070 - 2098) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, Crown Estate, 4Coffshore.com, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004 © 4C Offshore 2014
Fishing activity 2013 (vessels ≥ 12m) (MMO)
Upper 95%
R3 Wind farm areas (Crown Estate)
Scheduled
unknown
2019 - 2020
2021 - 2022
2023 - 2024
2025 - 2026
South Marine Plan Area (MMO)
Sea Surface Temperature change (1961 - 1990 to 2070 - 2098) (UKCP09)
[°C]
≤ 0.88
> 0.88 - 1.00
> 1.00 - 2.00
> 2.00 - 3.00
> 3.00 - 4.00
> 4.00


Marine Management Organisation
Monitored bathing sites and aquaculture locations with spring mean sea surface temperature change (1961 - 1990 to 2070 - 2098) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Sea Surface Temperature change (1961 - 1990 to 2070 - 2098) (UKCP09)
[°C]
≤ 0.88
> 0.88 - 1.00
> 1.00 - 2.00
> 2.00 - 3.00
> 3.00 - 4.00
> 4.00


Marine Management Organisation
Monitored bathing sites and aquaculture locations with summer mean sea surface temperature change (1961 - 1990 to 2070 - 2098) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Sea Surface Temperature change (1961 - 1990 to 2070 - 2098) (UKCP09)
[°C]
≤ 0.88
> 0.88 - 1.00
> 1.00 - 2.00
> 2.00 - 3.00
> 3.00 - 4.00
> 4.00


Marine
Management
Organisation
Monitored bathing sites and aquaculture locations with autumn mean sea surface temperature change (1961 - 1990 to 2070 - 2098) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Sea Surface Temperature change (1961 - 1990 to 2070 - 2098) (UKCP09)
[°C]
≤ 0.88
> 0.88 - 1.00
> 1.00 - 2.00
> 2.00 - 3.00
> 3.00 - 4.00
> 4.00



Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with relative (from 1990) sea level rise predicted for 2020 (50 %ile) in the South Marine Plan Areas
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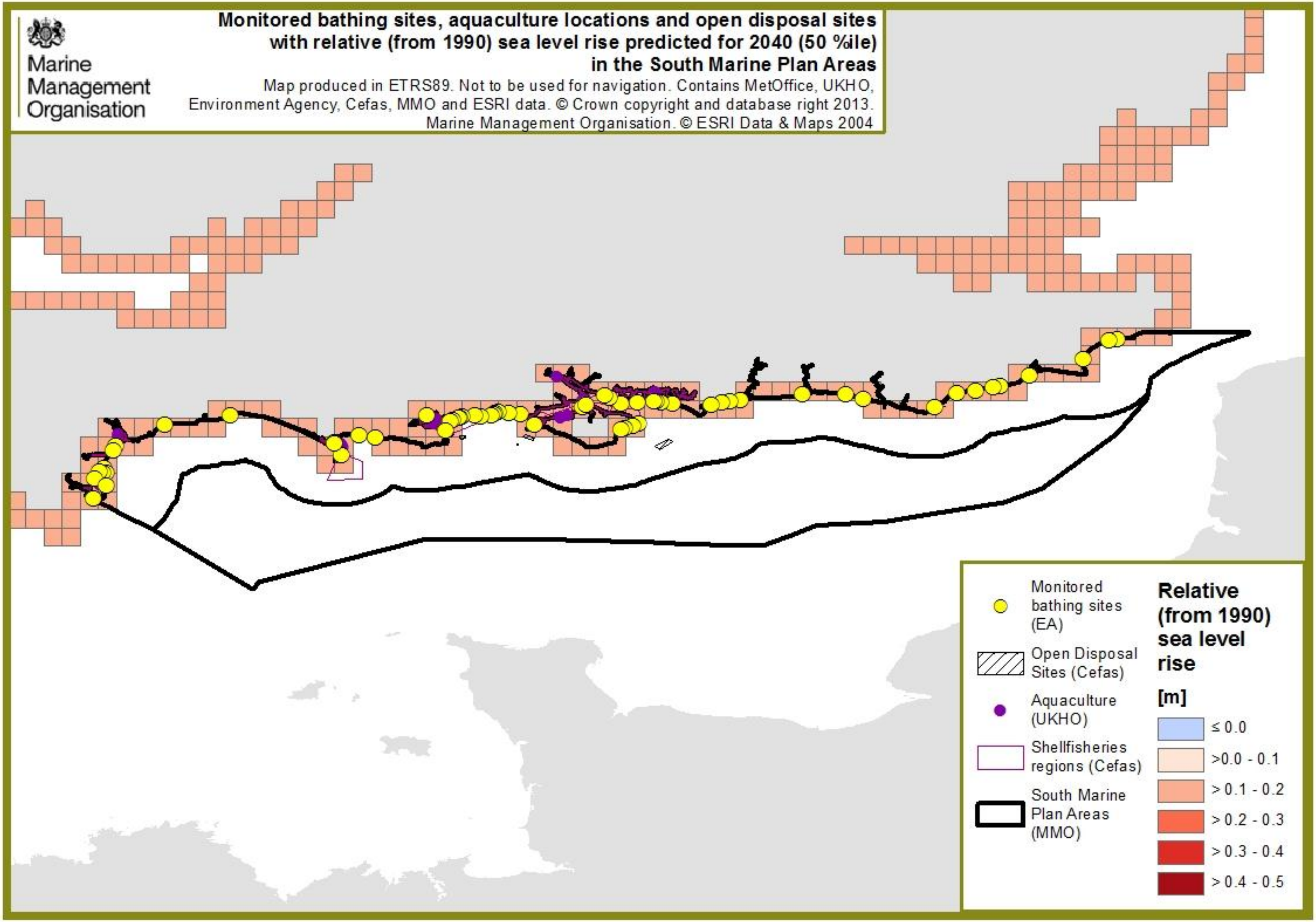
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Relative (from 1990) sea level rise
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5



Monitored bathing sites, aquaculture locations and open disposal sites with relative (from 1990) sea level rise predicted for 2040 (50 %ile) in the South Marine Plan Areas

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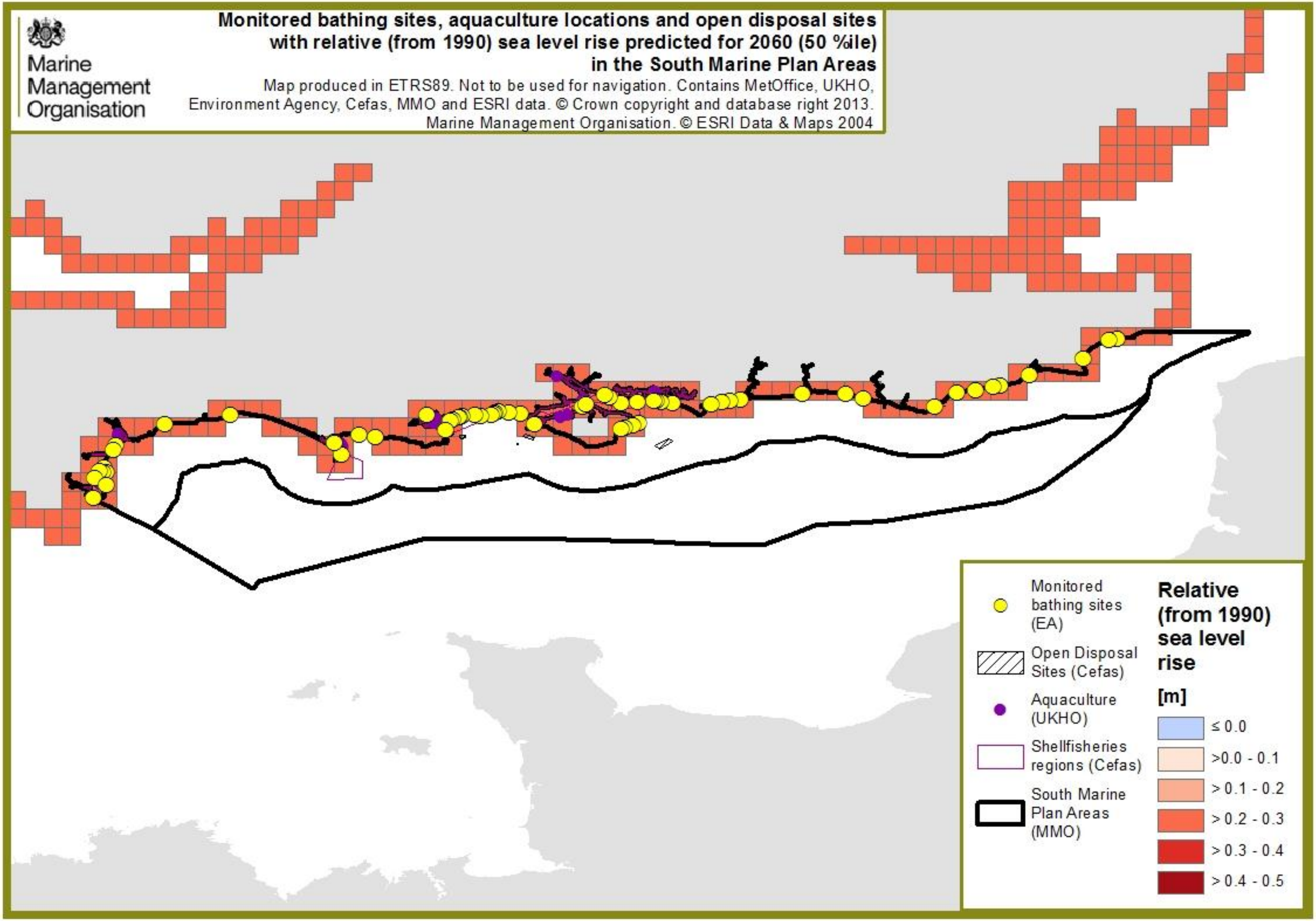
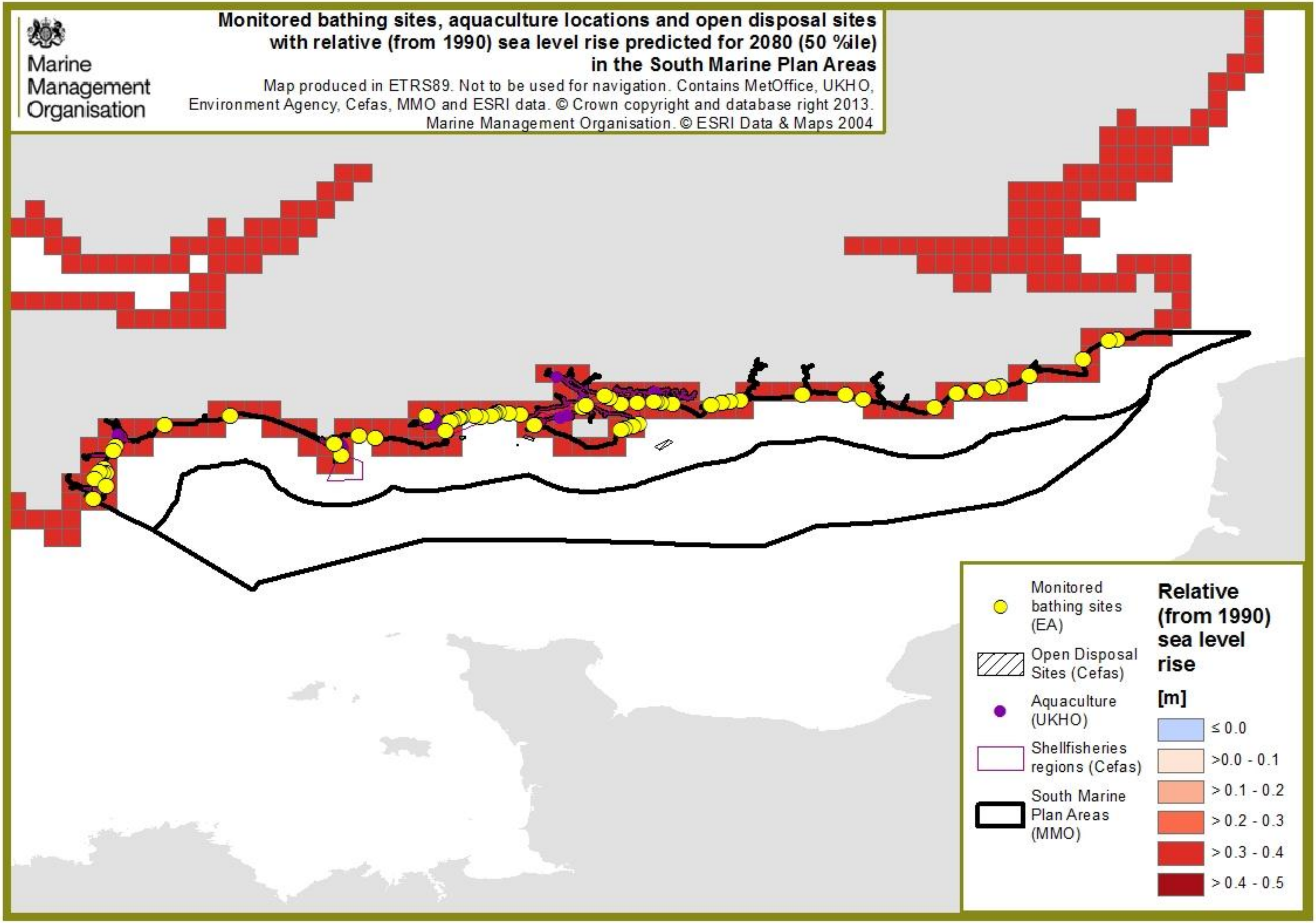
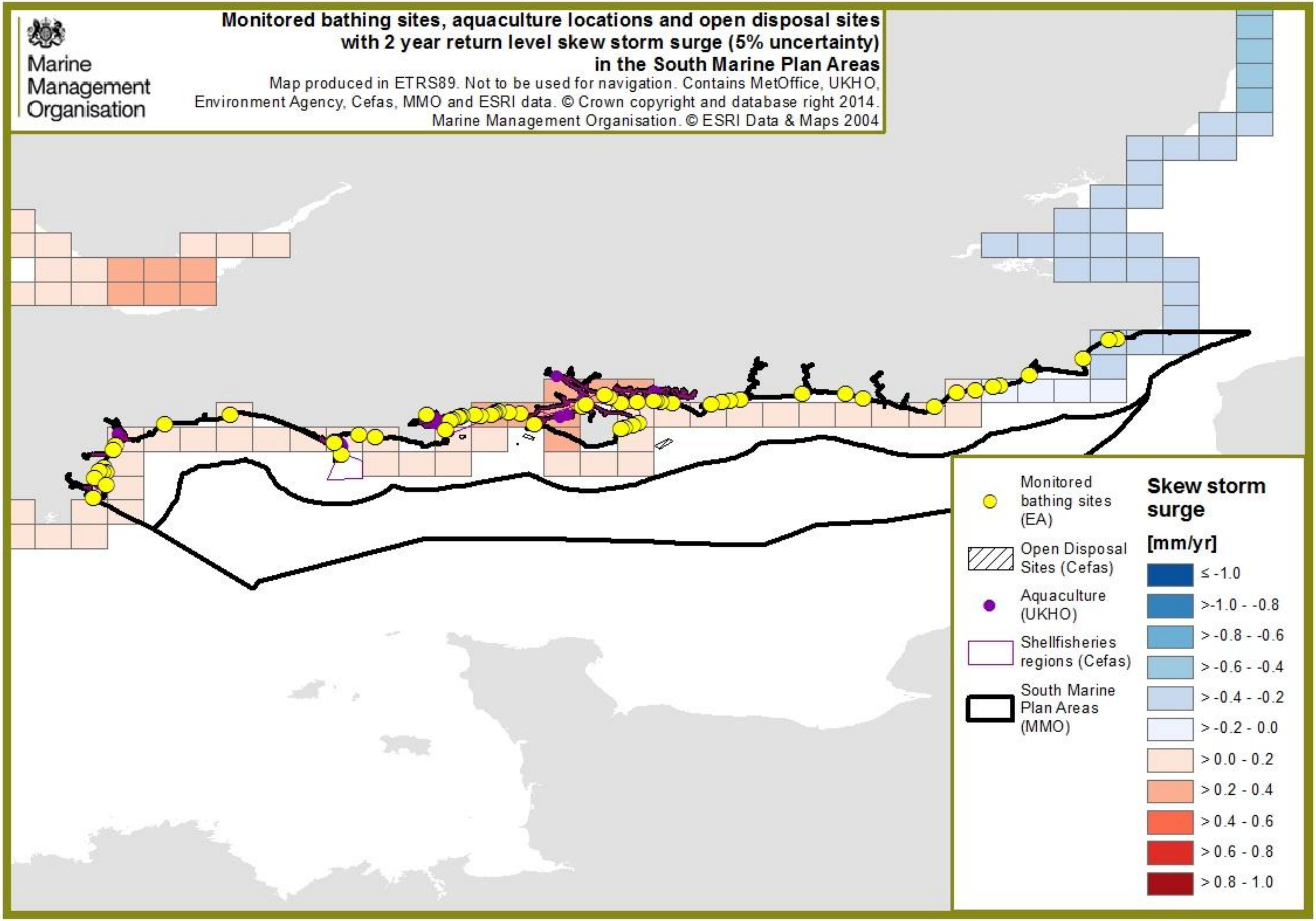
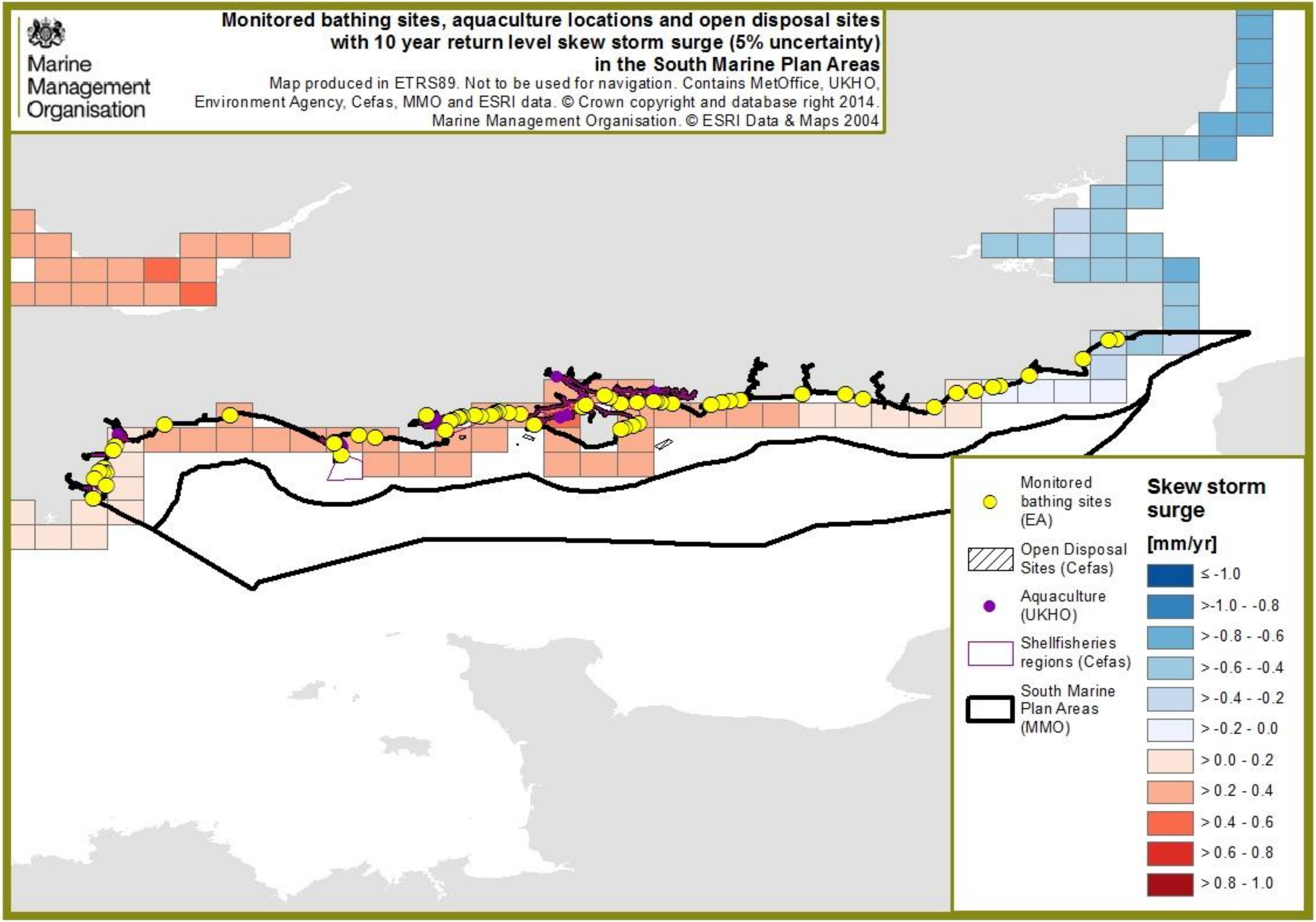
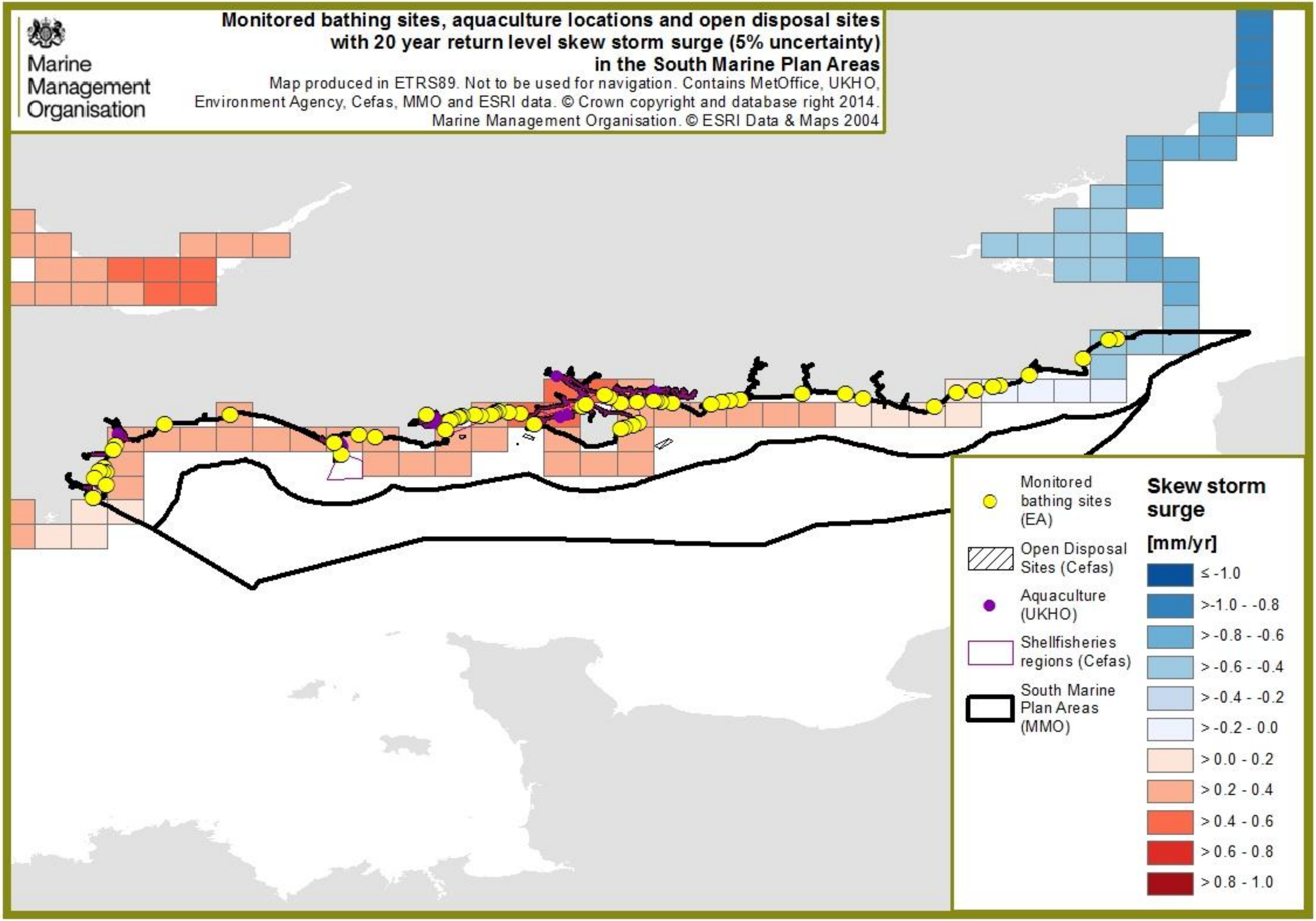


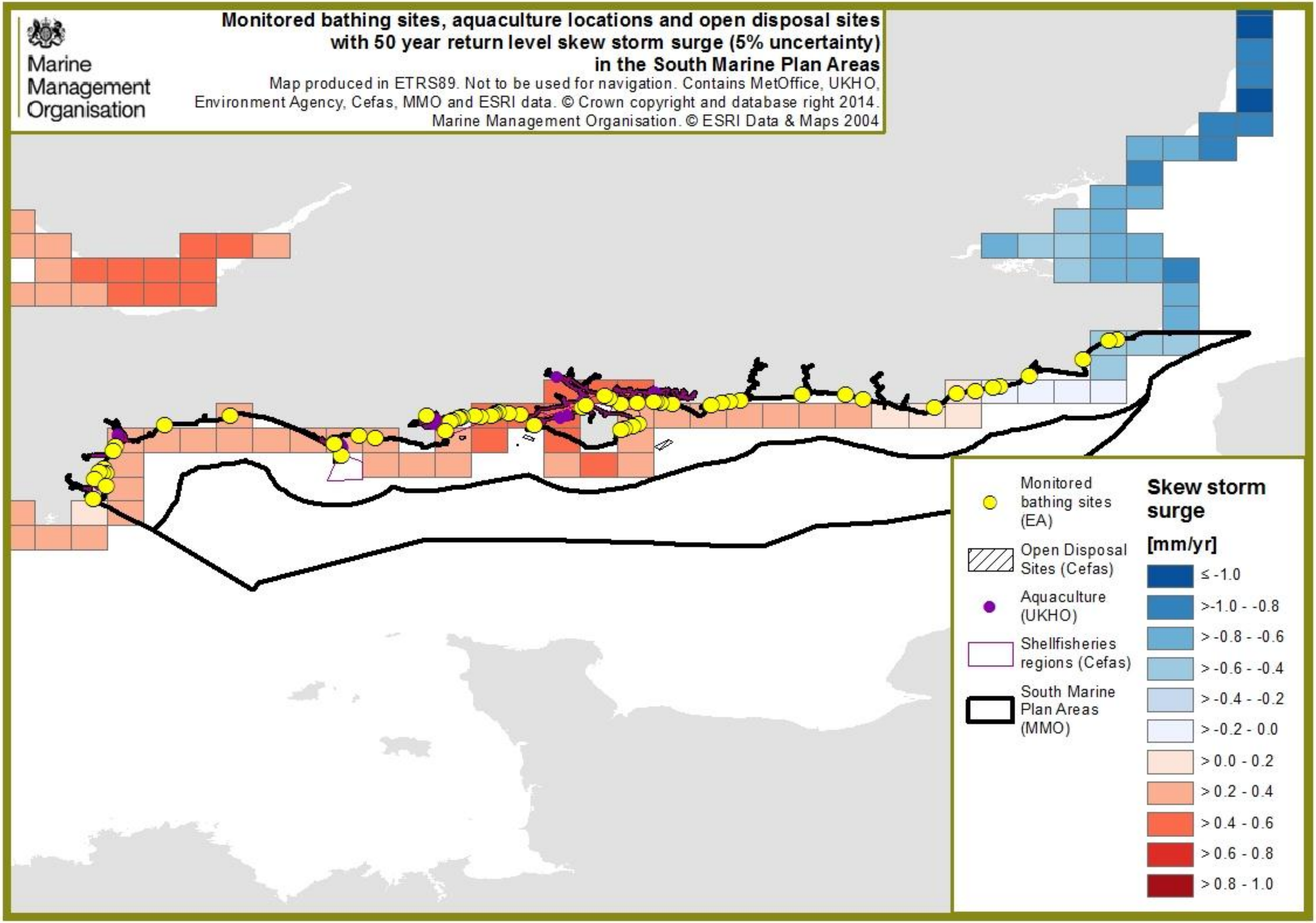
Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with relative (from 1990) sea level rise predicted for 2060 (50 %ile) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2013. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Relative (from 1990) sea level rise
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5


Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with relative (from 1990) sea level rise predicted for 2080 (50 %ile) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2013. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Relative (from 1990) sea level rise
[m]
≤ 0.0
>0.0 - 0.1
> 0.1 - 0.2
> 0.2 - 0.3
> 0.3 - 0.4
> 0.4 - 0.5


Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites
with 2 year return level skew storm surge (5% uncertainty)
in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Skew storm surge
[mm/yr]
≤ -1.0
>-1.0 - -0.8
> -0.8 - -0.6
> -0.6 - -0.4
> -0.4 - -0.2
> -0.2 - 0.0
> 0.0 - 0.2
> 0.2 - 0.4
> 0.4 - 0.6
> 0.6 - 0.8
> 0.8 - 1.0


Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with 10 year return level skew storm surge (5% uncertainty) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Skew storm surge [mm/yr]
≤ -1.0
>-1.0 - -0.8
> -0.8 - -0.6
> -0.6 - -0.4
> -0.4 - -0.2
> -0.2 - 0.0
> 0.0 - 0.2
> 0.2 - 0.4
> 0.4 - 0.6
> 0.6 - 0.8
> 0.8 - 1.0


Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with 20 year return level skew storm surge (5% uncertainty) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Skew storm surge [mm/yr]
≤ -1.0
>-1.0 - -0.8
> -0.8 - -0.6
> -0.6 - -0.4
> -0.4 - -0.2
> -0.2 - 0.0
> 0.0 - 0.2
> 0.2 - 0.4
> 0.4 - 0.6
> 0.6 - 0.8
> 0.8 - 1.0


Marine Management Organisation
Monitored bathing sites, aquaculture locations and open disposal sites with 50 year return level skew storm surge (5% uncertainty) in the South Marine Plan Areas
Map produced in ETRS89. Not to be used for navigation. Contains MetOffice, UKHO, Environment Agency, Cefas, MMO and ESRI data. © Crown copyright and database right 2014. Marine Management Organisation. © ESRI Data & Maps 2004
Monitored bathing sites (EA)
Open Disposal Sites (Cefas)
Aquaculture (UKHO)
Shellfisheries regions (Cefas)
South Marine Plan Areas (MMO)
Skew storm surge [mm/yr]
≤ -1.0
>-1.0 - -0.8
> -0.8 - -0.6
> -0.6 - -0.4
> -0.4 - -0.2
> -0.2 - 0.0
> 0.0 - 0.2
> 0.2 - 0.4
> 0.4 - 0.6
> 0.6 - 0.8
> 0.8 - 1.0