Townend *et al. Anthropocene Coasts* (2022) 5:13
https://doi.org/10.1007/s44218-022-00014-2

Anthropocene Coasts

TOPICAL COMMUNICATIONS

Open Access

Introducing a web-based portal to explore the concept of coastal resilience

Ian Townend[1*], Chris Hill[2], Jason Sadler[2] and Ian Waldock[2]

Abstract

For operational use there is a need to identify a set of measures that quantify the resilience. The 'CoastRes' project, a component of the UK Climate Resilience Programme, examined how an operational interpretation of resilience might be applied to the coast, building on existing approaches to shoreline management in the UK. The development of the methodology and resulting Coastal Resilience Model has been reported elsewhere. For this communication, we provide a brief summary of the management framework, the Coastal Resilience Model (CRM) and the preparation of the datasets, so that the limitations of the data available at a national scale are clear. We then illustrate how the Coastal Resilience Model has been implemented as the web-based CRM Portal. The purpose of the portal is to allow users to explore (i) the implications of future change on local and national resilience; and (ii) their own view of the relative importance of the Performance Measures that make up the Coastal Resilience Index. By exploring the influence of these weightings it is hoped that Stakeholders can develop a shared understanding of what is important for coastal communities. The CRM Portal can be accessed at: https://coastalresilience.uk/crm/.

Keywords: Coastal, Management, Policy, Adaptation pathways, Resilient communities, Web portal

1 Introduction

The term resilience is much used, especially in a policy context but its meaning can confound practical action because any definition is often context dependent or conceptualised with reference to systems in a single domain (Alexander 2013; Fekete et al 2020; Masselink and Lazarus 2019). Moving to a resilience-based management framework that is quantitative is widely perceived as an advance over current risk-based approaches (Linkov et al 2014). Numerous policy documents indicate a shift away from risk towards resilience, but this has not yet been carried through to supporting guidance and advice that explain how the concept should be implemented. For example, there is no clear definition of resilience, with different government bodies approaching the definition and wider issues of resilience from different angles. However, in order to measure resilience, it is not the precise resilience definition that matters, but that it provides a clear, pragmatic and consistent background throughout an analysis. For operational use there is a need to identify a set of measures that quantify the resilience in some way. This will necessarily be specific in terms of 'resilience against what?' and 'resilience for whom?'. In this application we focus on coastal flooding and erosion in England. We adopted the US Army Corps of Engineers (USACE) definition (USACE 2014; Rosati et al 2015), because of its direct relevance and clarity. This defines resilience as

*Correspondence: i.townend@soton.ac.uk

[1] School of Ocean and Earth Science, University of Southampton, Southampton, UK
Full list of author information is available at the end of the article

"the ability of a system to prepare, resist, recover, and adapt to disturbances in order to achieve successful functioning through time".

There is already a well-established risk-based framework for managing flood defences and erosion protection that is embedded in the Shoreline Management Planning framework. This was first developed in the early 90's following the completion of the Anglian Sea Defence Management Study (Townend 1990; Townend et al 1990; MAFF 1996). The first generation of 44 Shoreline Management Plans (SMPs) were produced for the coast of England and Wales. In a second iteration, these were consolidated to 22 SMPs covering the entire coast of England and Wales (Nicholls et al 2013). The SMPs continue to be updated and the SMP process has undergone regular review, with the latest refresh currently ongoing (2021/22).

The 'CoastRes' project was a component of the UK Climate Resilience Programme, funded by UK Research & Innovation, and examined how an operational interpretation of resilience might be applied to the coast, building on existing approaches to shoreline management. With a stated objective of seeking to enhance coastal resilience, the project explored how to quantify resilience to reflect the contributions made by the social, economic and environmental dimensions of resilience. The resulting methodology and issues related to the data requirements have already been reported (Lazarus et al 2021; Townend et al 2021). The detail of the proposed framework and the Coastal Resilience Model designed to support the framework are available at https://coastalmonitoring.org/ccoresources/coastalres/ and the data used for the local case studies have been archived at https://doi.org/10.5255/UKDA-SN-854523. The national data sets can be accessed via the portal, https://coastalresilience.uk/crm/, which is described in more detail below.

For this Communication, we provide a brief summary of the management framework, the Coastal Resilience Model (CRM) and the preparation of the national datasets, before describing the CRM portal in more detail.

2 Management framework

The overarching framework requires that we can determine the state of resilience and assess how it is likely to change (a) over time and (b) in response to interventions or proposed adaptation pathways. If the performance of a given option can be measured in some way, then it is possible to consider how best to optimise the selection of an option from a suite of options. Typically, such an assessment will consider how effective the adaptation is likely to be, whether the benefits outweigh the costs so that it is an efficient use of resources, whether the outcome is equitable and promotes social justice and whether the adaptation is considered legitimate by the affected parties. Whilst there are numerous methods available for evaluating evidence and decision making under uncertainty, the most well-established within this field is multi-criteria analysis. This type of analysis was used to support the decision-making process for the Thames Estuary, TE2100 project (Ranger et al 2013) and has also been widely used across government to support the decision-making process (DCLG 2009). A typical approach for the development of policy has the following steps:

1. Establish the decision-making context
2. Identify the objectives of the policy or plan.
3. Define the options available.
4. Identify the criteria to be used to measure the performance in delivering the objectives.
5. Assess the robustness of the Performance Measures and their ability to measure variations in performance over time.
6. Test the performance of each option using the defined measures

The context of coastal flood and erosion hazard in England and concerns the need to reduce overall risk, where possible, but where this is not possible, to adapt to enhance resilience. To achieve this, policies should aim to:

- Minimise injury, loss of life and health impacts (health);
- Minimise damage to property and infrastructure (assets);
- Minimise residual risk and community recovery time from events (residual risk);
- Minimise local economic disruption (economy);
- Minimise habitat loss and disruption of the natural coastal system (nature).
- Maximise community preparedness (community)

For these to be workable objectives, it must be possible to define what is to be minimised or maximised in order to do something (take action). This in turn means that the change must be measurable (even if only as a qualitative index). For this application, these high-level

objectives are sub-divided into more specific objectives, to a level of resolution that allows performance measures to be defined.

Within SMPs, Strategic Options are used to characterise the need - 'where and why' some form of defence is needed, which are implemented by Strategic Defence Plans - the 'how and when' (see Nicholls et al 2013 for a more detailed explanation). In the context of resilience, a much broader approach is required, that encapsulates adaptation options that allow communities to prevent loss, tolerate loss, spread and share loss, change use or activity, change location or have the capacity to restore and replace (Cimato and Mullan 2010). Many of these are already a part of existing government policies, or arrangements, but require greater integration across government in order to be applied as an effective set of Coastal Resilience Policy Options. To identify and test suitable performance measures we used the following options - Land use planning, Catchment management planning, Coast protection (erosion and flooding), Flood and storm proofing, Emergency planning, Storm forecasting, monitoring and warning services, Recovery and restoration, Habitat creation (space for water), Socio-economic regeneration (see Townend et al 2021 for details). In many cases there will be a need to use some combination of these options and there will be a need to consider how they might combine over time to define adaptation pathways (Haasnoot et al 2019), especially when considering transitions that involve some change in the state of the system, Fig. 1.

The remaining steps involve the identification and testing of performance measures. This requires a conceptualisation of the system, in order to define measures that contribute to the defined objectives. Combining the various measures enables the present state of resilience to be determined, and projecting how the measures may change over time provides a forecast, or scenario testing, capability. A summary of the Performance Measures adopted can be found in Townend et al (2021).

It is important to note that the Performance Measures need to reflect progress towards the management objectives, but also be available as data sets with sufficient resolution and spatial coverage. This necessarily constrains the selection of measures. The work presented here was a formative exploration as part of the UK Climate Resilience research initiative. It has subsequently informed the work of the Environment Agency, in developing their own set of flood and coastal erosion resilience indicators (EA 2022), which they are now planning to test in more detail.

3 Coastal resilience model

The Coastal Resilience Model uses a set of Performance Measures to define a Coastal Resilience Index, thereby providing a way of measuring progress towards

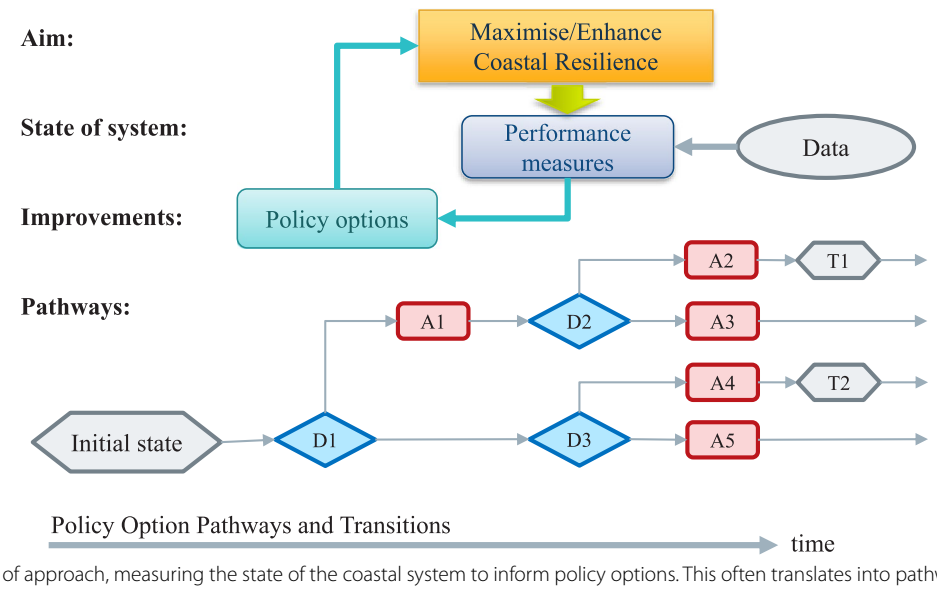

Fig. 1 Schematic of approach, measuring the state of the coastal system to inform policy options. This often translates into pathways with a series of decision points (D), which may lead to some action (A) to implement one or more policy interventions, or may simply delay any action to a later time. Some actions may lead to a change of state – a transition (T) – whereas others may simply adjust the existing state. The timing of the decision points and actions is likely to depend on changing system conditions, such as climate change, demographics, ecosystem health and the consequences of other government policies (eg, agriculture, housing, tourism, etc)

enhancing coastal resilience, as we adapt to future changes. The Performance Measures are combined using a set of stakeholder weightings that reflect the varying importance that different stakeholders place on the contributions that make up the Coastal Resilience Index. This is necessary when seeking to quantify performance across the complex and interacting social, economic and environmental domains.

The way in which Coastal Resilience is quantified at any point in time is summarised in Fig. 2. This shows how the raw data (*Metrics*) are first mapped over the range of the data, such that all data values can be given a *Metric Score* between 0 and 100. These metrics are combined to give a *Performance Measure*, using a set of weights that reflect the contribution each metric is thought to make towards the various measures of performance. Each *Performance Measure* is intended to reflect progress towards at least one of the objectives, that collectively contribute to the aim of enhancing resilience. The creation of metric scores and measure weights requires detailed consideration of each metric and the underlying data. This aspect is therefore the subject of ongoing research to identify a more rigorous methodology.

The way in which the *Performance Measures* are combined to give a *Resilience Index*, also makes use of weightings. Applying a weighting to a *Performance Measure* results in a *Preference Score*. This reflects the Users/Stakeholders view of the contribution that a specific *Performance Measure* makes towards the delivery of Coastal Resilience. The resulting *Performance Scores* are summed to give the *Resilience Index*, Fig. 2.

4 National Data

The 'CoastRes' project undertook several local case studies to test the resilience index concept using a data set that addressed the full set of performance measures that underpin the objectives (Townend et al 2021). The data available for a national scale analysis was considerably reduced because of the limited availability of open access datasets (see Appendix). As discussed by Lazarus et al. (Lazarus et al 2021), this is considered to be an important requirement if data are to be used to develop public understanding and confidence in the approach being proposed. 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.

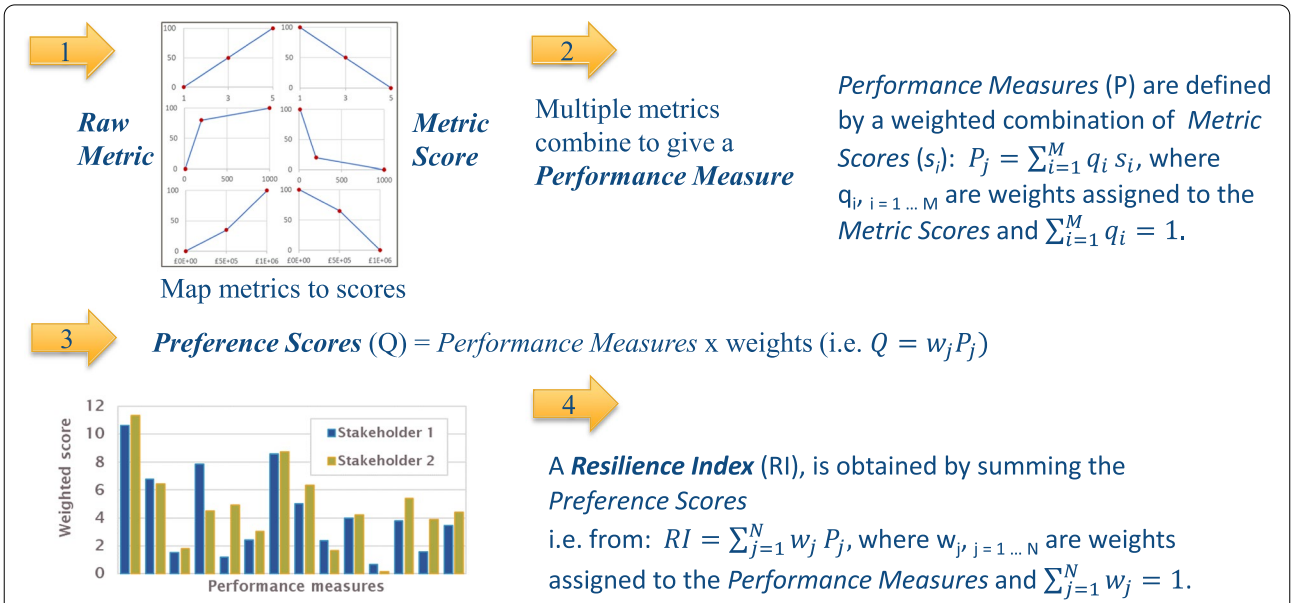

Fig. 2 Steps used to calculate a Resilience Index from a set of Metrics, by first converting the raw metrics to scores, combining them into performance measures and using the stakeholder weightings to establish Preference Scores, which are summed to give the Resilience Index

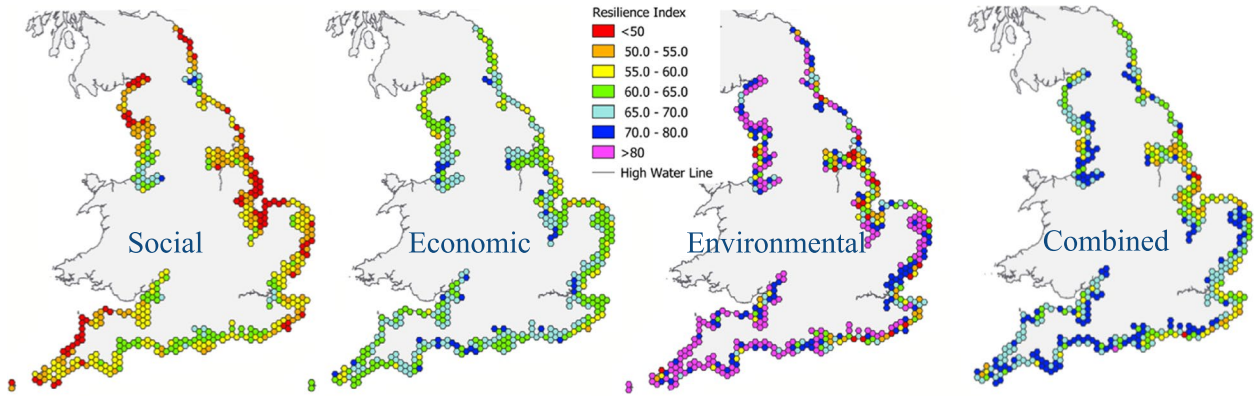

Fig. 3 State of resilience mapping for England, showing the Resilience Index mapped onto 90 km^2 hexagonal units. Weightings used reflect different stakeholder perceptions, classified as social, economic and environmental, with the combined case being the average of the three perspectives

To resolve geographical variation in resilience, the hazard zone had to be split into recognisable areas which are managed individually. The hazard zone was split into Output Areas (OA), the smallest unit of census reporting (ONS 2012). 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 disaggregated to the OA areas (the OA level is the most finely resolved output achievable using UK Census data). 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.

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. Therefore, OAs more than 1 km (an arbitrary choice) from the defence line were removed from the data set.

Our national resilience model contains a total of 8382 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 (see CRM Portal below), 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, Fig. 3.

The results, illustrated in Fig. 3, show considerable variations in the Resilience Index, ranging from less that 50 to close to 100 (the maximum score). This occurs spatially, as might be expected, but also for the different stakeholder perspectives. The three views tend to exhibit different levels of aggregated resilience (social is low and environmental is high with economic in between), which is averaged out in the combined case. This may reflect a limitation in the choice of metrics to adequately represent the different perspectives, or a bias in the scoring system used. At this stage this is to be expected, and reflects the preliminary nature of the measures, which now need to be explored and critiqued by user communities. This was a key driver behind the development of the portal.

It is also important to note that what is being presented is a snapshot, at a given point in time, based on the available up-to-date data. We have previously illustrated how this can be extended to incorporate future projections (Townend et al 2021). The approach adopted was simplistic and, as we noted (*op.cit.*) the modelling of the external changes, imposed management actions, and how these affect the interactions between the various measures, is

complex and will need a substantial research effort before it can be implemented as an interactive tool. However, managers make judgements, often informed by multiple process specific models, by synthesizing the information they are presented with to draw conclusions. We take advantage of this process to provide a means of allowing users to examine the consequences of a certain amount of change in the various measures, where we assume that the user has accounted for the interactions as part of their synthesis.

5 CRM portal

The CRM Portal has been designed to take the national CRM to a wider audience, test the weightings of the contributory metrics and performance measures and, through an online map-based user interface, enable stakeholders to explore the implication for coastal resilience measures of changing the relative weightings of the contributory factors. This is designed to further stakeholder understanding of coastal resilience and how any

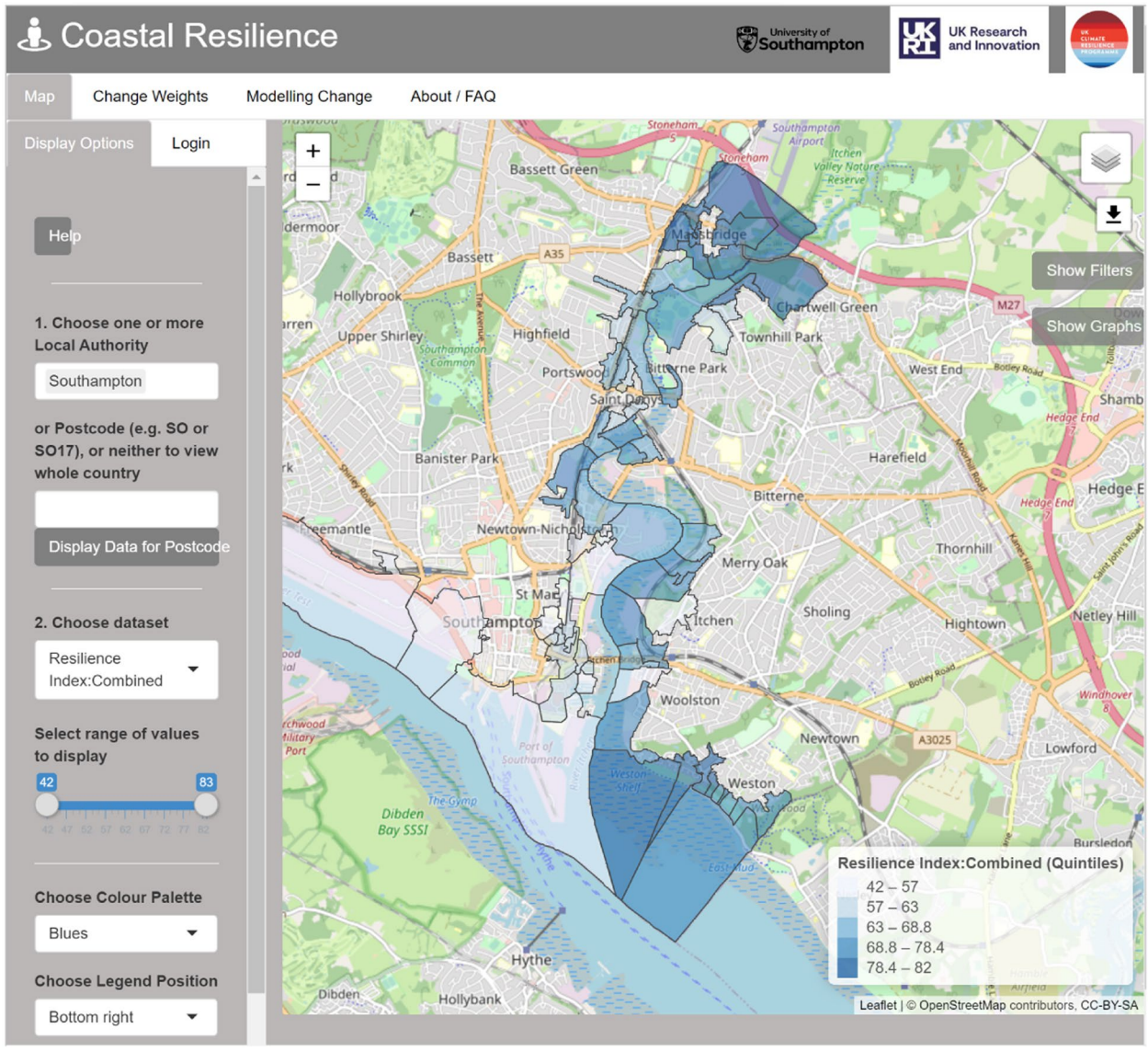

Fig. 4 Screenshot of CRM Portal map with location and variable selection, showing results for each hazard zone polygon. A description of how to change the weightings and explore future change is provided in the Quick Start Guide on the About/FAQ tab of the portal: https://coastalresilience.uk/crm/

evaluation depends on both the underlying data, and stakeholder preferences and values.

The analytical functionality of the CRM has been re-engineered using open source tools, including a database (PostgresSQL) and processing within a PHP/Python environment. The front-end is delivered to provide an attractive and engaging map-based 'Leaflet' implementation, that provides support for Discrete Geographic Grids and use of Javascript front end tools to re-run and update the mapping based on user interactions and online processing. The users are able to change the relative weights applied to the metrics and performance measures of resilience and view the changes real-time. The functionality includes the ability to re-run and compare analyses for comparative assessment, and basic online web-mapping functionality (e.g. to display the underlying data and hazard variables (erosion and flooding)).

A screen shot from the resulting CRM Portal is shown in Fig. 4. As already described with reference to Fig. 2, the raw data (*Metrics*) are first mapped over the range of the data, to obtain *Scores*. This conversion can be linear or bi-linear in the current model and the user can adjust the change point of a bi-linear mapping using the ***Change Metric Scores* tab**. These *Metrics* are combined to give a *Performance Measure*, using a set of weights that reflect the contribution each metric is thought to make towards the various measure of performance. Whilst this is considered to be part of the *Performance Measure* definition, the option to modify these weights using the ***Change Metric Weights* tab** is provided so that the user can explore their relative importance.

The way in which the *Performance Measures* are combined to give a *Resilience Index*, also makes use of weightings. Applying a weighting to a *Performance Measure* results in a *Preference Score* (Fig. 2). This relative weighting of the *Performance Measure* reflects the Users/Stakeholders view of the contribution that a specific *Performance Measure* makes towards the delivery of Coastal Resilience. This an important aspect of the Portal, allowing users to explore how different perspectives can change the resultant *Resilience Index*. These stakeholder weightings are adjusted using the ***Change Measure Weights* tab**, allowing the resulting *Preference Scores* to be summed to give a new mapping of the *Resilience Index*. The steps in the calculation are summarised in Fig. 2. The data displayed in the charts on the various Change tabs are based on the national data sets for England. Whereas the data displayed on the Map tab are for the user selected geographical area.

A further option is to modify the raw metric values. This is, in effect, a way of modelling future change that might result from changing conditions (climate, demographics, policies, etc), or specific interventions and adaptations. The influence of each raw metric can be adjusted by a selected percentage using the ***Modelling Change* tab**, allowing the effect on the *Resilience Index* to be investigated. This is implemented by adjusting the raw metrics, mapping to scores and applying the various weightings and takes no account of possible interactions between metrics, which is likely to be an important consideration when modelling future change. The effects on the *Resilience Index*, which includes any modifications to Metric Scores, Metric Weights and Measure Weights defined by the user, are then shown in the graphs on the various tabs and the resulting *Resilience Indices* can be viewed on the ***Map* tab**.

6 Conclusion

A method to quantify coastal resilience in both space and time has been developed. The resulting Coastal Resilience Model has now been implemented as the web-based CRM Portal. The purpose of the portal is to allow users to explore (i) the implications of future change on local and national resilience and (ii) their own view of the relative importance of the Performance Measures that make up the Coastal Resilience Index. The CRM Portal can be accessed at: https://coastalresilience.uk/crm/. By exploring the influence of these weightings it is hoped that Stakeholders can develop a shared understanding of what is important for coastal communities. Key limitations of the model, as presented in the portal, are (i) the measures chosen, (ii) the balance across the multiple dimensions of resilience, (iii) and the scoring adopted. By allowing users to explore the model and relate it to their own communities (for which only they have the detailed knowledge) it is hoped that this will lead to critiques that enable the development of a more robust set of measures and scoring process. Data availability is also key and currently a national scale analysis is limited by the availability of suitable open access datasets, at the desired level of resolution. This is considered to be an important requirement if data are to be used to develop public understanding and confidence in the approach being proposed. The scale of the data needs to resonate with the scale of the community and our choice of areas, that on average represent just over 300 people, is consistent with this ambition.

Appendix

Table 1

Table 1 Summary of data available at the national and included in the CRM Portal

Objective	Sub-Objective	Measures	Data
Human Health		Implications for human health	tba
Response Time		Access to first responders (emergency services)	Hospital Access Score
			Fire Access Score
Recovery Time		Ability to recover from an event	Homes with NO insurance cover
			Deprivation Decile
Displacement	Due to Flooding	Annual Average no. of days away from property	n/a
	Due to Erosion	Annual Average no. of homes abandoned/relocated	n/a
Preparedness	Warnings and awareness	Access to warnings and community awareness	tba
	Monitoring and maintenance	Adequacy of monitoring and maintenance	tba
Exposure to Risk	Avoidance	Level of exposure due to developments	Population Density
			Property Density
			Infrastructure Density
			Strategic Infrastructure Density
Exposure to Risk	Level of protection provided by defences	Defence design standard	Design standard (1:N years)
		Residual life	No. of years before replacement
Exposure to Risk	Residual risk faced by community	Residual risk	Annual damages for residual risk events
		Proportion of population that are in lower quartile of the Deprivation Index	Deprivation Decile
Exposure to Risk		Annual Average value of insurance claims	tba
Economic damage		Annual net cost due to damage and disruption	n/a
Economic disruption		Annual Average cost of clean-up, demolition, loss of business, etc	n/a
Habitat loss		Area of priority habitat in the hazard zone	Priority habitat area as a proportion of the hazard zone
		Area of coastal habitat (foreshore & backshore)	tba
Disruption of natural system		Proportion of shoreline that is defended or constrained	Defended length of shoreline
Social acceptance		Adoption of coastal resilience plan within the Local Plan	n/a

n/a not available, *tba* to be added

Acknowledgements
The project team included, University of Southampton, University College London, University of Middlesex and the Channel Coastal Observatory. Project partners included ABPmer, the Coastal Group Network, National trust, RSPB, Wildfowl and Wetlands Trust, National Flood Forum, Natural England and Network Rail. The East Solent Coastal Partnership and the Scarborough District Council hosted our regional workshops.

Authors' contributions
Townend and Hill designed and developed the CRM. Sadler and Waldock translated the model to a web-based environment and implemented the CRM portal. All authors contributed to the manuscript. The author(s) read and approved the final manuscript.

Funding
Development of the Coastal Resilience Portal was funded by the Strategic Priorities Fund, UK Climate Resilience Programme, Impact Funding and the Coastal Resilience Model was developed as part with a UK Research & Innovation award NE/ S016651/1 under the same programme.

Declarations

Competing interests
Townend is co-editor of Anthropocene Coasts.
The authors have no other competing interests.

Author details
[1]School of Ocean and Earth Science, University of Southampton, Southampton, UK. [2]School of Geography and Environmental Science, University of Southampton, Southampton, UK.

Received: 6 August 2022 Revised: 16 November 2022 Accepted: 21 November 2022
Published online: 12 December 2022

References

Alexander DE (2013) Resilience and disaster risk reduction: an etymological journey. Nat Hazards Earth Syst Sci 13(11):2707–2716. https://doi.org/10.5194/nhess-13-2707-2013

Cimato F, Mullan M (2010) Adapting to Climate Change: Analysing the Role of Government, Defra Evidence and Analysis Series, Report No: Paper 1, London, pp 1–79 https://www.gov.uk/government/publications/adapting-to-climate-change-analysing-the-role-of-government

DCLG (2009) Multi-criteria analysis: a manual. Department for Communities and Local Government, London, p 168 https://www.gov.uk/government/publications/multi-criteria-analysis-manual-for-making-government-policy

EA (2022) Measuring resilience to flooding and coastal change, FCERM Research & Development Programme Research report, Report No: FRS20288, Bristol, p 138 https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/measuring-resilience-to-flooding-and-coastal-change

Fekete A, Hartmann T, Jüpner R (2020) Resilience: on-going wave or subsiding trend in flood risk research and practice? WIREs Water 7:e1397. https://doi.org/10.1002/wat2.1397

Haasnoot M, Brown S, Scussolini P, Jimenez JA, Vafeidis AT, Nicholls RJ (2019) Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. Environ Rese Commun 1(7). https://doi.org/10.1088/2515-7620/ab1871

Lazarus ED, Aldabet S, Thompson CEL, Hill CT, Nicholls RJ, French JR, Brown S, Tompkins EL, Haigh ID, Townend IH, Penning-Rowsell EC (2021) The UK needs an open data portal dedicated to coastal flood and erosion hazard risk and resilience. Anthropocene Coasts 4(1):137–146. https://doi.org/10.1139/anc-2020-0023

Linkov I, Bridges T, Creutzig F, Decker J, Fox-Lent C, Kröger W, Lambert JH, Levermann A, Montreuil B, Nathwani J, Nyer R, Renn O, Scharte B, Scheffler A, Schreurs M, Thiel-Clemen T (2014) Changing the resilience paradigm. Nat Clim Chang 4(6):407–409. https://doi.org/10.1038/nclimate2227

MAFF (1996) A review of the first round of shoreline management plans in England and Wales. Ministry of Agriculture Fisheries and Food, London

Masselink G, Lazarus ED (2019) Defining coastal resilience. Water 11(12). https://doi.org/10.3390/w11122587

Nicholls RJ, Townend IH, Bradbury AP, Ramsbottom D, Day SA (2013) Planning for long-term coastal change: experiences from England and Wales. Ocean Eng 71:3–16. https://doi.org/10.1016/j.oceaneng.2013.01.025

ONS (2012) Changes to output areas and super output areas 2001 to 2011, In: Tait A (ed) Office for National Statistics, London. https://www.data.gov.uk/dataset/95815689-8dbd-4f40-a823-d1ce2536125e/changes-to-output-areas-and-super-output-areas-in-england-and-wales-2001-to-2011. published by UK Government.

Ranger N, Reeder T, Lowe J (2013) Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames estuary 2100 project. EURO J Decis Process 1(3–4):233–262. https://doi.org/10.1007/s40070-013-0014-5

Rosati JD, Touzinsky KF, Lillycrop WJ (2015) Quantifying coastal system resilience for the US Army Corps of Engineers. Environ Syst Decis 35(2):196–208. https://doi.org/10.1007/s10669-015-9548-3

Sahr K, White D, Kimerling AJ (2003) Geodesic discrete global grid systems. Cartogr Geogr Inf Sci 30(2):121–134. https://doi.org/10.1559/152304003100011090

Townend IH (1990) Frameworks for shoreline management. PIANC Bull 71:72–80

Townend IH, Fleming CA, McLaren P, Hunter-Blair A (1990) A regional study of coastal morphology. In: 22nd international conference of coastal engineering. American Society of Civil Engineers, Delft, pp 2589–2602 https://ascelibrary.org/doi/10.1061/9780872627765.199

Townend IH, French JR, Nicholls RJ, Brown S, Carpenter S, Haigh ID, Hill CT, Lazarus E, Penning-Rowsell EC, Thompson CEL, Tompkins EL (2021) Operationalising coastal resilience to flood and erosion hazard: a demonstration for England. Sci Total Environ 783. https://doi.org/10.1016/j.scitotenv.2021.146880

USACE (2014) From flood damage reduction to flood risk management: implications for policy and programs., U.S. Army Corps of Engineers, Report No: 2014-R-02. U.S. Army Corps of Engineers Institute for Water Resources, Washington, DC, p 63 https://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/2014-R-02.pdf