CoastalRes Technical Report

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1 Background

CoastalRes (https://www.channelcoast.org/ccoresources/coastalres/) was a project funded by the UK Strategic Priorities Fund Climate Resilience Programme from February 2019 to January 2020. The overarching aim was to explore the changing nature of coastal and estuarine erosion and flood risk and to consider how adaptation pathways could be informed by a resilience-based framework for the selection of appropriate policy options. This work is framed by the current Shoreline Management Planning (SMP) framework for England and Wales, as well as by the findings of the UK Committee on Climate Change (Committee on Climate Change, 2018) that current policies at the coast take insufficient account of the inevitability of future change and its consequences for both national government and local communities.

Resilience is widely viewed as a desirable property of coastal systems and the desirability of enhancing the resilience of the coast and of coastal communities is increasingly prominent in governmental policy statements. However, resilience-based management requires a shift away from the narrow and mutually exclusive set of policy options available within the current SMP process towards a broader suite of policy measures that are implemented in a more holistic way. Practical implementation of resilience-based coastal management has been held back by ongoing debate over its definition and by the lack of robust methods for quantitative measurement and assessment. Quantitative measures of resilience are essential - without them, the current state of the coastal system cannot be assessed and there is no basis for determining whether policy options will enhance or diminish resilience.

The CoastalRes project engaged with a wide range of stakeholders via a series of consultation workshops, held in London, Havant and York. These provided a deeper understanding of the issues surrounding the existing SMP process, and the potential offered by a broader suite of policy options that embrace the concept of resilience as an overarching policy goal. The proposed coastal resilience framework makes use of established methods for evaluating evidence and decision making under uncertainty, to both assess the state of resilience of our coastline and provide tools to help plan how best to improve the resilience. It is important to emphasise that the conceptualisation of resilience adopted here is not simply an attribute of natural geomorphological and ecological systems but one that also incorporates the complex socio-economic system at the coast (Townend et al., 2020). This more holistic system resilience can also be viewed from different perspectives, including a top-down governmental economic view, a more localised community social view, and a nature management view as well as an overall view combining these three perspectives.

This report provides a summary of the data resources and geospatial data processing undertaken by the GeoData Institute to demonstrate how the prototype CoastalRes Coastal Resilience Model (CRM) might be implemented in practical terms and scaled up to cover the whole of England.

2 Objectives and Principles

The objectives of this CoastalRes Work Package were twofold. First, to evaluate the available data resources and the processing required to derive a set of resilience measures within the prototype CoastalRes CRM and, second, to evaluate the potential to scale this up this to a national (England-wide) model of coastal resilience.

The above objectives were developed against the following set of principles:

i. **Replicability at a national scale.** The aim is to develop an approach that is extensible, in terms of the indicators used and that can be implemented not only for England but potentially for the UK as a whole. A challenge here is that the Shoreline Management Plan process is currently only implemented in England. The datasets available differ for other parts of the UK and the pilot studies and the national resilience model have been limited to England at this stage.

ii. **Open data / distributable outputs.** The aim is that the data products generated by the project have no inherent intellectual property (IP) issues that would restrict their free distribution. This relies on using open data (under an OGL licence or equivalent, e.g. the outputs area polygons that accompany the Census data attributes) and/or an output resolution that does not allow reconstruction of the input data layers from the derived data products.

iii. **Extensibility beyond demonstrator.** (e.g. separate flood and erosion boundaries) to national model. This initial programme was limited to the development of the demonstration of the CoastalRes approach within three pilot sites. This work has already been extended to the mapping of the current distribution of coastal resilience at the national level (England), although at this stage, future scenarios have not been explore beyond the pilot sites.

iv. **Maintainability.** It is important that the workflow can be re-run with new data, different indicators and new scoring and weightings applied to the indicators. The aim is to develop a workflow and associated data structures allow this.

One of the first tasks is to segment the coast into appropriate spatial units. Initially, consideration was given to the generation of a multi-dimensional resilience index using the Shoreline Management Units (SMUs) defined within the existing SMPs as the mapping unit. However, evaluation indicated that the SMUs are primarily developed from shoreline classifications of three key variables: hazard data, current defence status and whether the hinterland is urban or rural. They thus neglect broader social, environmental and economic aspects of the hinterlands (Gerrard 2017). Furthermore, errors in the relevant SMP data layer made it clear that this was not a viable dataset to use as a baseline for the analysis.

The stages of the work package included: i) data assessment; ii) data collection and processing requirements for selected pilot sites; iii) data processing for the national resilience assessment; and iv) resilience model creation. This draws on the methods outlined by Townend et al. (2020)

3 Data Evaluation and Processing

3.1 Data Assessment

An assessment of data quality and availability was undertaken to evaluate appropriate geospatial data sources to support the coastal resilience analysis and mapping. This included both the baseline data for representing the hazard zone as well as the data needed to model resilience.

3.1.1 Hazard Zone Data

From a geospatial analysis perspective, a coastal hazard zone is defined using four principal datasets:

1. A shoreline
2. An erosion dataset
3. A flood extent dataset
4. An analysis layer

An up-to-date shoreline is essential. The Shoreline Management Plan Mapping[1] line, created by the Environment Agency, was considered as it could have been used to split the hazard zone inland between management units. However, in this study the focus is on community resilience and inland management units were deemed more suitable. Also, the SMP line suffered from attribution duplications and digitisation errors.

Long term (50-100 yrs) erosion (National Coastal Erosion Risk Mapping[2] (NCERM)) data under 'No Active Intervention' were used to create an erosion zone and emulate the worst-case scenario. This matched the time period and context of the flood zone data (Flood Map for Planning[3]). NCERM data was used in preference to a satellite-based coastline erosion dataset available from Deltares[4], since this is not regularly updated. The erosion and flooding datasets are both managed by the Environment Agency under an Open Government Licence (OGL) and updated regularly. The erosion distance specified by NCERM data was extended from the SMP line to create the erosion zone. In some areas the erosion rate was not accurate. For example, at Barton, Hampshire, the SMP review (Bournemouth Borough Council, 2011) reports erosion rates of up to 300 m, yet NCERM data reports no erosion at all. This shows that an erosion dataset that achieves acceptable accuracy along the entire English shoreline is not yet available, despite this being a basic requirement for erosion hazard zone mapping.

The flood zone data was refined to include just the coastally-influenced floods by including '*Fluvial/Tidal*' and '*Tidal Model*' type floods from the 23 classes of flooding recorded in the EA Flood Zone data (Environment Agency, 2020). The quality of this dataset is uncertain due to isolated and apparently spurious tidal and coastal flood zones appearing inland as far as North Newark; these were removed from further analysis. The Flood Zone dataset takes no account of existing defences. The Risk of Flooding from Rivers and Seas (RoFRS[5]) dataset was also evaluated. This is based on a 50 m grid and does not include an attribution of the flood source but does consider the protection afforded. Accordingly, the level of flood risk categories (high, medium and low risk) from this dataset was used within the calculation of '*annual damaged for residual risk events'.*

3.1.2 Modelling Data

The CoastalRes project generated a 'wish list' of hypothetical datasets that stemmed from a conceptual model of coastal community resilience. This approach included a set of 'performance questions' and associated 'performance measures' that can be used to assess how well a given set of policy options deliver enhanced resilience. It was then necessary to map the desired measures onto datasets that actually exist and are also freely available. This process was undertaken at two levels: firstly, for the pilot study sites and, secondly, at the national level. The availability of data and the attributes within these datasets was explored, based on knowledge from coastal management experts, coastal managers and via internet searches.

Given the large number of potential sources of data pertaining to some properties of resilience, the 'wish list' of data sources was subjected to an initial scoring process using a scale of 1 to 5 across six categories: whether the measure is direct or a surrogate; data class; resolution; geospatial quality; the availability of historical data; and precision. Improvements or alternatives to the lowest scoring

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[1] https://data.gov.uk/dataset/0c492f70-8d54-42d9-ba2c-23cd2e513737/shoreline-management-plan-mapping
[2] https://data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021
[3] https://data.gov.uk/dataset/cf494c44-05cd-4060-a029-35937970c9c6/flood-map-for-planning-rivers-and-sea-flood-zone-2
[4] https://www.deltares.nl/en/software/aqua-monitor/
[5] https://data.gov.uk/dataset/bad20199-6d39-4aad-8564-26a46778fd94/risk-of-flooding-from-rivers-and-sea

categories of each dataset were targeted and selections were then based on the most suitable data for the resilience property being addressed.

This exercise showed that some of the desired datasets did not exist or were not freely available at a national scale. For example, numbers of people impacted by flood or erosion events had to be obtained from literature or secondary sources for the pilot study. Measures based on flooding/erosion events, such as '*number of lives lost*', '*number of displacements*' and '*annual average cost of replacing properties*' were challenging to obtain even at a local level. Consistent data on defence standards were also difficult to source. Where there were unresolved data gaps, or where access to a known licenced dataset was not possible within the project timescale, the relevant data were highlighted as a priority for future acquisition and removed from our preliminary national analysis.

Some information was easier to obtain at a national scale. One example is the distance to hospitals. This was measured manually, changed to 'access scores', with multiple hospitals within 30 km scored according on their distance to an Output Area centroid and then summed. Similarly, the desired 'value of infrastructure' measure was replaced by an 'infrastructure density' dataset based on Points of Interest[6], which described all infrastructure within a study area. A number of processing decisions were made to convert the raw data into information that related to the required performance measures. These details are summarised in Section 8.1.

Given that the CoastalRes pilot studies were intended purely as illustrative demonstration cases, the modelling of scenarios and policy pathways was deliberately kept simple, using a limited set of data which was partly based on best estimates. At the national level, development of future scenarios was also beyond the scope of this short-duration project and the modelling undertaken here is therefore restricted to capturing the current state of coastal resilience.

3.1.3 Linear versus Area-based Processing

The original SMP approach developed a set of the policy options for a set of Policy Management Units (PMUs) based on segmenting a vector dataset of coastal cells and sub-cells (Townend et al., 1995). This shoreline vector dataset was subsequently developed inconsistently in the roll out of individual SMPs, but the 'line' was defined as close to the top of defences where these existed and the Mean High-Water Mark where the coast was undefended. However, no standard for this PMU dataset was generated nationally within the Shoreline Management Planning process. The datasets that are available have several basic GIS errors (duplications and digitisation errors) and attribution duplications (e.g. units with the same notation in different Coastal cells). An early approach adopted within the first SMP for the South Downs (Selsey to South Foreland) was to use a linear reference system, which attached the location and attributes of coastal elements to a coastal chainage line (using ChainMap GIS software), in accordance with an approach adopted earlier in the East Anglia Anglian Coast Sea Defence Management Study. The use of linear referencing was considered for the development of the coastal resilience mapping within CoastalRes, but it was felt that separate indicators of resilience presented in the context of their full spatial extent would be more intuitive and easier to communicate to stakeholders.

3.2 Data Collection and Processing

To resolve geographical variation in resilience, the hazard zone had to be split into recognisable areas which are managed individually. Candidate spatial units based on SMP sediment cells and PMUs were considered, but these do not represent how the coastline is managed inland. Instead, the hazard zone

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[6] https://www.ordnancesurvey.co.uk/business-government/tools-support/points-of-interest-support

was split into Output Areas (OA), the smallest unit of census reporting (ONS 2011). These were developed specifically for statistical purposes, meeting confidentiality thresholds and consistency in the number of households per OA. Many of the datasets used in the model, such as census data and deprivation indices use OA for reporting. Data reported at the Lower Super Output Area (LSOA) level were aggregated to the OA areas. The coastal OA units extend seaward (to map the administrative boundaries to the 'extent of the realm') and required clipping to the shoreline to provide area polygons that do not include areas seaward of the shoreline.

3.2.1 Coastal Archetypes and Output Areas

The development of coastal community archetypes formed part of the initial methodological development of the coastal resilience model. Coastal archetypes have been used to characterise coastal adaptation pathways (Hasnoot et al 2019) based upon a restricted set of typical system types. The classification of a basic set of estuarine and open coastal archetypes combined with the degree of development (urban and rural) and social characteristics (deprived and not deprived) generated eight archetypes within which to compare the quantitative measures of resilience.

The England OA boundaries (ONS 2011) are clipped to those adjacent to the shoreline and attributed with the deprivation data from the Index of Multiple Deprivation (IMD; 2011) [7] and the urban/rural classification derived from the Local Enterprise Partnership Rural / Urban GIS Shapefiles (Census 2011) classification of the Outputs Areas. The distinction between open coast and estuary was based on the Coastal Physiographic Features – Estuaries (05.18[8]). Estuary is defined within Habitats Directive Annex 1 H1160 - Large Shallow Inlets and Bays. Some OAs include both estuary and open coast and their classification is rather subjective; here a simple threshold of 50% was set where 'Estuary' OAs were defined as those which have a longer length of estuarine than open coastal shoreline. The IMD ranks all output areas by deprivation and divides them into 10 equal groups (or deciles) according to their rank. In this study, deprived status within the IMD is defined as the lowest two deciles of the IMD dataset. Archetypes have only been mapped for those OAs that are immediately at or adjacent to the coast or estuary.

3.3 Data limitations and improvements

3.3.1 Hazard Zone

Before manipulating the erosion and flood data to define the hazard zones, the SMP line had to be improved due to breakages and overlaps. This required creating a topology to snap and remove lines and create a single multipart continuous line. This line was smoothed so that sharp changes in the shoreline would produce erosion points that were landward. It should be noted that London was excluded from the preliminary national mapping as it was not included in the SMP process. All datasets, other than those that include defences, include London, and its inclusion should be a priority for further work. It is important to note that, as with the original SMP line, the accuracy to which the line reflects the actual 'coastline' is debateable and therefore suitable for strategic level use only.

Another limitation is the removal of OAs within the hazard zone that are more than 1 km from defences. The model requires each OA to have information on defence condition and residual life. This can be attached to the nearest defence, but in areas of the hazard zone that are distant from the defence it may be unclear which defence is most critical for protection. An arbitrary value of 1 km

[7] http://dclgapps.communities.gov.uk/imd/idmap.html
[8] https://data.gov.uk/dataset/225fb0e1-5cfd-43fa-a6bf-c108091f3825/coastal-physiographic-features-estuaries

away from the defence was used to attach defence data for that OA. Any area outside this buffer was removed from further analysis.

3.3.2 Modelling Data

A summary of each dataset in the resilience model, limitations, improvements whether it was included in the national model, can be found in Section 8.1. The following datasets merit special mention due to their importance within resilience assessment and the need for improvement:

Property count / % homes with no insurance – both datasets require accurate estimation of the number of properties and categories of properties. Here, building vector count is used, which positively skews the final count. *AddressBase PLUS* [9], from the Ordnance Survey, is a potential source, but as a commercial product did not meet the principles of use of open data and would require additional negotiation with OS to licence for the project.

[Strategic] Infrastructure data - Created using a point density of Ordnance Survey's '*Points of Interest*'[10], this dataset includes points that do not always relate to infrastructure, such as lakes and ponds. The refining and extraction of purely infrastructure points should be considered. This dataset was added to the measure '*Exposure to Risk (Avoidance)*'. This addition minimised the weighting of the dataset and the others within this measure. A consequence of this is that the presence of crucial infrastructure, such as nuclear power stations that arguably make an area significantly less resilient, may not be reflected within the overall resilience index value.

National defence standard and condition data - (which are used within the inferred Residual Risk model) are not complete. Where defence standard data were missing, a national average design standard and condition were transferred to a secondary dataset, which included the location of national defences. Defence information is crudely attached to hazard zones within 1 km of the defence. Any hazard zones outside this buffer were removed from the analysis as they could not be accounted for with a reasonable degree of certainty. Future improvements should be directed towards finding out which areas are defended (i.e. benefiting areas related to defences), so that their criteria can be forwarded to the appropriate hazard zones.

Priority Habitat Areas – This dataset is hugely influential within the resilience model, especially when considering resilience from an environmental perspective. The objective of minimising 'habitat loss' is entirely described by these data, and it describes 47% of the resilience index value for the environmental perspective (see Section 8.2). These data summarise the total area of priority habitats both within the hazard zone and the area of priority habitat that lies within the output area offshore. Once a function of the output area has been taken, this results in large percentages for small output areas within the hazard zone in those areas with offshore habitats. Within the analysis, percentages are capped to 200% to allow a sensible scoring process. Coastal habitats, such as mudflats and saltmarshes, are closely related to managed realignment and can form a natural coastal defence system. These were spatially joined to coastline OAs, which means that these areas have a considerably greater resilience compared to inland areas. Further consideration of how intertidal habitat relate to landward resilience measures is needed.

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[9] https://www.ordnancesurvey.co.uk/business-government/products/addressbase
[2] https://www.ordnancesurvey.co.uk/business-government/tools-support/points-of-interest-support

Fire/Hospital Access Score – As with to Priority Habitats, this dataset can be very influential in the model, accounting for 47% of the social resilience perspective. The output from the dataset produces a largely urban/rural distribution, which describes access in terms of Euclidean distance to hospitals. Urban areas, which are more likely to have a higher density of emergency services, score more highly. Future improvements should be directed towards driving or average call-out times at each area.

4 Coastal Resilience Model (CRM)

Our national resilience model contains a total of 8,382 OAs within the hazard zone. For each of these, the current state of resilience is modelled based on the combination of social, environmental and economic indicators. The raw output at this level includes small and narrow zones along the coastline, which are difficult to visualise nationally. Aggregation to larger regularly-shaped areal units was used to achieve more effective visualisation. Discrete global grids (Sahr et al., 2003) use hexagons to reduce sampling bias and these also offer the ability to follow the coastline without producing gaps within the data. This is related to the low perimeter to area ratio of hexagons when compared to Cartesian grids[11]. A hexagonal tessellation, specifically positioned to the national area, was created and OA resilience index values were aggregated to each hexagon.

4.1 Outputs

The main output from the CRM is a set of national coastline resilience. These incorporate the various stakeholder perspectives (Economic, Social and Environmental) considered within the CoastalRes project. Resilience maps that represent a combined viewpoint were also generated, based upon an arithmetic mean of the individual perspective resilience values. More comprehensive maps of pilot study areas under each perspective were also synthesised. Mean resilience index values were calculated to summarise the data for each coastal archetype (see Section 8.3). The classification of coastal archetypes requires OAs to be located along the coast, therefore inland output area resilience scores are not included in this analysis.

4.1.1 National (Aggregated) results

National resilience under the combined perspective has an average index value of 62.2, with minimum and maximum bounds of 33 and 88. The index is higher under the economic and environmental perspectives, but the social perspective gives a national resilience index value of just 56.5. Economic and social perspectives result in similar, normal distributions of resilience (see Figure 1).

[11] https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-whyhexagons.htm

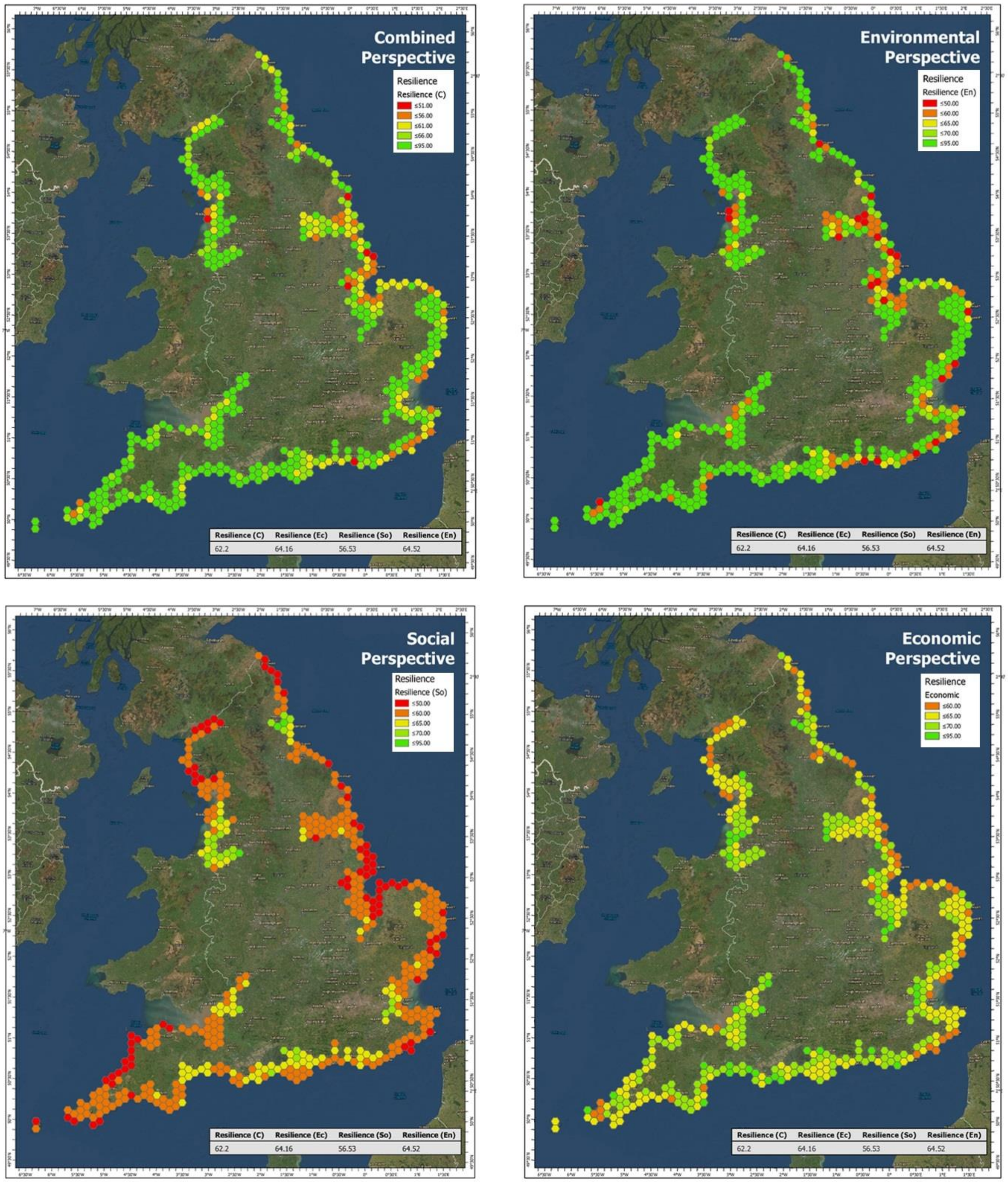

Figure 1. Individual and combined Resilience Indices for the coast of England. Hexagons are 90km^{2}and represent a mean calculation for all output areas within the hexagon. National mean values for Combined (C), Economic (Ec), Social (So) and Environmental (En) perspectives are also shown.

Resilience based upon an environmental perspective has both the highest and lowest resilience index values and large standard deviation (Table 1 and Figure 2), as well as demonstrating a bimodal distribution. A strongly bimodal distribution is evident for the combined perspective, with peaks at index values of 51-54 and 72-75.

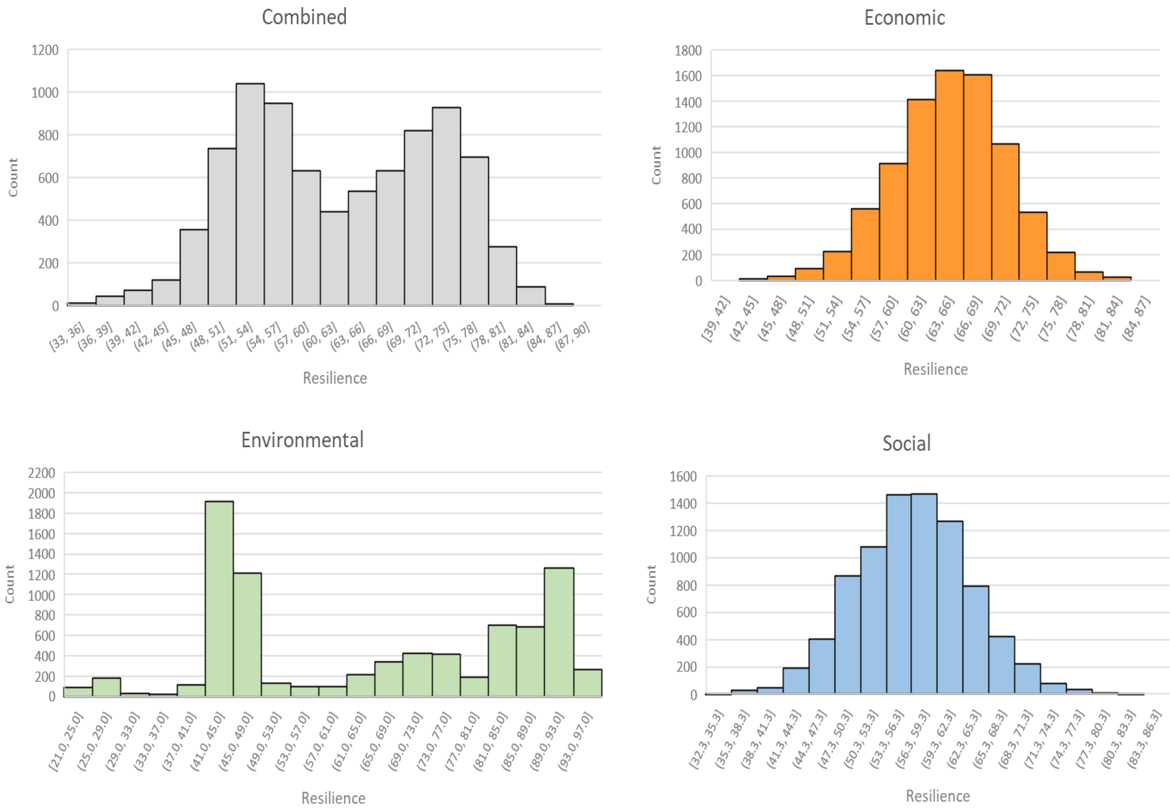

Figure 2. Distributions of resilience scores across England under the combined, economic, social and environmental perspectives

Table 1. Resilience Index Summary Statistics for each perspective

Perspective	Min	Mean	Max	Standard Deviation	Range
Combined	33.1	62.2	88.2	10.5	55.1
Economic	38.6	64.2	84.1	6.0	45.5
Social	32.3	56.5	83.6	6.7	51.2
Environmental	21.0	64.5	95.7	20.9	74.7

Along the south coast, the coastal areas of Kent and East Sussex demonstrate a lower combined resilience score below 56. Here, large distances to emergency services coupled with a number of strategically important infrastructure points (e.g. power stations) reduce the resilience of the area. Output areas here, continue to show a reduced resilience score under each perspective. Lower than average scores of recovery time (deprivation and insurance) result in the lowest resilience score under the social perspective - ~45.

Despite high erosion rates, resilience along the North Norfolk coast remains close to the average. High environmental resilience scores keeps this figure high, in spite of the low social scores. Alongside this, output areas at The Wash demonstrate a mixed variety of resilience scores, the lowest resilience areas along the coast, where measures 'habitat loss' and 'response time' reduce the resilience. Further inland, output areas consistently have large areas of priority habitats which translates some of the highest resilience scores under the environmental perspective (~90).

Patterns of high economic and low environmental and social resilience persist along the east coast where resilience scores lower than 56 are common up to the Humber. The low scoring of small and frequent output areas in dense urban areas negatively skew the mean and reduce the resilience at Grimsby and Hull. Though surrounding areas have relatively high resilience scores from large priority habitats, these are often large output areas that are represented by a single value when aggregated to the hexagon.

Generally, the resilience north of the Humber to Scotland is above average, the exceptions being Hartlepool, Sunderland, Blyth and South Berwick. Environmental resilience consistently scores lower than the other perspectives. Changes in social resilience here, like the rest of the map, shows a correlation with urbanised areas. The highest scoring across the nation include cities such as Southampton, Bristol, Liverpool and Newcastle suggest a high accessibility around cities. The measure 'response time', which consists of emergency service access scores, accounts for 47% of the resilience score under the social perspective. Due to the high influence of this data under the social perspective, it is crucial that the scoring process is suitable. Perhaps the lower social scores when compared with Economic and Environmental perspectives are an impact of a lower scoring for this data. An adjustment to the dataset from euclidean distances to driving travel times or average call out times should be made when improving this model to prevent an urbanised skew.

A varied level of resilience under the environmental perspective can be seen on the North West coastline of England, but with more areas that have lower resilience scores; Blackpool and outer Morecombe Bay proving the least resilient. Though urbanised, Barrow in Furness and Morecombe both have low social resilience. Low scores for measures 'Exposure to Risk' (Avoidance and Protection) reduce the resilience of this area.

Combined resilience along the coastline of the Bristol Channel is high relative to the rest of England. Low environmental scores in Chittening (Avonmouth) and low social scores in Western-super-mare prevent these areas from scoring higher than their surroundings. Along this coast the hazard zone has minimal erosion or flooding (Figure 3), therefore although St Ives and Leswidden score below average, there is no cause for concern. Higher erosion rates at Penzance, a lack of priority habitats and urbanisation drive down the scores for 'Exposure to Risk' and 'Habitat Loss' and reduce overall resilience.

Figure 3. Low erosion rates resulting in small hazard zones at St Ives

4.1.2 Local results: Barton-Highcliffe, Dorset

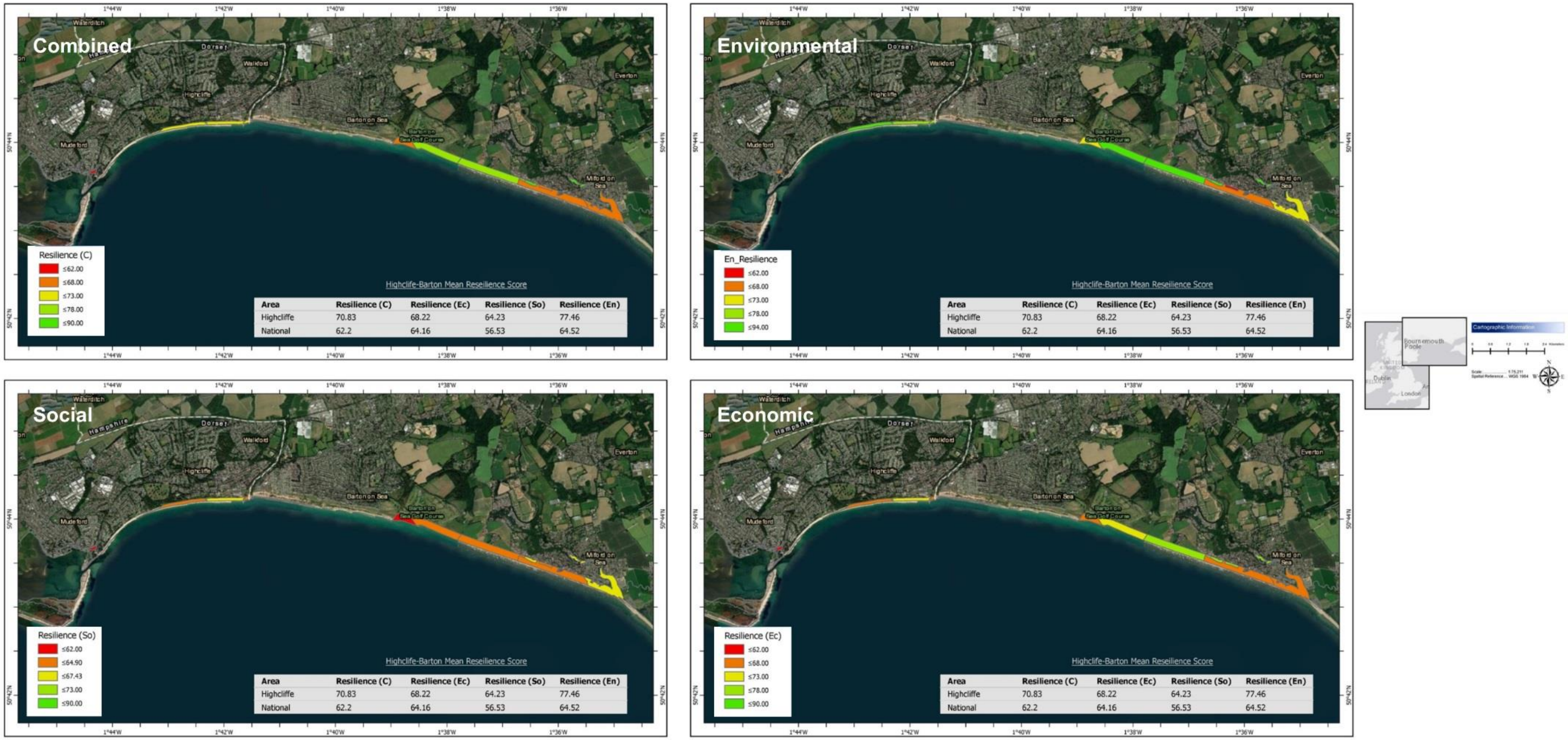

Figure 4. Individual and combined Coastal Resilience Indices for Barton-Highcliffe. Local and national Resilience Indices are compared in the table

Barton to Highcliffe is very resilient under all perspectives with a score 8 higher than the national average (Figure 4). The dominating hazard is erosion, which is more extensive at Milford than Highcliffe. A large erosion zone at Milford extends into the town which is also at risk of flooding. The resilience at the Milford coast is consistently scoring 62-68 under each perspective. Resilience improves inland due to the habitat areas on the flood plain. The rural coastline between Barton and Milford is highly resilient due to the lack of urbanisation and because behind it lies a local golf course. A reduced social score here can be attributed to the lack of defences or habitats. The small hazard zone at Highcliffe is permanently above the national average, and very resilient under the environmental perspective.

4.1.3 Local results: Portsmouth, Hampshire

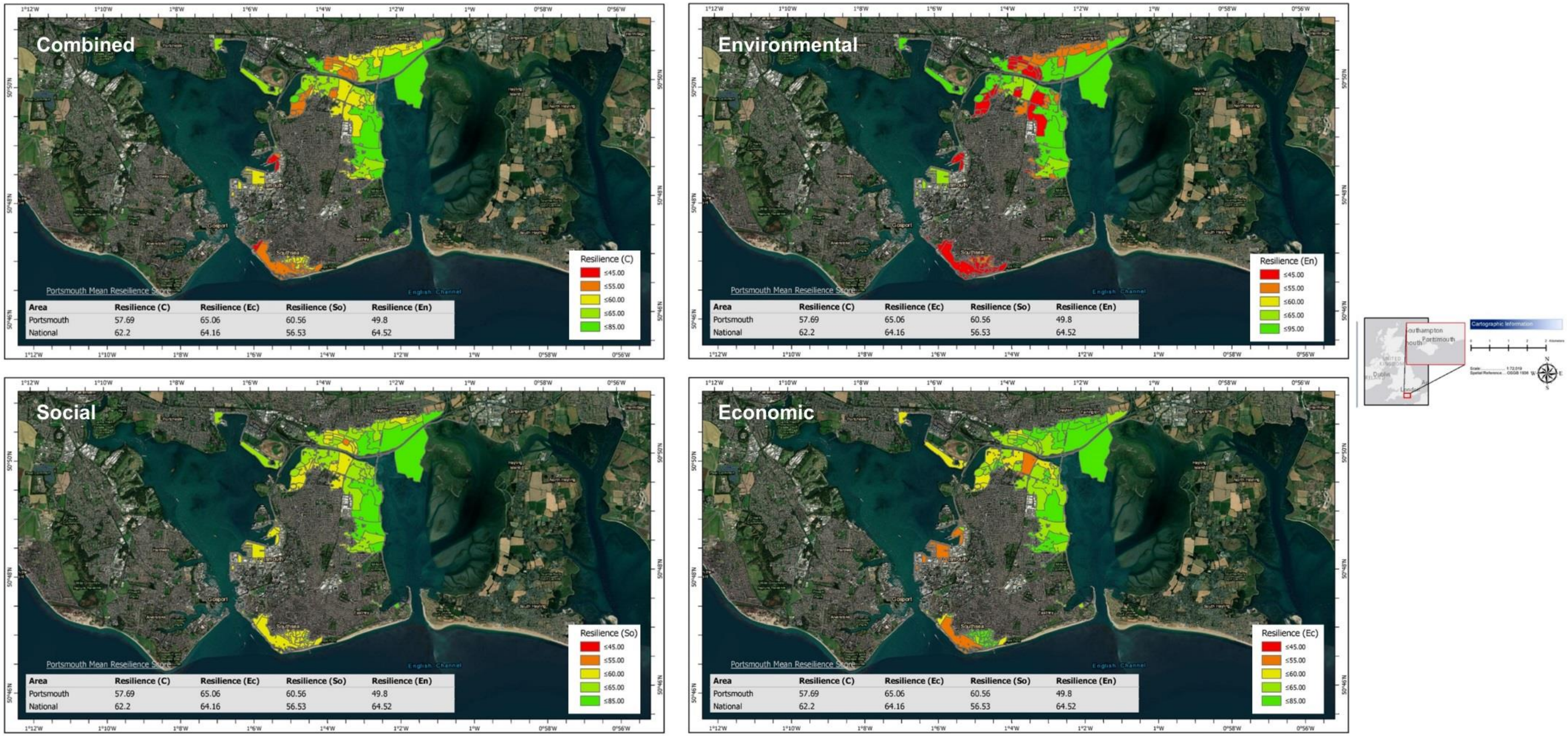

Figure 5. Individual and combined Coastal Resilience Indices for Portsmouth. Local and national Resilience Indices are compared in the table

There is large variation in resilience at Portsmouth, with high scores at Farlington and low scores at Southsea that is less resilient than the national average (Figure 5). Dense urbanisation increases the exposure to hazard and the residual risk despite a high level of protection from defences. This results in considerably lower scores from the economic perspective. Very low resilience under the environmental perspective for output areas in the centre of Portsmouth due to a lack of habitat areas reduces the overall score.

4.1.4 Local results: North Humber, Humberside

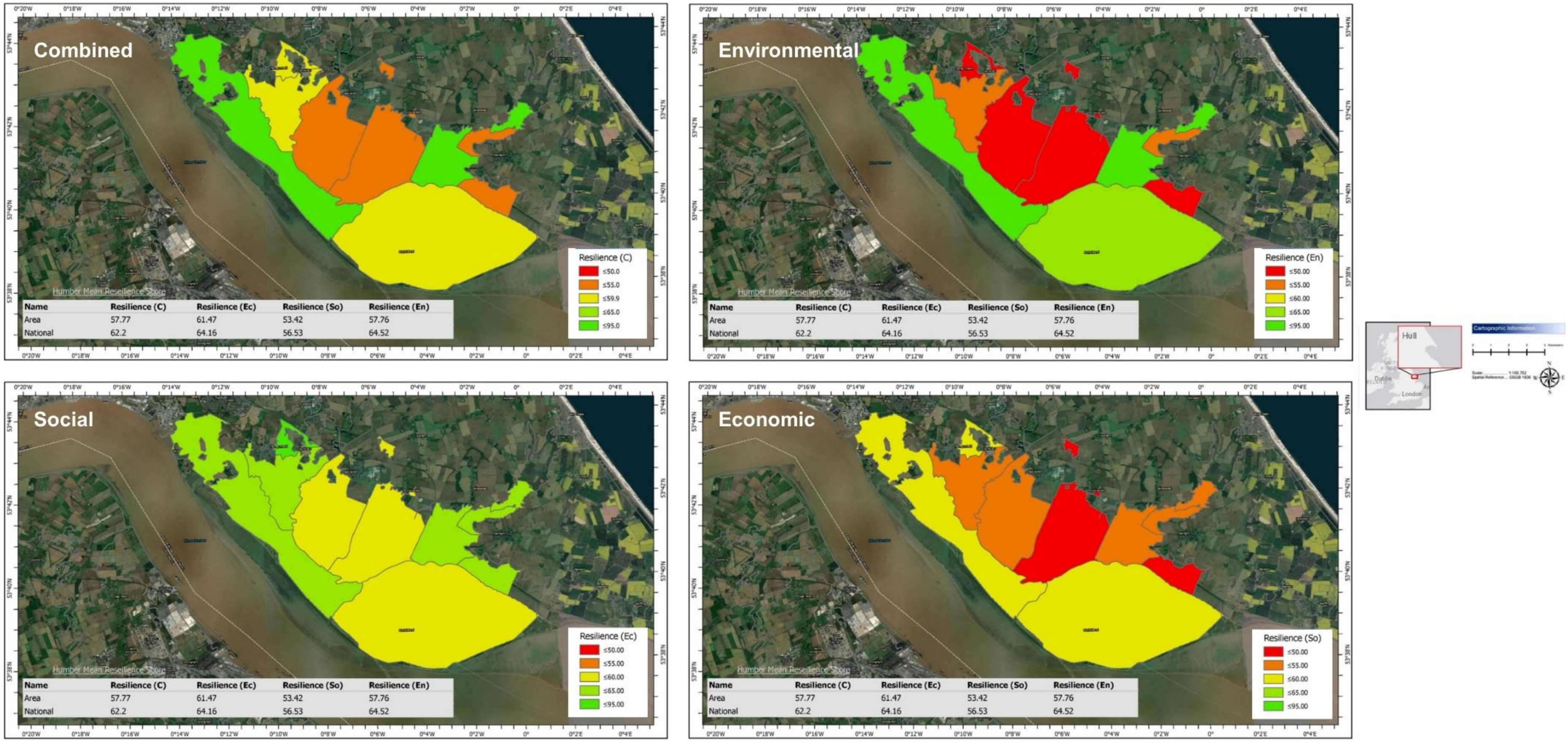

Figure 6. Individual and combined Coastal Resilience Indices for North Humber. Local and national Resilience Indices are compared in the table

North Humber is less resilient than the national averages under every perspective (Figure 6). Despite the wide coverage of offshore habitats which accredit high scores to coastal output areas, a lack of habitats inland reduce the resilience at Keyingham and Winestead. Emergency service data describes the measure 'Response Time' which accounts for 17% of the combined resilience score. Therefore rural inland areas which are distant from emergency services reduce resilience. Various strategic infrastructure points, a couple of local wind turbines, and a large number of 'properties' further reduces its resilience. The buildings layer, which inferred property density, positively skews the number of properties which are present on the Humber. Farming areas often have multiple buildings and are often described by multiple points (Figure 7).

Figure 7. Building points inferring property coun

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4.2 Lessons from national implementation

The shoreline dataset to clip output areas and create the hazard zone, needs refining at national levels and expansion to include the Thames (London), Wales, Northern Ireland and Scotland. Up to date and accurate erosion data is also essential in defining the hazard zone. There is a need for an open data national standardised defence layer with all attributes completed round the coast, on an effective geospatial model. A generalised defence layer with levels of defence and standards is needed to include all areas within the flood zone that are impacted by coastal / tidal floods. A data structure and programme for capturing the impacts of hazard events (deaths, displaced, health impacts of events, insured and un-insured) is essential to include the historical elements of coastal flooding and erosion impacts. No current dataset has been identified that collates this information, although it is likely that the data are collated by multiple agencies, insurance companies and responders. The failure of the model to incorporate population density or driving time within emergency access is likely to alter resilience under the social perspective and currently results in a national urban skew. The influence of strategic infrastructure, e.g. large scale power stations, within the objective 'Exposure to Risk (Avoidance)' is currently minimised due to the presence four datasets within this objective. Summarising habitat coverage as a percentage of hazard zone can result in large percentages due to the inclusion of offshore habitats. This benefits coastal output areas and increases resilient but disregards inland areas. These areas, often coincide with managed realignment which was not included in the analysis.

5 Next Steps

A series of steps are identified to improve the data and processing steps for future analyses of coastal resilience. These include:

1. A sensitivity analysis of the scores and weighting process and subsequent impact on the resilience values is needed to explore how changes in the data impact the model outcomes.
2. The scores and weighting process forms a crucial component of the resilience model and more extensive evaluation of this with local and national stakeholders and decision makers is required. This could be achieved through online consultations to build and validate the results.
3. Sourcing or developing a complete coastline dataset that includes the Thames (London), Wales, Northern Ireland and Scotland should be a priority.
4. Additional data and indicators should be considered. National coverage of an open defence dataset that defines attributes of the standards of protection would allow a full national coverage. Additional data, not used within this pilot or national model phase should be further evaluated for inclusion, such as National Receptor Data / Address Base Plus.
5. If the Coastal Resilience Model is fully operationalised, it would be advantageous to develop a consistent data structure and recording protocol for additional indicators, such as economic damages, costs of clean-up, insurance cover, loss of life, displacements etc.
6. The creation of a graphic user interface to allow users to explore different scores, weights, stakeholder perspectives and scenarios is needed. It would also be useful to have a tool that allows reconfiguration to allow additional datasets to be added to the analysis according to local requirements and stakeholder needs.

These recommendations should be considered alongside those provided by Townend et al. (2020)

6 Open Data outputs

The data outputs from the project include data and metadata / INSPIRE compliant records. Data are hosted within the Channel Coastal Observatory (CCO). Three key dataset outputs have been generated

1. Coastal combined hazard zone (combining flood zone data and erosion prediction data)
2. Coastal Archetypes (LSOA)
3. National resilience model runs at OA level
4. National model runs aggregated with different perspectives

7 References

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8 Supporting data

8.1 Coastal Resilience Model data inputs, sources, comments and improvements

Summary of national Coastal Resilience Model data inputs, sources, comments and improvements. This table indicates whether the data and indicators have been used within the context of the pilot case study and/or national models, and also describes the processing workflow and the potential for data improvements.

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
Human Health	**Pilot** - Remove for National Model	No. of reported lives lost in N events No. of reported injuries in N events No. of reported health issues in T years	Not available at local level. 1st CCRA report on flooding - National Dataset – used as a function of hazard zone areas within the Pilot study	None	Recommended for future collection
Response Time	**National model** (New Dataset)	Hospital Access Score Fire Access Score	Use of population weighted centroids in Output Areas (2011) to define euclidean distance to service. Distance converted to score through a Logarithmic point scale. 0-4km =14pnts 4-8km = 10pnts 8-12km = 7pnts 12-20km = 3pnts >20 km=1pnt. Some Output Areas had no pop weighted centroid and were removed from the analysis.	*Generate near table*: Input: Population Weighting Centroids Near = Hospitals/Fire Stations Radius = 20km (Geodesic) *Add field > Calculate field* (see left) *Join field* (via output code) *Dissolve* (by output code) + sum scores	Use traffic travel data and average call out time to refine scoring process
Recovery Time	**Pilot + National Model**	% homes with no insurance cover	Used LIVING COST AND FOOD SURVEY data on tenure and insurance [1]. Data includes % of properties which have no insurance premium by tenure type. <u>Data Calculation example:</u>	In EXCEL. Open Census tenure (2011) data Multiply tenure count by % no insurance (+shared ownership to owned)	Find up-to-date address data which categories by tenure type

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
			Output area = E00***** Owned properties count = 14 Owned Properties = 16% with no insurance Owned, no insurance = 2.24 Combine with; Owned, Social, Private Rented and Rent-free.	Calculate total properties Divide by total no insurance. *Join field* (via output code)	(Ordnance Survey *AddressBase Plus*)
	National model (New method)	Deprivation Decile	Index of Multiple Deprivation categorised output areas by deprivation decile. Smaller decile = more deprived. Higher weighting on deciles 1-3. Inclusion of all deprivation scores (instead of the lowest two within the pilot study)	*Spatial Join* IMD data (originally in LSOA). One to many	Maintain
Displacement	**Pilot** - Remove for National Model	No. of days displaced from property in T years	Not available at local level.	None	Recommended for future collection
		No. of homes abandoned in T years			
Preparedness 1	**Pilot** - Remove for National Model	Availability of broadband	Data not downloadable at national level.	None	Remove from model
		4G coverage			
		No. of households signed up to EA flood alerts	Data not available.	None	Recommended for future collection. Possible source: https://www.gov.uk/check-flood-risk
		Event or location specific emergency response exercise in last 10 years			

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
Preparedness 2	**Pilot** - Remove for National Model	Adequacy of coverage and standard of monitoring (high/med/low) Adequacy of coverage and standard of defence maintenance (high/med/low)	National Data is limited	None	Recommend future collection
Exposure to Risk (Avoidance)	**Pilot + National Model**	Population in the hazard zone	Extracted count of population from OpenPopGrid [2] – a gridded population dataset from GeoData Institute based on Office of National Statistics data (2011). Population count aggregated to output area boundaries. Population per km^2 calculated	*Extract by mask* Input raster: OpenPopGrid Input feature: Hazard Zone	Maintain
	Pilot + National Model	No. of properties in the hazard zone	OS Open Vector district 10.19 – Buildings layer used to create a point dataset of buildings. It is assumed all buildings are properties. Properties per km^2 calculated	*Repair geometry* *Merge* – OS vector buildings (from each British National Grid Zone) *Feature to* point - OS buildings *Spatial Join* – Buildings to hazard zone. Join count = buildings count	Find up-to-date address data which categories by tenure type (Ordnance Survey *AddressBase Plus*)
	National model (New Dataset)	Infrastructure Point Density	Use of Ordnance survey '*Points of Interest*' Point count within output area hazard zone Infrastructure point density per km^2 calculated	*Select by attributes* – strategic infrastructure (export + delete) *Spatial Join* – points of interest to hazard zone Join count = infrastructure count	Group infrastructure points based on; Essential, needed, not needed, and not important – by

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
					independent body. Currently includes all points which may not be defined as 'infrastructure'
	National model (New Dataset)	Strategic infrastructure Point Density	Use of Ordinance survey '*Points of Interest*' Extraction of: **() = pointX code** Railway stations, junctions and halts (10570738) Accident and emergency hospitals (05280780) Energy Production (07410534) Airports and landing strips (10530728) Point count within output area hazard zone Strategic infrastructure point density per km^2 calculated. Note: dataset contains individual wind turbines therefore point density is skewed	*Select by attributes* – strategic infrastructure (export) *Spatial Join* – points of interest to hazard zone Join count = strategic infrastructure count	Refine wind turbines into a single point. Ensure all critical points are collected.

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
Exposure to Risk (Protection)	**Pilot + National Model**	Design standard (1 in N years)	Environment Agency Flood defences Data [3]- Defences owned, managed or inspected by the EA (updated: 19/12/19). Some defences not included therefore a complete dataset of defence position (CCO) [4] (without information on design standard or condition) was added. For those defences with no data, standard and condition information is assumed the same as other defences less than 1km from the original EA defences dataset. Any defences still without data, are assumed the average (mean) condition/standard to the original EA defences data. This was the following; design standard=223.8, condition = 2.61. Defence data is spatially joined to output areas within 1km of the defence. If no defence is within 1km, the output area is	*Select by location* Target = CCO, Selecting = EA. Delete defences. *Spatial Join* Output (above) + EA (within 1km) 'design standard' + *'condition'* *Merge* Output (above) + EA defences *Select by attributes* Condition = NaN *Calculate field* Condition = 223.9, Design standard = 2.61 *Calculate field* Residual life (see left) - see *'exposure to Risk (P)' folder for ArcGIS code*	Add comment on uncertainty of data – was the design standard/residual life inferred? This dataset is updated on a semi-regular basis (6-month in 2019). Explore how each defence impacts the surrounding environment – which output areas does it provide protection for?

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
		Residual life	removed from the study as it becomes too uncertain about which defence is defended which area. <u>Residual life</u> was subjectively categorised based on a function of defence condition: 50 > 1 - Very Good - Cosmetic defects that will have no effect on performance 40 > 2 - Good - Minor defects that will not reduce the overall performance of the asset 25 > 3 - Fair - Defects that could reduce performance of the asset 10 > 4 - Poor - Defects that would significantly reduce the performance of the asset. Further investigation needed 5 > 5 - Very Poor - Severe defects resulting in complete performance failure.		Maintain
Exposure to Risk (Residual)	**Pilot + National Model**	Annual damages for residual risk events	Number of buildings (see exposure to risk (avoidance)) *average loss per property in a flood [5] * Probability of event. + Infrastructure Count (see exposure to risk (avoidance)) *average loss per infrastructure in a flood [expert estimation] * Probability of event. <u>Probability of event calculation</u> Determine largest risk area within the hazard zone classed as high/med/low/vlow using Flood Risk model data [6].	*Calculate field* = property count * £25,000 * probability = infrastructure count * £12,500 * probability	Repeat analysis using more accurate property data. Recommend the collection of *'average loss per property'* at a regional scale. Recommend the collection of

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
			Erosion-dominated zones (>20m long term rate under shoreline management plan) supplemented the *'high'* flood risk category – "each year, there is a chance of flooding of greater than 1 in 30".		*'average loss per infrastructure type'* at a regional scale.
	National model (New Dataset)	Deprivation Decile	Index of Multiple Deprivation categorised output areas by deprivation decile. Smaller decile = more deprived. Higher weighting on deciles 1-3.	Spatial Join IMD data (originally in LSOA). One to many	Maintain
Exposure to Risk (Financial)	**Pilot** - Removed for National Model	Value of insurance claims in T years	Data not available.	None	Recommended for future collection
Economic damage	**Pilot** - Removed for National Model	Annual Average cost of repairing or replacing property	Data not available.	None	Recommended for future collection
		No. of homes in lowest 2 decile of deprivation index protected by defences	Minimising duplication of deprivation data within the model	None	Remove from analysis
		Annual Average cost of repairing or replacing infrastructure	Data not available.	None	Recommended for future collection
Economic disruption	**Pilot** - Removed for National Model	Annual Average cost of clean-up, demolition, loss of business, etc	Data not available.	None	Recommended for future collection
Habitat loss	**Pilot + National Model**	Priority habitat area	Priority Habitat Inventory data used to include inshore and offshore habitats. Offshore habitats are described by those output areas that lie within output area boundaries (pre- shoreline clipped). Small output areas with large offshore associated habitats have a very large % over 100. The	<u>*Intersect*</u> – Habitats and output area polygons (pre-shoreline clipped) *Dissolve* and sum area with same output area code. Divide output area by total priority habitat zone.	Maintain

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
			scoring process of the model centres an XY coordinate of 15, 80. I.e. an area with 15% habitat outputs a resilience score of 80/100.		
	Pilot - Removed for National Model	Shoreline habitat (foreshore & backshore)	Priority Habitats included shoreline habitats so was unnecessary	None	Remove from analysis
Disruption of natural system	**Pilot + National Model**	Defended length of shoreline (%)	<u>(1) Defended Length</u> / shoreline length *100 Hard defended areas [8] used to define 'defended'. Defences described as hard include: (*=wildcard) *Beach – Embankment, Breakwater, Cliff – Groyned Beach, Cliff – Rock Revetment, Cliff – Seawall – *, Embankment, Groyned Beach, Other hard Defence / Structures, Piling, Rock Revetment - *, Seawall - *.* Defence split into 10m intervals and output area code transferred to each segment. Total defence length = Sum (all 10m defence segments) <u>(2) Shoreline Length</u> Hazard zone converted to lines. Lines which intersect with shoreline management line extracted. Shape length and geocode maintained and joined to original hazard zone polygon Those > 100% reclassed as 100%	*(1) Add field* – Hard defence *Calculate field* – see ArcGIS code '*Disruption of natural system*' folder. *Select by attribute* 'Hard' defences *Generate points along lines* - 10m intervals *Split line at Points* - Hard defences line *Spatial Join* – Output (above) + Hazard zone. *Dissolve* – by output area code + sum 10m segments *(2) Feature to line* – Hazard zone *Select by location* - SMP line + hazard lines. Export hazard shore length data by OA code	Maintain

Objective	Inclusion for Pilot /National Model	Data	Methods / Comments	Processing Steps	Data Improvements / Future Recommendations
Social acceptance	**Pilot** - Removed for National Model	Acceptance of coastal resilience plan - Status of SMP/CRP (3-part of Local Plan,2- approved plan, or 1-reference document)	National Data exist within reports, creation of the dataset requires a manual collection procedure of information from each individual council.	None	Recommend future collection

8.2 Scores and Weights

This table contains information on units and statistics for each metric using a minimum, maximum and central xy positions which score each dataset. These score limits were subjectively defined, and can completely change the final resilience score. Therefore it is crucial that the scoring and weighting process is evaluated with local and national stakeholders – this is noted within 'next steps'.

There are two levels of weighting, one at the measure and one at the objective. I.e. 'Hospital Access Score' and 'Fire Access Score' have equal weighting and are both multiplied by 0.5, to create the objective 'Response Time'. 'Response Time' is then multiplied by the final column (objective weight) of 0.17. This was the weight created by an average of social, economic and environmental stakeholders.

Dataset	Unit	Score Limits (Min-x, Central-x, Max-x, Min-y, Central-y, Max-y)						Metric Weight	Weight (C)	Weight (Ec)	Weight (So)	Weight (En)
Hospital Access Score	dimensionless	2	28	263	0	50	100	0.5	0.17	0.09	0.47	0.03
Fire Access Score	dimensionless	15	28	518	0	50	100	0.5				
Homes with no insurance cover	%	100	50	0	0	50	100	0.5	0.10	0.08	0.17	0.07
Deprivation Decile	Decile (1-10)	1	3	10	10	50	100	0.5				
Population Density	No./km2	80301	40150	0	0	50	100	0.4	0.18	0.26	0.07	0.19
Property Density	No./km2	1512	756	0	0	50	100	0.3				
Infrastructure Density	pnts/km2	6811	3405	0	0	50	100	0.15				
Strategic Infrastructure Density	pnts/km2	21.67	0.05	0	0	0.05	100	0.15				
Design standard	1:N	0	50	1000	0	50	100	0.5	0.16	0.28	0.17	0.05

Dataset	Unit	Score Limits (Min-x, Central-x, Max-x, Min-y, Central-y, Max-y)						Metric Weight	Weight (C)	Weight (Ec)	Weight (So)	Weight (En)
Years before replacement	yrs	5	100	1000	5	80	100	0.5				
Annual damages for residual risk events	£ / yr	248333	6208	0	0	50	100	0.5	0.07	0.17	0.05	0.01
Deprivation Decile	Decile (1-10)	1	3	10	10	50	100	0.5				
Priority habitat area as a proportion of the hazard zone	%	0	15	200	0	80	100	1	0.21	0.03	0.06	0.47
Defended length of shoreline	%	100	50	0	0	50	100	1	0.10	0.07	0.00	0.19

8.3 Resilience for Coastal Archetypes

Coastal Archetype	Resilience			
	Combined	Economic	Social	Environmental
Rural/Estuary/Deprived	68.2	63.2	59.5	78.2
Rural/Estuary/Not Deprived	69.6	64.9	59.6	80.2
Rural/Open/Deprived	61.7	60.2	54.1	68.2
Rural/Open/Not Deprived	66.9	63.4	56.5	76.9
Urban/Estuary/Deprived	64.7	62.0	60.8	69.5
Urban/Estuary/Not Deprived	67.3	64.3	60.1	74.6
Urban/Open/Deprived	57.4	59.0	55.8	57.1
Urban/Open/Not Deprived	63.8	63.1	57.9	68.6

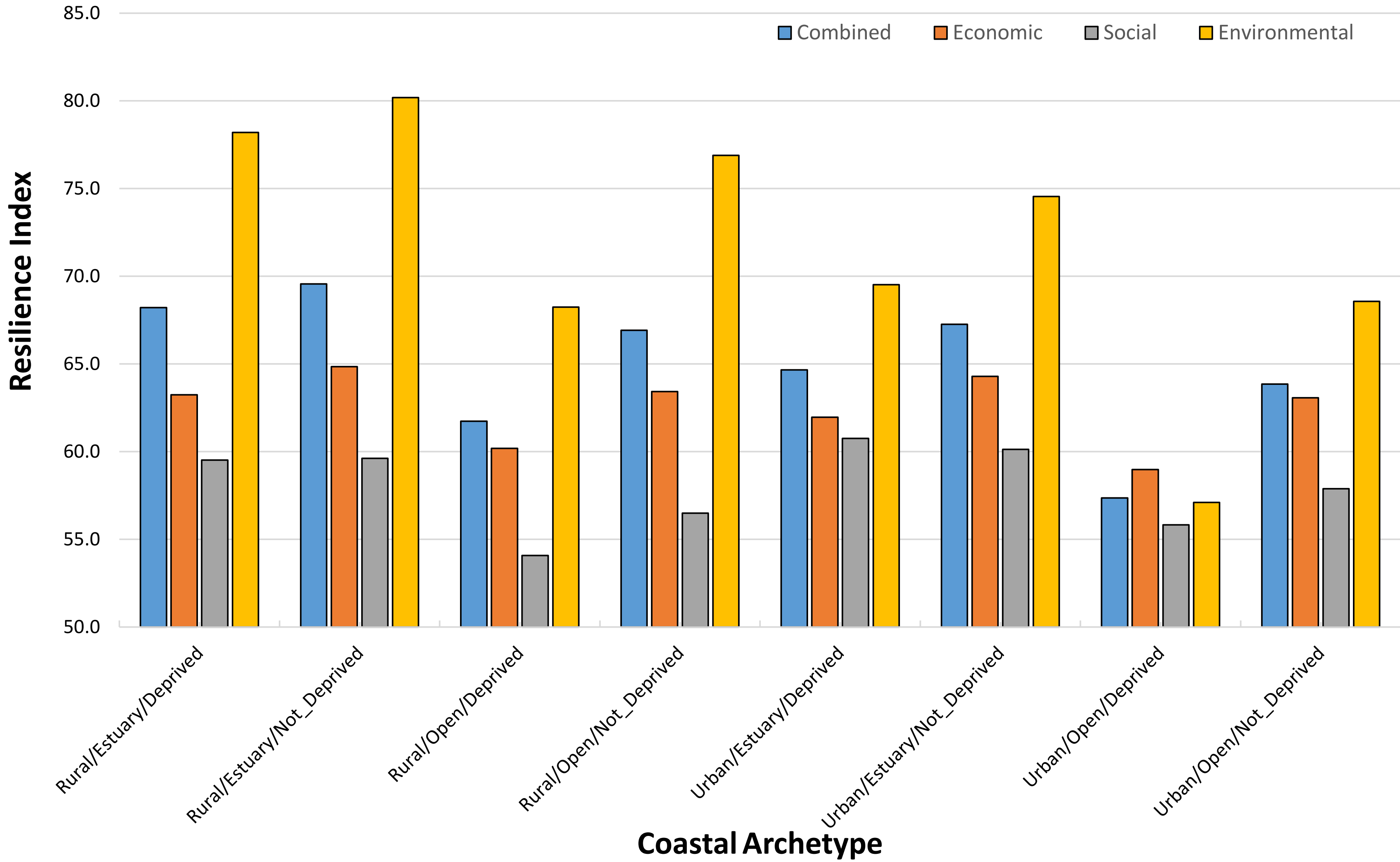

Figure 8-1. Variation in resilience index value by coastal archetype