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Dynamic Coast

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R.A. Dunkley, C.J. MacDonell, L.A. Naylor, F.M.E Muir, J.M. Fitton

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Published by CREW – Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes and Research Institutes supported by MASTS. The Centre is funded by the Scottish Government.

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Project Managers: Emily Hastings (2017), Nikki Dodd (2018), Sophie Beier (2019-2021). Centre of Expertise for Waters/James Hutton Institute.

Please reference this report as follows: R.A. Dunkley, C.J. MacDonell, L.A. Naylor, F.M.E Muir, J.M. Fitton (2021). Dynamic Coast: Mapping Coastal Erosion Disadvantage in Scotland. CRW2017_08. Scotland's Centre of Expertise for Waters (CREW). Available online at: crew.ac.uk/publications

The Scottish Government's Dynamic Coast project is funded by: The Scottish Government, CREW, NatureScot & St Andrews Links Trust

Our Partners: Adaption Scotland, Ordnance Survey, Orkney Islands Council, Historic Environment Scotland, Scottish Environment Protection Agency (SEPA), Crown Estate Scotland, Scottish Coastal Archaeology and the Problem of Erosion (SCAPE), National Library of Scotland

Research undertaken by: University of Glasgow

Dissemination status: Unrestricted

ISBN: 978-0-902701-91-5

The cover image shows: (Top) Storm waves reflecting and undermining artificial defences at Golspie, Highland. Copyright: A. MacDonald (2020). (Bottom left) coastal erosion of the beach crest adjacent to the World Heritage Site at Skara Brae, Bay of Skaill in Orkney. Copyright: A Rennie / NatureScot (2019). (Bottom right) an oblique aerial image of the Splash play park at Montrose looking north. In the 1980s the play park was set-back within the dune, due to the subsequent coastal erosion, now it is in a more exposed position relying on artificial coastal defences. Copyright: F. McCaw (2021).

The Scottish Government's Dynamic Coast project is funded by:

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Leabharlann Nàiseanta na h-Alba

Research undertaken by:

University of Glasgow
VIA VERITAS VITA

The authors would like to acknowledge:

Scottish Environment Protection Agency (SEPA) and Ordnance Survey for their ongoing support and data.

Contents

Executive Summary

Social Justice is an increasingly important policy consideration for the Scottish Government, particularly in relation to Climate Justice. Currently, spatial planning and risk management decisions within Scotland do not typically take account of the relative disadvantage of socio-economic groups across coastal communities. especially in relation to how coastal erosion. Flood Risk Management Appraisals have included Social Vulnerability since 2016. For the first time in the UK, using Scotland as an exemplar, this work aims to couple anticipated erosion risk with consideration of the social vulnerability of Scotland's coastal communities, to produce Coastal Erosion Disadvantage maps.

Key findings of this study are:

- Scotland's coastal communities are generally only slightly less socially vulnerable than the Scottish average, but coastal communities have a slightly higher proportion of the most socially vulnerable groups.
- The National Coastal Erosion Disadvantage map shows that under an IPCC Climate Change "High Emissions Scenario" (HES RCP8.5), and assuming no future maintenance of coastal defences, 37% of the residential property anticipated to be affected by coastal erosion are within data zones classified in the top three categories of vulnerability according to the Social Vulnerability Classification Index (SVCI) developed here.
- 67% percent of socially vulnerable properties that are anticipated to be at coastal erosion risk by 2050, are currently undefended.
- Local authorities with higher Coastal Erosion Disadvantage include East Lothian, South Ayrshire and Argyll & Bute.
- The analysis presented here is based on the combination of data devised through the SVCI, and measures of anticipated coastal change identified by Dynamic Coast 2.
- The Coastal Erosion Disadvantage maps also highlight a need to consider the effects of coastal erosion and erosion-related flooding on smaller communities particularly in island groups such as Orkney and the Western Isles. Although island communities often exhibit higher than average levels of social resilience, the limited availability of resources and critical services (such as road networks, local General Practices, grocery stores and workplaces), means that loss of access to services or lifeline routes could have a significant effect.
- This Coastal Erosion Disadvantage Mapping assessment brings parity with Mapping Flood Disadvantage (Scottish Government, 2015). This initial assessment will act as a catalyst of further in-depth place-based assessments to examine in greater depth the vulnerability of coastal communities to anticipated coastal erosion and erosion-induced flooding, and what improvements can be made.

Introduction

Communities are increasingly engaged in discussions related to the climate emergency (for example, the Scottish Government's 'Big Climate Conversations'), however, these mainly focus on emissions reductions with discussions on adaptation being less common. Recent RESIL Risk research (http://orca.cf.ac.uk/129452/1/resilrisk-FINAL-ONLINE.pdf) identified that people are increasingly concerned with climate change, and that storms and flooding remain the highest perceived risks, prompt high levels of concern, and are seen to be likely to increase in the future. The wellbeing of the most vulnerable in society, people's health, and the emergency services were identified as being the top 3 priorities for protection. However, coastal planning decisions within Scotland do not currently consider the current and/or future socio-economic profiles of coastal communities in terms of relative disadvantage to coastal erosion or to erosion-related flooding. The work presented here aims to consider the anticipated erosion risk (based on the anticipated erosion mapping produced by Dynamic Coast 2) alongside the Social Vulnerability Classification Index (SVCI), adapted from the Coastal Erosion Vulnerability Index (CEVI), developed by Fitton et al. (2018). These are then combined with anticipated erosion to show Coastal Erosion Disadvantage in Scotland.

Recognition of the social vulnerability of coastal communities to coastal erosion is an important knowledge gap since over the next century, Climate Change is likely to result in the acceleration of coastal erosion rates and thus increased risk to communities. The Scottish Government completed a Mapping Flood Disadvantage assessment in 2015, but did not consider coastal erosion or combined flood and erosion risk (https://www.gov.scot/publications/mapping-flood-disadvantage-scotland-2015-main-report/pages/8/). However, in 2017 SEPA identified "Potentially Vulnerable Areas" which included a factor for erosion. Sayers et al., (2018) flood risk vulnerability assessment did not consider coastal erosion. A key recommendation of Dynamic Coast 1, the National Coastal Change Assessment (Hansom et al, 2017: p. 44), was a need "*to establish whether linkages exist between social vulnerability and coastal erosion and coastal flooding vulnerability*". Both social justice and climate justice are key emerging issues of concern for the Scottish Government (Fitton et al 2018; Scottish Government 2020) and provided the impetus for the Dynamic Coast 2 study reported here. This report aims to provide an assessment of the relative social vulnerability of Scotland's communities to coastal erosion. Dynamic Coast erosion data from the recent past and modern day is projected forwards to predict the anticipated erosion by 2050 (including the anticipated influence of relative sea level rise on erosion). Social vulnerability has been mapped, using the latest Census data from 2011 and the latest data from the Scottish Index of Multiple Deprivation (2016 & 2020). The SVCI uses existing academic and policy literature concerning coastal erosion and flooding vulnerability to identify key indicators of social vulnerability to coastal erosion and flooding. It builds upon previous considerations of social vulnerability related to coastal erosion (Fitton et al., 2018) and flooding (Kazmierczak et al., 2015; Lindley et al., 2011a and 2011b; Wade et al., 2005). In doing so, the SVCI indicators go beyond consideration of deprivation related indicators as the primary factors governing social vulnerability to coastal erosion to consider context specific factors that would govern the ability of communities to response to coastal-related flooding events, for instance, the presence of an aging population. It should be noted that the Coastal Erosion Disadvantage map produced here differs from that developed by Fitton (2015), which used

Experian's Mosaic Scotland Dataset. This report aims to describe how the Coastal Erosion Disadvantage map was devised, detailing how the social indices have been selected and mapped for Scotland, thereby allowing social vulnerability issues to be considered within the Dynamic Coast project. The methodology described has value beyond Scotland since it uses a transferable and scalable methodology to map Coastal Erosion Disadvantage.

Coastal Erosion Disadvantage Mapping

Accelerated rates of coastal erosion, exacerbated by climate change and impacting on a relatively densely populated coast (Fitton et al., 2018), makes consideration of the resilience of coastal communities to climate change a pressing question. Historically, little consideration has been given to the need to consider the impact of coastal erosion in any assessment of the socio-economic vulnerability of coastal communities. Consequently, global understanding of the relative resilience of communities to coastal erosion and of coastal erosion-related flooding (hereafter grouped together as "coastal erosion") is limited.

As is the case with other environmental hazards, such as flooding (Wade et al., 2005) and heatwaves (Lindley et al 2011a), assessing the relative vulnerability of communities likely to experience coastal erosion-related hazard is an important and useful exercise. Socio-economic factors govern community level vulnerability and resilience to hazard. Providing an understanding of the situations that individuals occupy within differing spatial contexts enhances the ability of governments and local authorities to prepare for and respond to such events.

In a novel attempt to assess what makes people vulnerable at the coast, Fitton et al. (2018) set out to develop the CEVI, using Scotland as a test case. This identified land assets and people who would be at high risk of coastal erosion, relying upon socio-spatial indicators of vulnerability (for example, health, age and income). The coincidence of anticipated coastal erosion and social vulnerability allow disadvantaged communities to be identified (Figure 1).

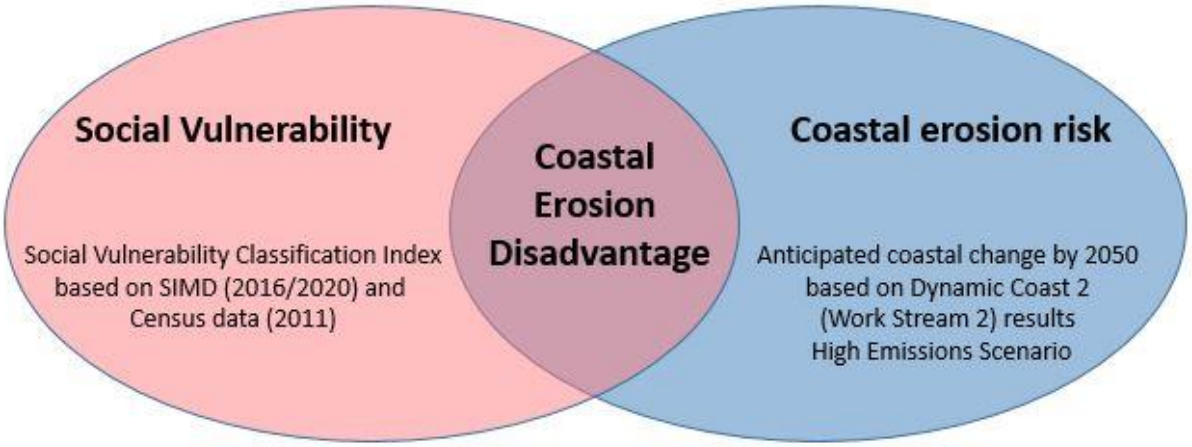

Figure 1 Coastal Erosion Disadvantage is the consideration of the combined characteristics of the Social Vulnerability of a community and the coastal erosion risk. The diagram outlines the input data used for each. Note the baseline coastal erosion assessment is based on a High Emissions Climate Scenario and a 'do nothing' coastal management approach, alternative management approaches are also shown (Table 9 show presence of coastal defences).

A key cautionary point is that whilst the social vulnerability is based on current (2016/2020) data, the coastal erosion risk data is that anticipated by 2050. Unavoidably, the current social data lags the anticipated erosion data by 30 years and thus it is especially important for current and future development planning processes to use the Dynamic Coast 2 results to inform planning and development application decisions to minimise future social risks being amplified between now and 2050 and beyond. The report conclusion includes a summary of significant findings and recommendations for policy and future research.

Methodology

Defining Coastal Erosion Disadvantage: coupling social vulnerability & erosion risk

Within this study, we draw upon Sayers *et al.'s* (2017, p.ii) definition of flood vulnerability, risk and disadvantage conceptualising "Coastal Erosion Disadvantage" as comprising of understanding of both "geographic flood disadvantage", and of "places where many socially vulnerable people are exposed to flooding". Fitton et al.'s (2018) characterisation of social vulnerability as the likelihood of being affected by a hazard is adopted here. Vulnerability is thought of as an individual or group capacity to i) anticipate; ii) cope; iii) resist + recover from an event (Twigg 2001). Within Fitton et al. (2018), vulnerability is measured in terms of sensitivity (degree of effect on individual/household) and resilience (degree of change any "system" can undergo while staying within a desirable state) to any coastal erosion hazard. However, vulnerability is a quality that exists even if exposure to a hazard is not present; for this reason, the mapped result of vulnerability as presented below includes the coast but also extends inland from the coast. Understandings of socio-spatial vulnerability to flooding and climate change have recently expanded in the UK. For example, the Neighbourhood Flood Vulnerability Index (NFVI) (Sayers et al., 2018) (Figure 2) builds upon previous studies of socio-spatial vulnerability (Kazmierczak et al., 2015; Lindley et al., 2011a; Lindley and O'Neill 2013; Sayers et al., 2017) to determine five dimensions of socio-spatial vulnerability (susceptibility, ability to prepare, ability to respond, ability to recover and community support). These five dimensions identified initially by Lindley et al. (2011a) and subsequently developed by Sayers et al. (2017, 2018) helped develop the domains and subdomains that are used within the development of the Coastal Erosion Disadvantage map here. Lindley et al (2011a: 2–3) originally defined their approach to determining socio-spatial vulnerability as a "'capabilities' approach to welfare". Their approach includes consideration of dimensions of well-being "defined in terms of the opportunities (capabilities) people must be able to achieve and things they can do or be (functions), in contrast to traditional resource-based measures of wellbeing, for example, property values and loss of income". Such an approach, arguably, has the potential to provide a more realistic analysis of the factors likely to govern a community's ability to respond to environmental forces.

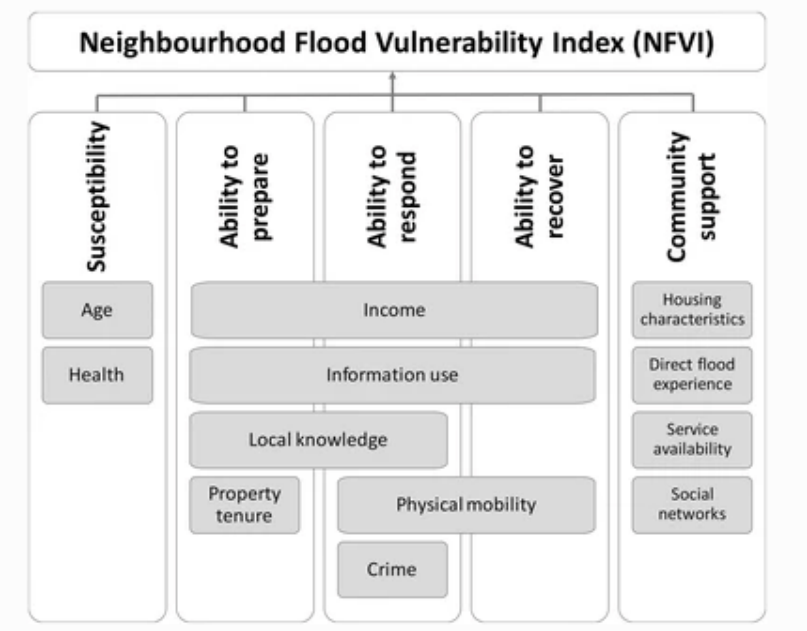

Figure 2: Neighbourhood (fluvial) Flood Vulnerability Index (Sayers et al, 2018)

Developing a Social Vulnerability Classification Index to underpin the Coastal Erosion Disadvantage map

A mixed-methods approach was used to determine a set of indicators needed to produce a map of social vulnerability for Scotland. Dynamic Coast explored the existing UK approaches to assessing community vulnerability to flooding, as well as identifying ways of assessing social vulnerability to a range of flooding types. A literature and policy documentation review enabled identification of ways in which social vulnerability to coastal erosion might be perceived and an understanding of the factors that might impact on the vulnerability of communities and individuals within them. It also enabled an appreciation of the key aspects (specific to coastal erosion) that needed to be included within any development of indices and their subsequent mapping to anticipated coastal erosion. From this more general literature review, key studies were chosen as the basis for identifying the key domains that enhance or reduce social vulnerability to coastal erosion (Fitton et al., 2018; Kazmierczak et al., 2015; Lindley et al. 2011b; Sayers et al., 2018; Wade et al., 2005) and subsequent use for the Disadvantage mapping.

The literature review demonstrated the utility of a vulnerability model that delineated a series of domains and sub-domains as an effective way of capturing the key factors relating to the societal vulnerability to coastal erosion. For reasons of brevity the reference to 'coastal erosion' within the name of the Social Vulnerability is excluded from the remainder of the report and the term SVCI results. To develop the SVCI we used seven domains, 18 sub-domains and 22 potential indicators. The chosen domains are detailed in Table 1. Indicator selection was based upon the availability of open-source data, the rationale for the inclusion of the specific sub-domain/ indicator, and the removal of duplication between indicators.

Table 1: Social Vulnerability Classification Index (SVCI) (continued on next page)

Domain	Sub-domain	Indicators (*attribute name*)	"Directionality" of indicator (i.e. greater than mean = more/less vulnerable)	References
Population	Total Population	Total population *(Total_population)*	More vulnerable	Required for SIMD/ Census result contextualisation
	Number of Children	People under 5 years old *(age_4_less)*	More vulnerable	Fitton et al, 2018; Lindley et al, 2011b
	Number of Elderly people	People 75 years or older *(age_75_over)*	More vulnerable	Fitton et al, 2018; Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005
Physical and mental health and wellbeing	Physical Health	Limited day to day activity *(Activ_limit_sum_adjust)*	More vulnerable	Fitton et al, 2018; Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005
	Mobility	No car *(no_car)*	More vulnerable	Fitton et al (2016)
	Mental Health	Depression % *(HlthDprsPc)*	More vulnerable	Lindley et al 2011b
Cohesive and Connected Communities	Community Engagement/ social isolation	Single person households *(One person household)*	More vulnerable	Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005
		Primary School Age children *(primary_school_child)*	More vulnerable	Sayers et al, 2018
	Information Use	English language skills *(Limit_Eng_lang_adjust)*	More vulnerable	Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005
	Social cohesion	Crime *(CrimeRate_2020)*	More vulnerable	Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018
Skills, education and training	Education	Education attendance *(EduAttend_2016)*	Less vulnerable	Fitton et al 2018
	Skills and lifelong learning	No qualifications *(EduNoQuals_2016)*	More vulnerable	Fitton et al 2018; Lindley et al 2011b;

Domain	Sub-domain	Indicators (*attribute name*)	"Directionality" of indicator (i.e. greater than mean = more/less vulnerable)	References
Economic Prosperity	Income/ expenditure	Long-term unemployed *(Longterm_unemploy)*	More vulnerable	Fitton et al, 2018; Lindley et al 2011b; Wade et al, 2005
		Dependent children households no employed adult *(No_work_parent_tot)*	More vulnerable	Sayers et al, 2018
	Employment	Employment deprivation *(Employment_rate_2020)*	More vulnerable	Sayers et al, 2018
Sustainable communities	Tenure	Social rented households *(Social_rent_total_adjust)*	More vulnerable	Fitton et al 2018; Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005
		Private rented households *(Priv_RentFree_adjust)*	More vulnerable	Fitton et al 2018; Lindley et al 2011b
	Physical Access	People working >30km from home *(Worktravel_30km_plus)*	More vulnerable	Kazmierczak et al, 2015
	Geographical access to services	Public transport travel time to GP, Post Office, retail *(Ave_PT_Services_2020)*	More vulnerable	Lindley et al 2011b; Sayers et al, 2018
	Remoteness	Building Density *(Building_Density_km2)*	More vulnerable	Fitton et al 2018
Physical assets	Housing	Mobile home *(Mobile_home)*	More vulnerable	Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018)
		Overcrowded households *(overcrowded_rate_2020)*	More vulnerable	Overcrowding is expected to detract from an individual's level of resilience.

In identifying the selected domains, in contrast to previous vulnerability assessments, descriptive headings have been used to give a sense of the "capabilities" and "functions" that Lindley et al. (2011a) identified as central to the understandings of social vulnerability. The SVCI developed here seeks to consider both mental and physical health factors, partly addressing the observation of Fitton et al. (2018) that mental health was not well accounted for within existing assessments of social vulnerability to environmental hazards. Consideration of insurance held by individuals, commonly included within social vulnerability to flooding assessments, for example, Lindley et al. (2011a) was omitted from the domains. This is because coastal erosion *per se* is not routinely covered by insurers; erosion-enhanced flooding is covered but assumes the building itself remains unaffected by direct erosion. Also omitted is consideration of loss of physical transport assets such as road and railway networks, as these are measured here indirectly, via indicators within the "Sustainable Communities" domain of the SVCI. Moreover, a road network analysis by local authority area was carried out in Dynamic Coast 1 and the SVCI results here usefully extend and can be linked to this important earlier work.

Data Sources

Given the currency and availability of freely accessible datasets, a combination of the most recent Scotland's Census data (2011) and Scottish Index of Multiple Deprivation (SIMD) data from 2016 and 2020 was used within this study. This is a similar approach to previous studies of flooding and climate change across the UK (Kazmierczak et al, 2015; Lindley et al 2011b; Sayers et al, 2018; Wade et al, 2005).

Spatial resolution adjustment method

Several of the socio-economic indicators selected for the SVCI from the Scottish Census (2011) datasets contain sensitive data, therefore the data was publicly published in less-specific spatial units: Council Areas (CA; total number (n) = 32) and Detailed Characteristic Postcode Sectors (DC; (n) = 866). This difference in spatial scale required a "spatial resolution adjustment method" to be derived to adjust these larger spatial unit datasets (CAs and DCs) into consistent Data Zone units. The method assumes that the characteristics of a given indicator are spread evenly across an area, and hence can be adjusted to any given area (i.e. Data Zone units), if the relative percentage of areas can be calculated. The workflow of the method is detailed in Figure 3.

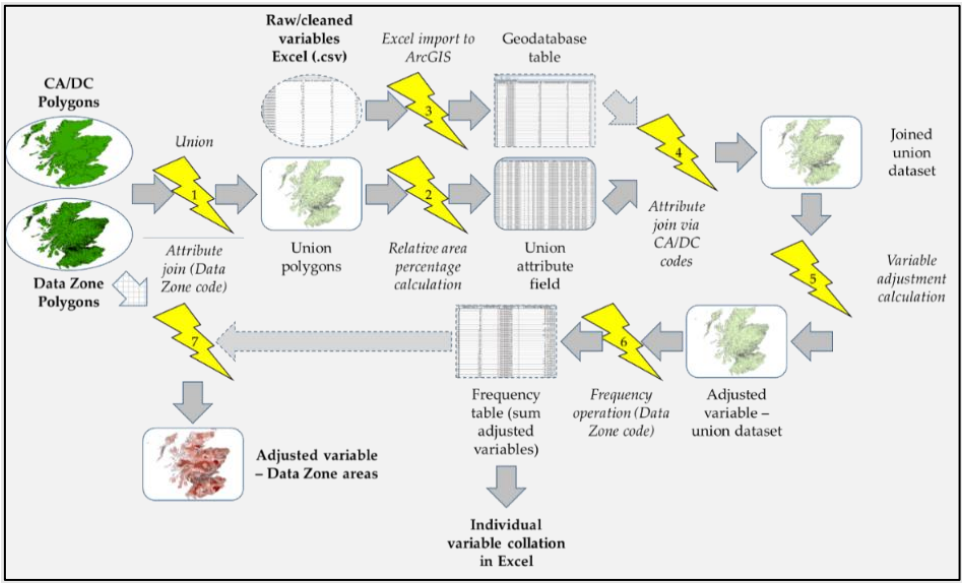

Figure 3: Spatial resolution adjustment method – workflow diagram.

Cross-correlation checks

To identify unintentional weighting towards correlated variables, each indicator was checked against all other variables using Spearman correlation to identify strong correlations (both positive and negative). Using a threshold of ± 0.85 (Willis et al., 2010) several indicators were identified with strong correlations and, where there was a known reason for such correlations, these indicators were removed or changed (dates, sources etc.). These correlation checks were an iterative process with updated lists of indicators and re-tested to determine if the change resulted in further strong correlations. Several strong correlations were not removed since there was no obvious known reason for the correlation existence (Table 2).

Table 2: Variables with strong (> ± 0.85) correlations – retained in model

Indicator 1 (*attribute name*)	Spearman's correlation co-efficient	Indicator 2 (*attribute name*)
Limited daily physical activity (*Activ_limit_sum_adjust*)	0.917	**Limited English Language** (*Limit_Eng_lang_adjust*)
Limited daily physical activity (*Activ_limit_sum_adjust*)	0.923	**Persons in social rented properties** (*Social_rent_total_adjust*)
Limited daily physical activity (*Activ_limit_sum_adjust*)	0.892	**Persons in private rent or rent-free properties** (*Priv_RentFree_adjust*)
Limited English Language (*Limit_Eng_lang_adjust*)	0.894	**Persons in social rented properties** (*Social_rent_total_adjust*)
Limited English Language (*Limit_Eng_lang_adjust*)	0.919	**Persons in private rent or rent-free properties** (*Priv_RentFree_adjust*)
No formal qualifications (*EduNoQuals_2016*)	0.873	**Unemployment rate** (*Employment_rate_2020*)

Variable standardisation and classification method

To summarise the 22 individual socio-economic vulnerability indicators into a single classification index (1 – 6) for each Data Zone (Table 3), an established methodology (Fitton et al 2018; Kazmierczak et al, 2015) was applied using domains and z-scores. Figure 4, each of the indicators was standardised using z-scores (Step 1) and each domain for a summary of indicators in each domain). Note that equal weighting was applied to all the indicators based on the number of indicators in a given domain (Step 2; e.g., 4 indicators in a domain, weighting coefficient = 0.25). The domains were then standardised again using z-scores (Step 3), which were then summed together to create an overall vulnerability value (Step 4). This value was once again standardised (Step 5), and then classified into the SVCI.

Table 3: 6-class SVCI – class ranges and description.

Class Number	Class range (summed overall z-scores)	Description
1	z > 2	**Highly vulnerable**
2	1 < z >= 2	**Moderately vulnerable**
3	0 < z >= 1	**Slightly vulnerable**
4	-1 < z >= 0	**Slightly resilient**
5	-2 < z >= -1	**Moderately resilient**
6	z <= -2	**Highly resilient**

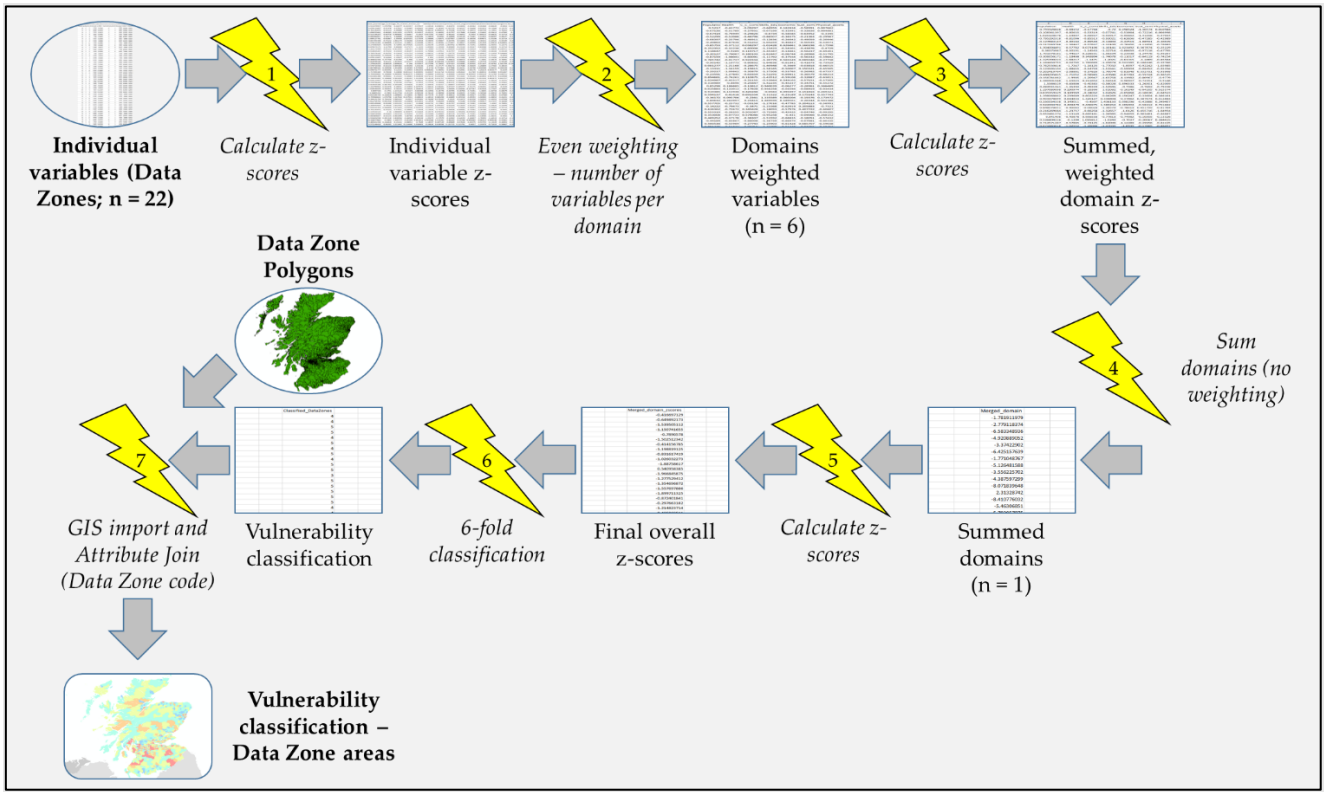

Figure 4: Variable standardisation and classification method - workflow diagram.

Coastal buffer zones and areas of anticipated erosion

Multiple coastal buffer zones were created at a national scale using both MHWS[1] (Mean High Water Springs) and other Dynamic Coast 2 outputs. These buffer zones were used to identify properties across Scotland that lie close to the coast and may be impacted by coastal erosion and flooding. The following scenarios are detailed below:

1. Within 25 and 50 metres of MHWS (2 separate datasets)
2. Within Dynamic Coast 2 (Work Stream 2) erosion prediction zones.

The Dynamic Coast 2 prediction zones identify areas of potential future erosion, based on both past historic MHWS change (i.e., areas of known past erosion) and changes anticipated under future sea level rise as depicted by the modified Bruun Rule model used in Dynamic Coast 2. Dynamic Coast 2 modelled the rates of erosional change (i.e., x metres per year) by decade forward to 2050 and 2100. However, given the likely pace of intervening social change over the next 80 years or so, projections of social vulnerability to 2100 was deemed unreliable and not used here. These erosion polygon areas were also limited by the Coastal Erosion Susceptibility Model (value between 40–100 CESM; Fitton et al., 2016) to ensure erosion is halted when bedrock is encountered and so any predicted future erosional extent only relates to erodible (i.e. soft) shores only. It is important to note erosion modelling has been undertaken in areas where a natural shoreline exists (ie a natural beach, or a natural beach in front of defences). Erosion modelling approaches (developed and reported in the Work Stream 2 Report) cannot be deployed on heavily engineered shores (where MHWS line rests against an artificial structure). Where these defences are known, we have mapped their extent and used this to account for 'defended' or 'undefended' residential property. These zones could be vulnerable to future erosion risk depending on the condition, maintenance and design life of these defences. For further detail on the methods, see Work Stream 2 report. The Dynamic Coast 2 polygons were subdivided into three further sub-polygons as follows:

a. Erosion Area: defined as the area of actual or highly probable erosion within the given timeframe (in this case 2050);
b. Erosion Influence: the area where some assets may suffer negative but indirect impacts from coastal erosion since (wave thrown debris for example or slope instability) they are or will be situated close to MHWS;
c. Erosion Vicinity: the area that includes assets (in this case residential properties) that may be indirectly affected by the coastal erosion/loss of other assets respectively (such as loss of an access road) (Fitton et al., 2018). This category also informs the number of people who perceive impacts of climate change nearby.

As outlined in the Work Stream 2 report, the anticipated coastal change information cannot be used at individual property levels, due to general nature of the coastal positions used tidelines and smoothing of results. Nevertheless, they provide regional (rather than detailed) assessment of generalised change anticipated under certain climate and

[1] Ordnance Survey's Master Map MHWS (published in September 2019).

management scenarios. To appraise the social disadvantage resulting from exposure to erosion, it is necessary to identify a dataset that can act as a 'bridge' that connects the risks of exposure (i.e., anticipated erosion) to the societal data. Residential property is the obvious dataset, but it is acknowledged here that this is an imperfect proxy. Such an approach assumes socio-economic uniformity across Data Zone areas (amongst other limitations), and ignores key services and lifeline transport links, but its use here may be justified to provide an initial insight and catalyst for further research. It is also worth noting that this is an initial assessment and further analysis could be undertaken, for example, to consider the risk of erosion the road networks supporting coastal communities. Whilst this has not been done in this project, these are the sorts of research questions than can be asked in follow-up work.

The rationale for the various coastal buffer zones (MHWS and Dynamic Coast 2) was to identify, not only properties directly impacted by a given coastal erosion event, but also those properties that would be close to an affected area and which may incur further damage or inconvenience to residents due to secondary effects (i.e. coastal flooding). Such an approach also provides a societal impression of how many people across Scotland may have erosion 'nearby' and prove valuable in societal perceptions of climate change impacts. The initial starting point was the 25-metre buffer, determined as a reasonable maximum landward extent of direct impact from a single erosion event. This was based on general observations of damage done behind protected artificial coasts. It is possible that other coastal types (soft or hard and mixed) could be differentially impacted. A further buffer zone at 50 metres was identified to establish residential properties which may be impacted by secondary effects. It should be clarified that analysing the impact of coastal flooding was considered secondary in this analysis since coastal flooding has been the focus of other studies (e.g., Kazmierczak et al, 2015). All MHWS coastal buffers were subsequently clipped to include only areas landward of the September 2019 OS MHWS, using a closed polygon dataset derived from the MHWS line and the English border derived from the Data Zone boundaries. A further buffer zone was created in the final stage of identifying locations of clusters of properties within the Dynamic Coast 2 erosion prediction areas. This was created by first merging the Erosion Area and Erosion Influence zones. This was then intersected with areas that are deemed "defended" by a variety of artificial structures (e.g. seawalls) to identify areas that remain undefended by artificial structures and hence at even more at-risk.

Property analysis

To link vulnerability classifications to individual residential properties, building footprint data was used (see page 14 regarding property level assessments). This approach differs from previous approaches (e.g. Kazmierczak et al, 2015), by using building footprints that partially intersect the coastal buffer zone described above and aligns closely with the Scottish Environment Protection Agency's (SEPA) 2018 National Flood Risk Assessment exercise (NFRA) (footprints sourced from Ordnance Survey MasterMap Topography Layer product). This more accurately identifies properties that fall within the coastal buffer zones than approaches using the central point of a property (which were used in SEPA's 2012 NFRA exercise). This step generated the number of residential properties within (or intersecting with) the coastal zone buffer. The SVCI focuses on residential dwellings only to enable a holistic understanding of the impact of coastal

erosion on current communities. Nevertheless, non-residential properties were partially included when considering the Building Density variable (Sustainable Communities domain, Table 1) to account for available space to rebuild/recover after an event. Here "partial inclusion" of buildings refers to circumstances wherein only part of the building concerned is included in the assessment. This means that, in the case of the non-residential building density variable, it was necessary to take the central point of the building as a reference point, which resulted in the partial inclusion of the buildings in question. This was seen as the most accurate way of considering available space for rebuilding, given that the properties concerned were currently non-residential.

The next step was to locate residential property footprints that fall within the coastal buffer zones and identify their vulnerability, using the GIS attribute vulnerability classifications. A 'Select by Location' operation was run to ensure that a whole building footprint was selected, rather than just the "sliver" portions of an intersect. A general overview of the workflow is shown in Figure 5, with this procedure repeated for local authority areas (* symbol). The spatial join to attribute buffer attributes to properties was undertaken for the two MHWS buffers (# symbol).

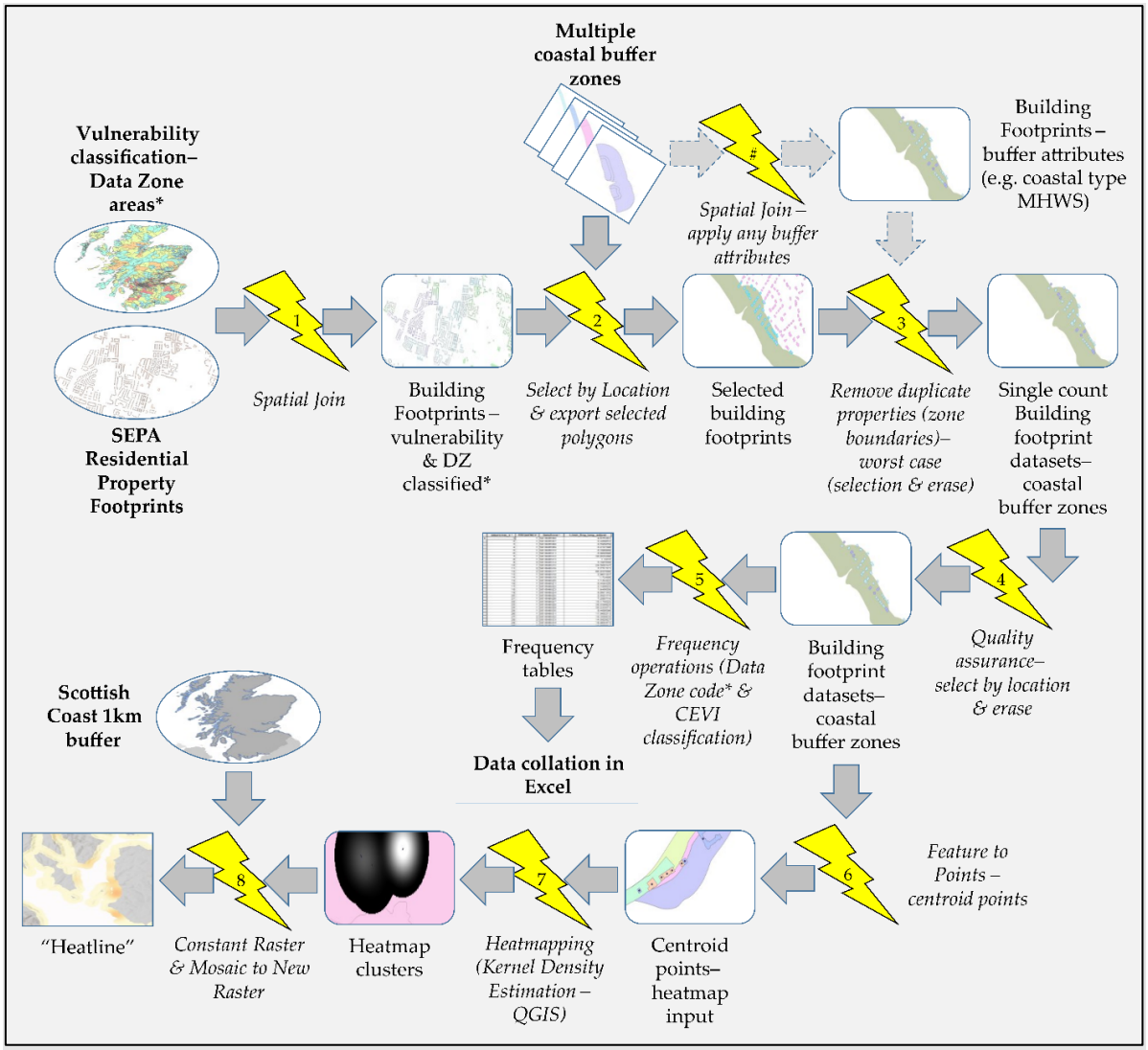

Figure 5: Workflow diagram showing the attribution of SVCI data to properties (thereby creating coastal erosion disadvantage), coastal buffer zone property selection & analysis, plus spatial distribution heatmapping analysis.

The spatial distribution of properties selected within each Data Zone (especially those with social vulnerabilities) was also analysed using aggregated counts for Data Zones for each of the erosion prediction zones as well as other combinations. A regional scale analysis was also done for local authorities to identify those more relatively impacted. Finally, heatmapping shows the Coastal Erosion Disadvantage by identifying clusters of properties selected within the various erosion prediction zones with these property clusters weighted towards those with lower (more vulnerable) Social Vulnerability classifications. For example, two areas with a similar number of nearby properties, but one area with greater social vulnerability would be ranked higher than another with a similar number of properties but a more resilient social vulnerability classification. This mapping was continuous around the whole coast of Scotland and termed here a "heatmap", to indicate the continuous nature of the social vulnerability exposure to coastal erosion. The methodology behind such a national scale analysis is demonstrated using two main exemplar focus areas (on the South Ayrshire and East Lothian coasts) where the methodology leading to different Coastal Erosion Disadvantage classifications is explored further. It is worth noting that only current properties were assessed rather than future risks from any planned developments that may be located in zones of risk; it is thus recommended that Local Authorities use these and other Dynamic Coast data to assess future development plans.

Results summary

The following section outlines some initial findings emerging from the Coastal Erosion Disadvantage analysis in three parts. Part 1 considers the characteristics of coastal areas in terms of social vulnerability, focusing upon major Scottish cities as well as the Super Sites of Dynamic Coast 2. Part 2 examines the distribution of properties identified to be at risk of coastal erosion events, focusing particularly upon coastline characteristics and residential property type. Part 3 analyses the spatial distributions of both social vulnerability and at-risk properties on the Scottish coast to identify Coastal Erosion Disadvantage.

As previously discussed, this study uses two main types of buffer zone to identify at risk properties on the Scottish coast: MHWS buffer variants, and the Dynamic Coast 2 2050 erosion areas. This separation aims to emphasise the difference between potential erosion across the entire coast (two MHWS buffers) and the anticipated erosion modelled for the soft coast areas (Dynamic Coast 2 2050 erosion prediction zones). The separation also allows for a more meaningful analysis of the results, given the variable sample sizes across the buffer zones.

Part 1: Coastal areas and Social Vulnerability

Figure 6 and Table 4 demonstrate that, according to findings emerging from SVCI analysis, there are no significant differences in the social vulnerability of those living within coastal Data Zones (in Data Zones identified as being within 50 m of MHWS) and the Scottish population as a whole. When compared, the coastal Data Zones sample exhibits a similar distribution in terms of shape, mean and standard deviation of classifications, and relative classification

percentages to the National Data Zone population. Considering the three "more vulnerable" categories in Figure 6 and Table 4 (i.e., "highly", "moderately" or "slightly vulnerable") 44% of Data Zones are classified nationally, whilst only 39% of those Data Zones deemed coastal. Coastal areas have slightly more "highly vulnerable" Data Zones, with a 1% difference compared to the nationwide data, but around 3% less in both the "moderately vulnerable" and "slightly vulnerable" classes each. Of the remaining 56% "resilient" Data Zones nationally, 42% were deemed to be "slightly resilient", while only 0.1% could be considered "highly resilient". Similarly, of the remaining 60.9% of coastal Data Zones, 48% are "slightly resilient", whilst no coastal Data Zone population exhibited a high level of resilience.

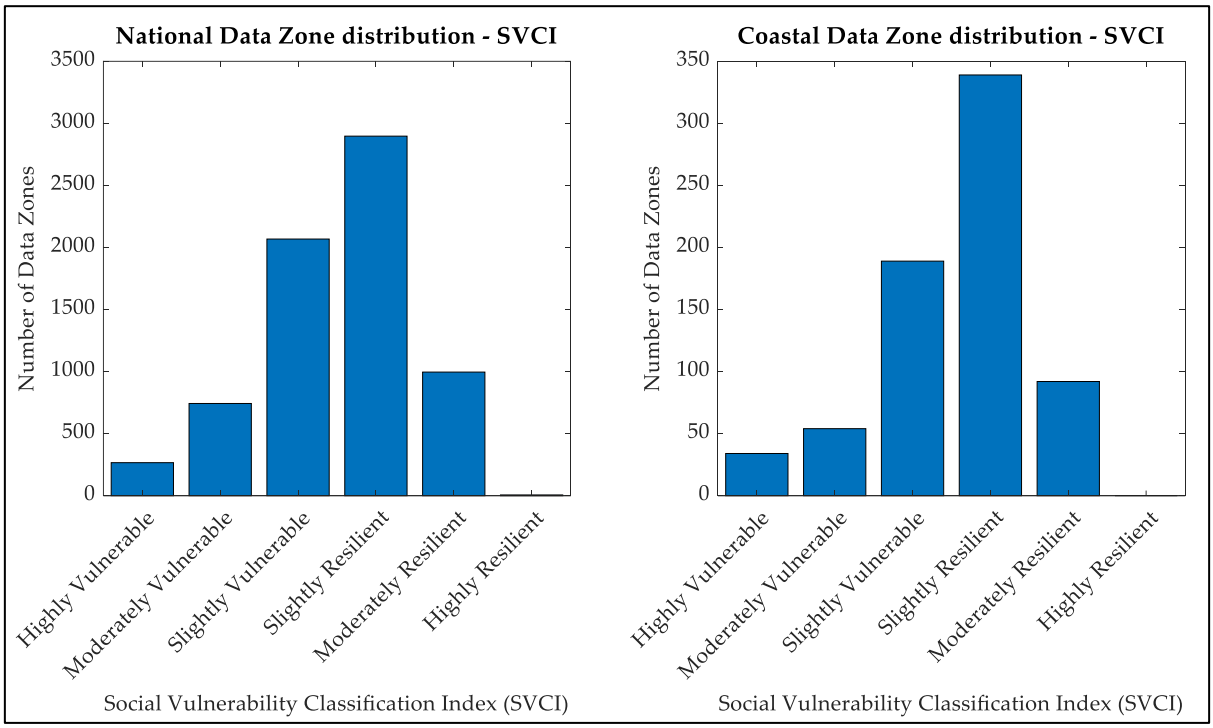

Figure 6: Distribution of Data Zones within each SVCI for the whole of Scotland and within 50 m of MHWS (coastal).

Table 4: Counts and relative percentages of Data Zone classifications across Scotland and the selected coastal Data Zones.

Class Number	Classification Value	National Data Zones			Coastal Data Zones		
		(n)	(%)	(%)	(n)	(%)	(%)
1	**Highly vulnerable**	266	3.8%	44.2%	34	4.8%	39.1%
2	**Moderately vulnerable**	743	10.7%		54	7.6%	
3	**Slightly vulnerable**	2,068	29.7%		189	26.7%	
4	**Slightly resilient**	2,897	41.5%	55.9%	339	47.9%	60.9%
5	**Moderately resilient**	996	14.3%		92	13.0%	
6	**Highly resilient**	6	0.1%		0	0%	
TOTAL Data Zones		**6,976**	100%	100%	**708**	100%	100%

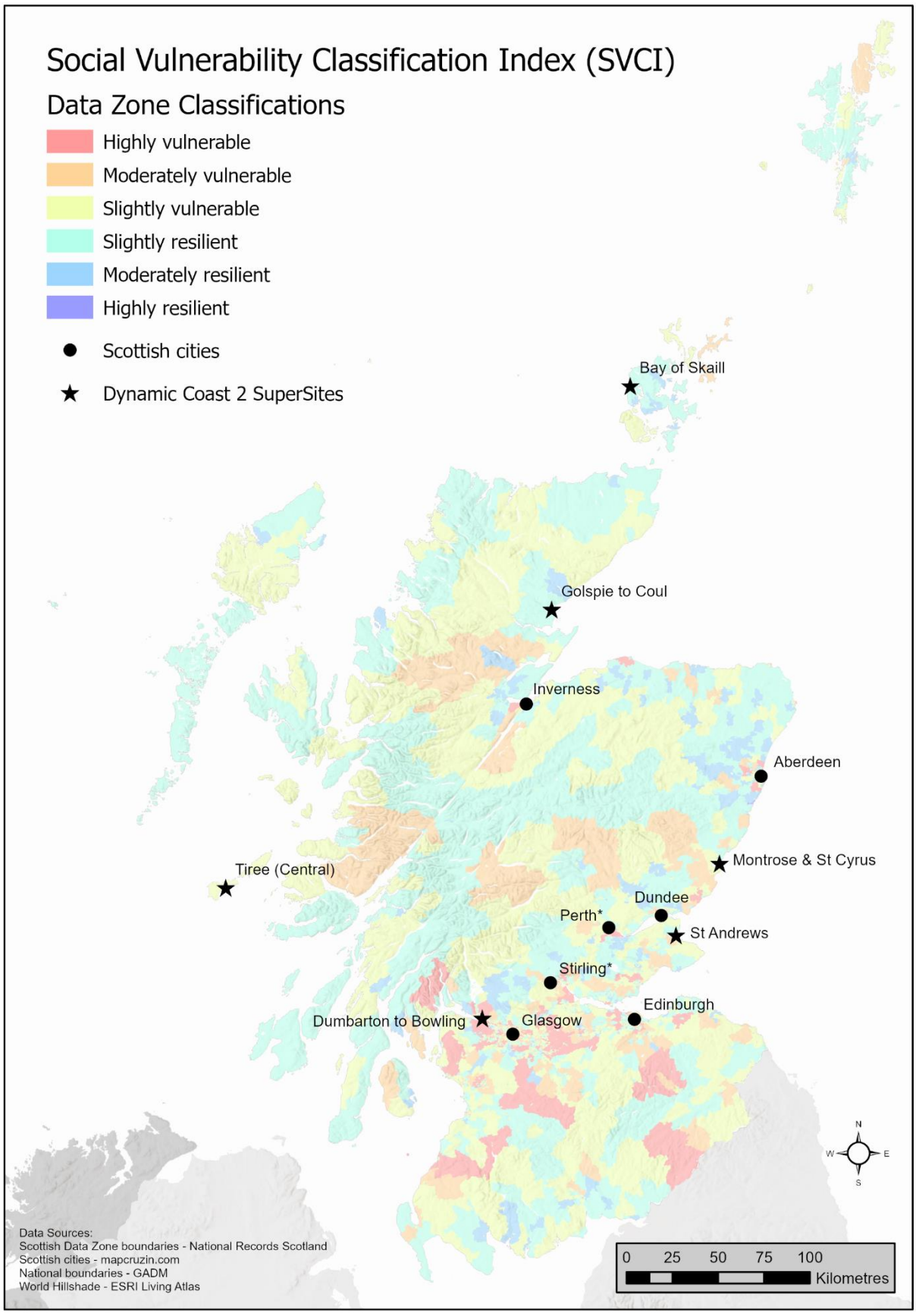

*Figure 7: National SVCI Data Zone map across Scotland. Major cities and Super sites shown for context. *Note, Stirling and Perth are omitted from Figure 8, as they are inland tidal/estuarine, rather than coastal (in terms of Dynamic Coast 2 MHWS erosion prediction zones).*

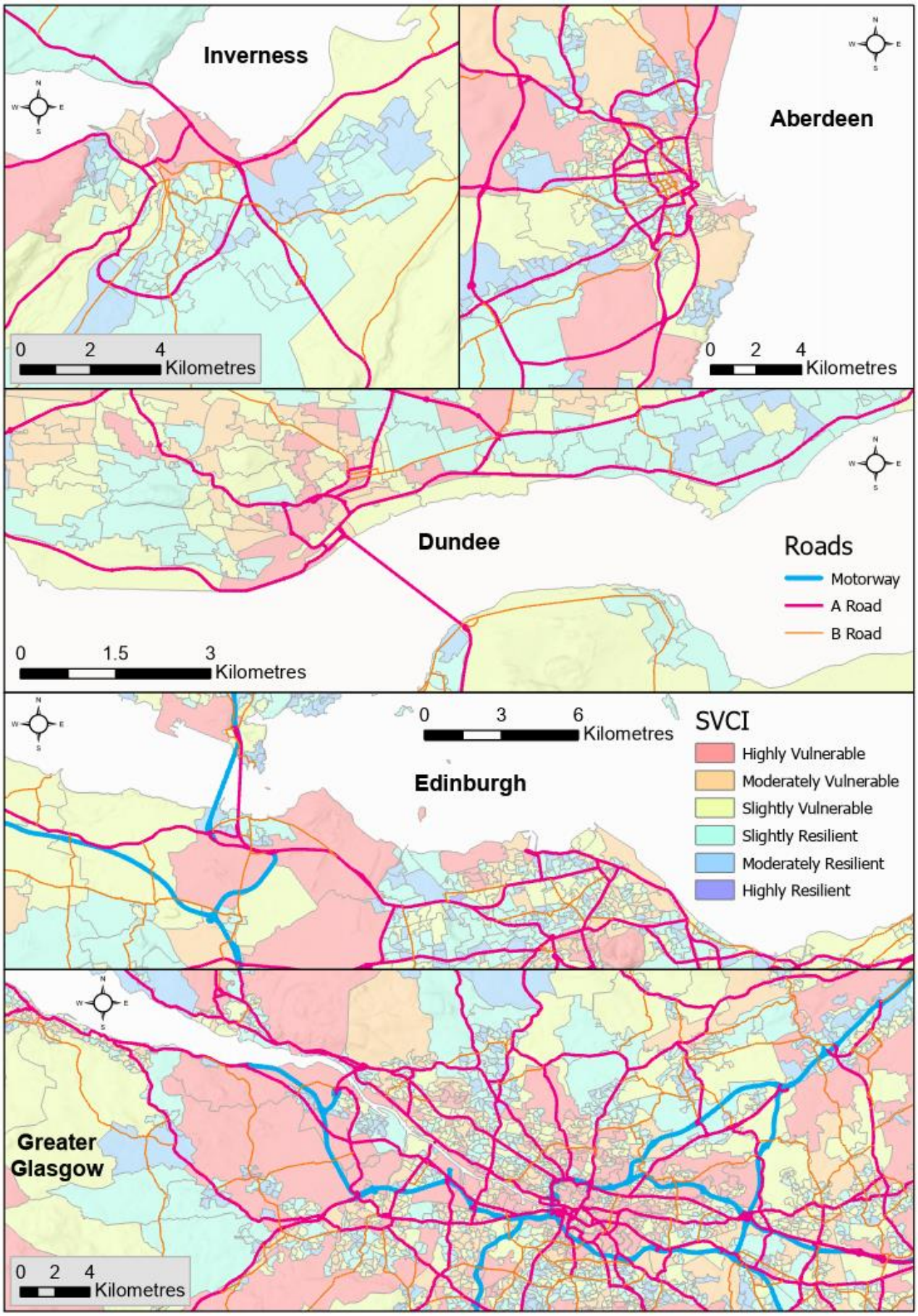

Figure 8: Localised SVCI maps by Data Zone for Scotland's coastal cities (excluding Stirling & Perth).

Urban coastal communities

Figures 7, 8 and 9 suggest the populations residing in Scotland's urban areas emerge from the SVCI analysis as being more highly socially vulnerable than those living in rural coastal areas. Figure 7 indicates that Data Zones within the coastal city regions of Scotland (excluding Stirling & Perth) and several "Super Sites" studied in Dynamic Coast 2 (including Dumbarton and Bowling, St Andrews, and Montrose) display slight, moderate, or high levels of social vulnerability. Figure 8 also shows there are several areas of higher socio-economic vulnerability identified in the SVCI assessment in these urban areas.

Super site Analysis

Figure 9 presents SVCI results for the Dynamic Coast 2 Super Site areas (Bay of Skaill, Golspie and Coul, Montrose and St Cyrus, Tiree, St Andrews, Dumbarton and Bowling). The site that emerges as the most socially vulnerable is Dumbarton and Bowling and the supersites with the greatest level of resilience are Bay of Skaill and Golspie and Coul. For a more detailed exploration of these findings, please see individual Super Site reports.

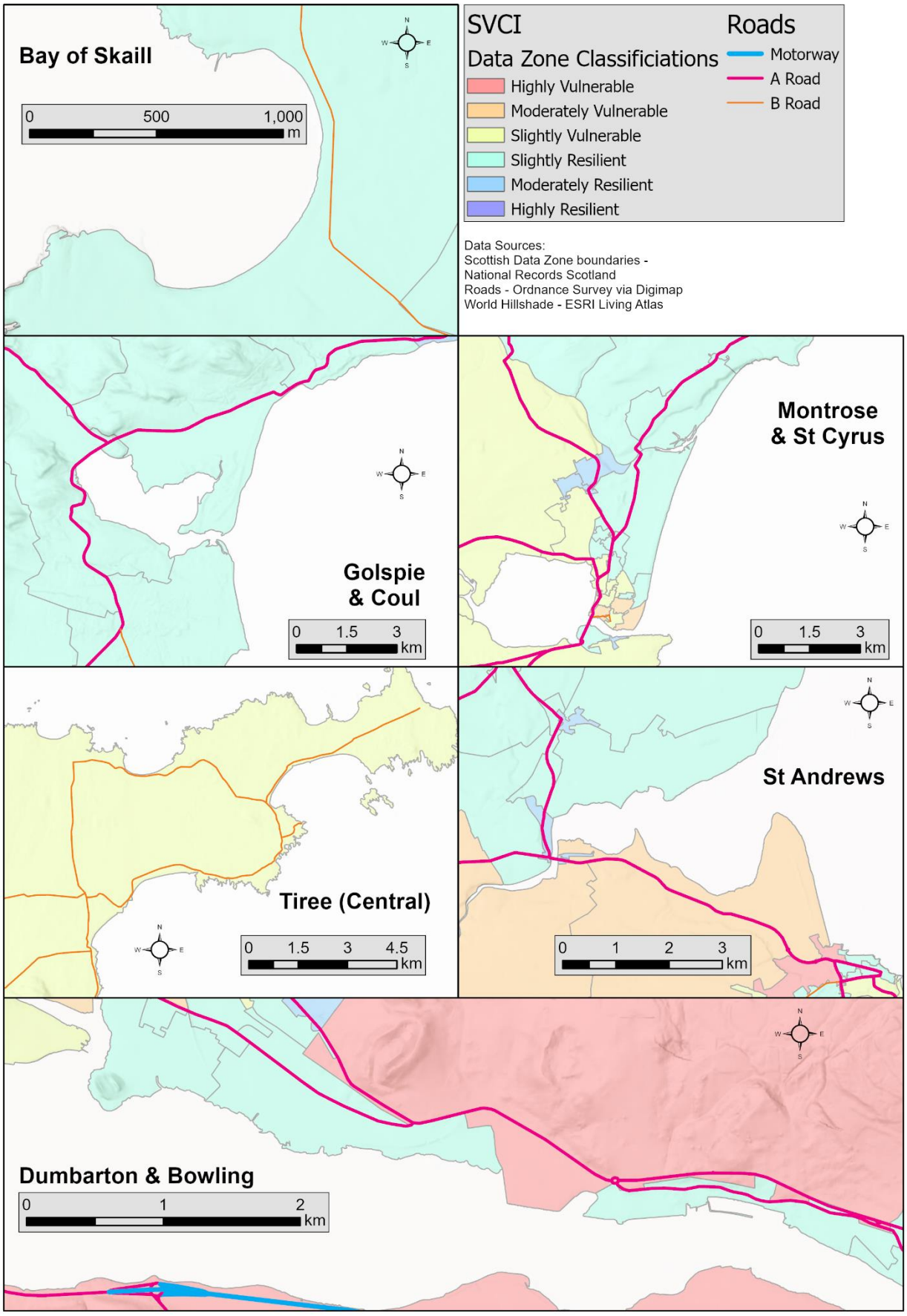

Figure 9: Localised data zone SVCI maps for the six Dynamic Coast 2 "Super Sites".

Part 2: Identifying social vulnerability of coastal properties to Coastal Erosion

National MHWS buffers

Figure 10 and

Table 5Table 5 show the distribution of properties within the coastal buffer zones for the Scottish coast relative to the SVCI of the Data Zone where they are located. The two MHWS coastal buffer (25 and 50 m) scenarios follow a similar distribution. Approximately 45–46% of those residing within coastal properties identified in the MWHS buffer zones were classified within the three "more vulnerable" classifications. It also worth noting that of the other properties not within the more vulnerable classifications, a further 43–44% are identified as only slightly resilient across both the MHWS buffer zones.

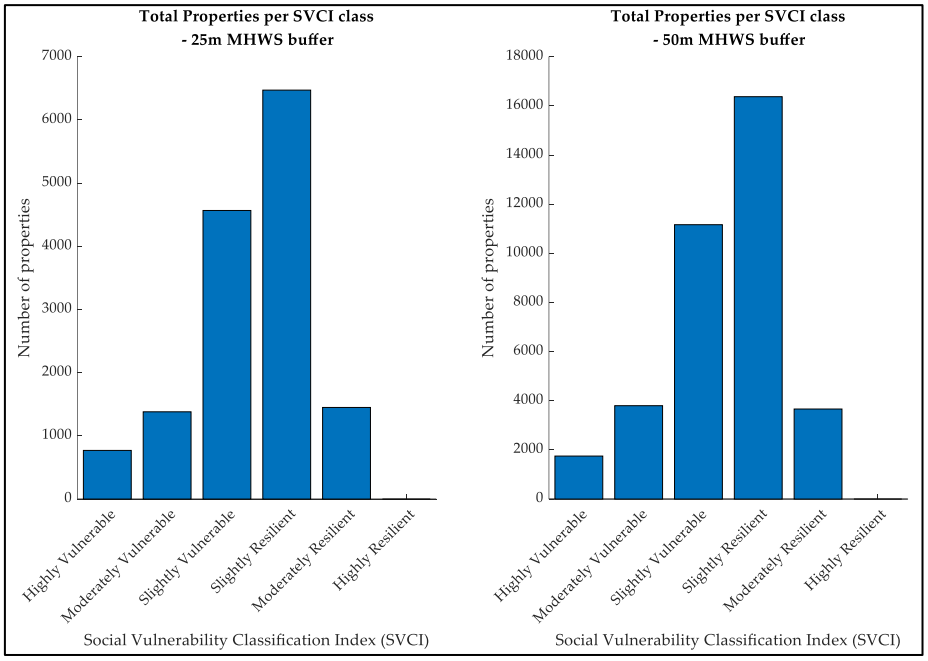

Figure 10: MWHS buffer zone distributions of the number of properties within SVCI analysis.

Table 5: Number of properties in each SVCI grouping for each of the MHWS buffer zones. Percentages shown for each grouping are relative to total properties selected across six SVCI groups. Total percentages are relative to total number of residential properties in Scotland (see footnote 3).

Class Number	Interpretation	Number of Properties - coastal buffer scenarios			
		25m MHWS		50m MHWS	
1	Highly vulnerable	770 (5.3%)	45.9%	1,750 (4.8%)	45.5%
2	Moderately vulnerable	1,381 (9.4%)		3,800 (10.3%)	
3	Slightly vulnerable	4,568 (31.2%)		11,167 (30.4%)	
4	Slightly resilient	6,473 (44.2%)	54.1%	16,377 (44.6%)	54.6%
5	Moderately resilient	1,450 (9.9%)		3,665 (10.0%)	
6	Highly resilient	0		0	

TOTAL[2]	***14,642 (0.57%)***		***36,759 (1.42%)***	

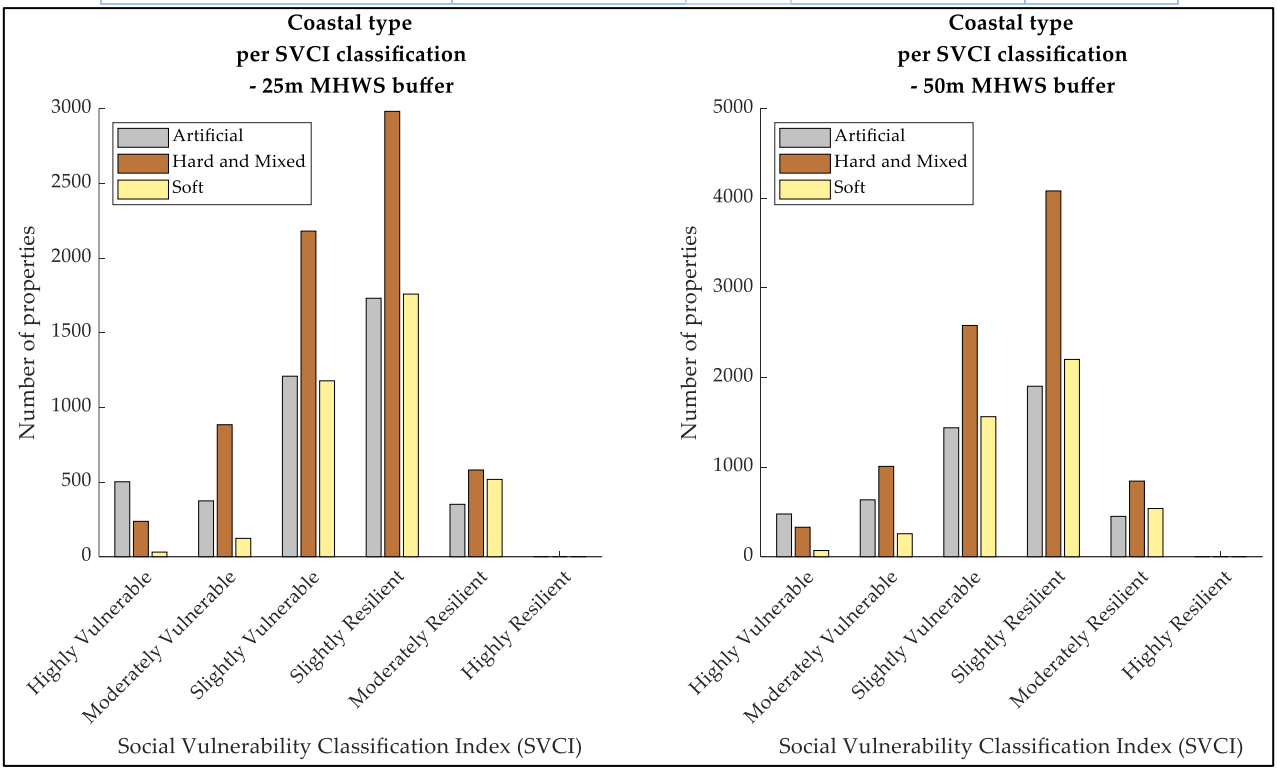

Figure 11: Number of properties per SVCI grouping, divided into associated coast type within 25m and 50m MHWS buffers).

Figure 11 illustrates the number of properties per SVCI group by coastal type (i.e., behind artificial, hard and mixed and soft coast, Fitton et al. 2017, Section 7.1.1 Page 21), demonstrating that the artificial category (i.e., defended coast) currently protects the largest proportion of properties that are classified as highly vulnerable and the second highest proportion of properties within the next two most vulnerable categories. There is also a smaller proportion of properties within the MHWS buffer zones behind soft coasts that are similarly classified as more vulnerable in the classification. The possible effect of correlation between more urban property types and coastal defences explored within the discussion section.

[2] Total percentages calculated from total number of residential properties in Scotland (OS Residential Footprints) = 2,582,346 properties

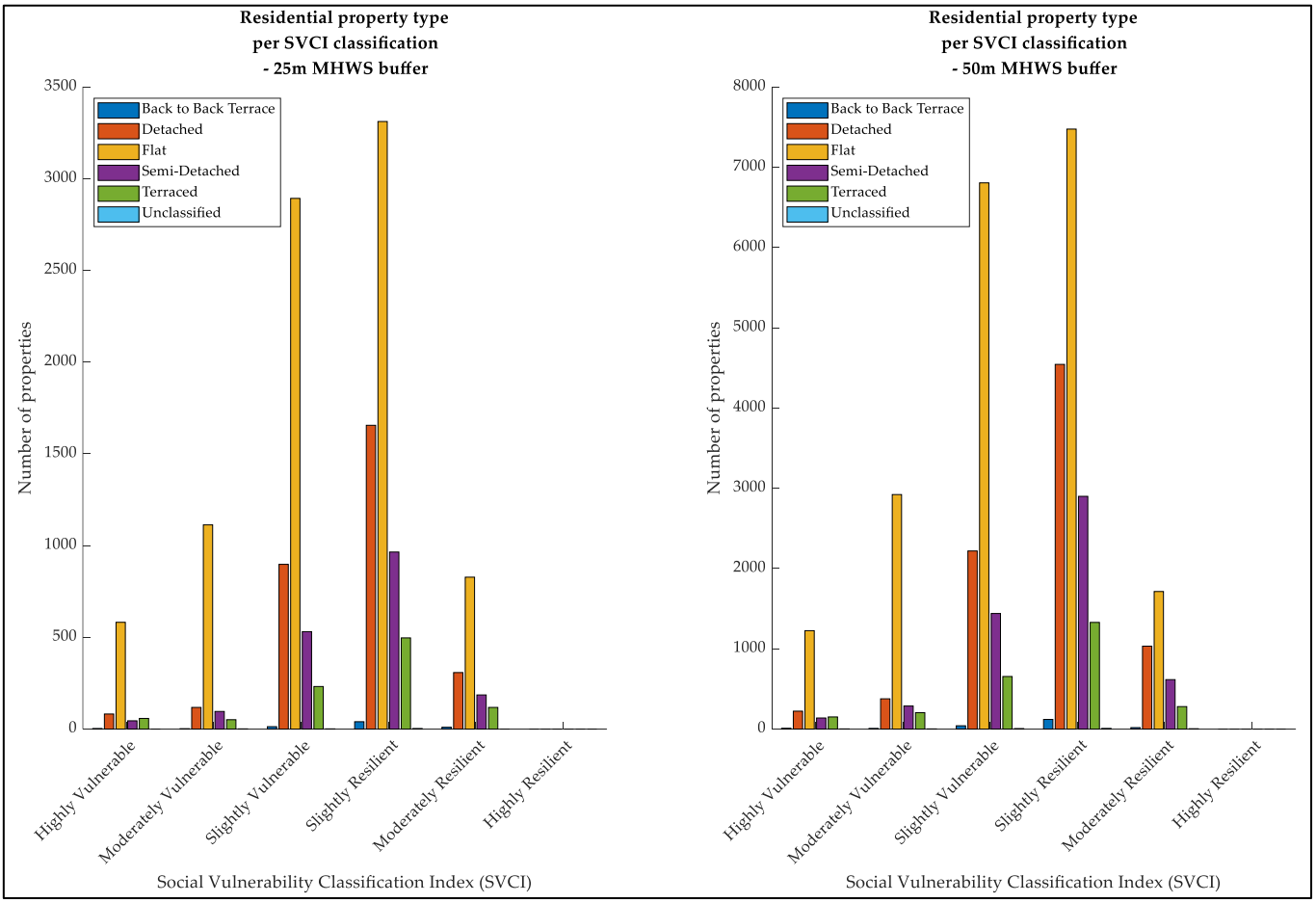

Figure 12: Number of properties within each SVCI grouping, divided into residential property type 25m and 50m MHWS buffers)

The residential property types shown in Figure 12 highlights a predominance of dense, "flat or apartment" housing in coastal areas across almost all SVCI groupings. Interestingly, property types that could be more associated with affluence (e.g., detached) are the second highest numbers of properties in the higher vulnerability classifications (Highly vulnerable to Slightly resistant). This is likely due to the fact that in rural areas property densities are that low that detached properties dominate, this reflects availability of land rather than affluence as it might in in urban areas.

Part 3: Coastal Erosion Disadvantage mapping at regional scales

Mapping Coastal Erosion Disadvantage

This section explores the national-scale analysis of Social Vulnerability and coastal erosion risk, to inform Coastal Erosion Disadvantage. The section above explains how the areas of anticipated erosion (Erosion Area, Erosion Influence and Erosion Vicinity) are matched with the SVCI groupings per data zone. It should be noted that this initial assessment provides a general pattern, and it is hoped that these data are used to further investigate this subject.

Caution is recommended when interpreting the assessments presented below since they are partial and based only on the areas of soft / erodible shores which have been modelled, and exclude those areas not modelled. The areas not modelled include heavily engineered urban shores (where MHWS lies along an engineered structure), salt marsh shores and rocky shores and inner estuarine settings (e.g. Dumbarton), where the modified Bruun rule approach is

inappropriate. Nevertheless, in these instances as sea level continues to rise, future erosion remains entirely plausible. This is particularly true in areas of soft (erodable) materials of mixed origin that were historically claimed land, such as many urban foreshores.

It is worth acknowledging again that residential property is being used to 'bridge' between the risk of erosion and the social vulnerability, as the anticipated erosion mapping cannot be used to support detailed property-level assessments (OS MasterMap shorelines are smoothed/simplified version of reality, our modelling is not designed to account for the local processes operating at these scales). Figure (13) below clarifies the method, by considering two hypothetical locations, both with 5 residential properties clustered within an erodible shore. In these examples both sets of properties are expected to be affected by erosion by 2050 (see anticipated Erosion Area and Erosion Influence polygons), however the social vulnerability is different between these locations. As a result, the Coastal Erosion Disadvantage Mapping highlights the relatively higher disadvantage (with more intense colours in the heat-mapping) for the area with greater social vulnerability. The heat-mapping method (for Coastal Erosion Disadvantage) works well at a regional scale but, cartographically, thin coastal lines are difficult to view at a national scale.

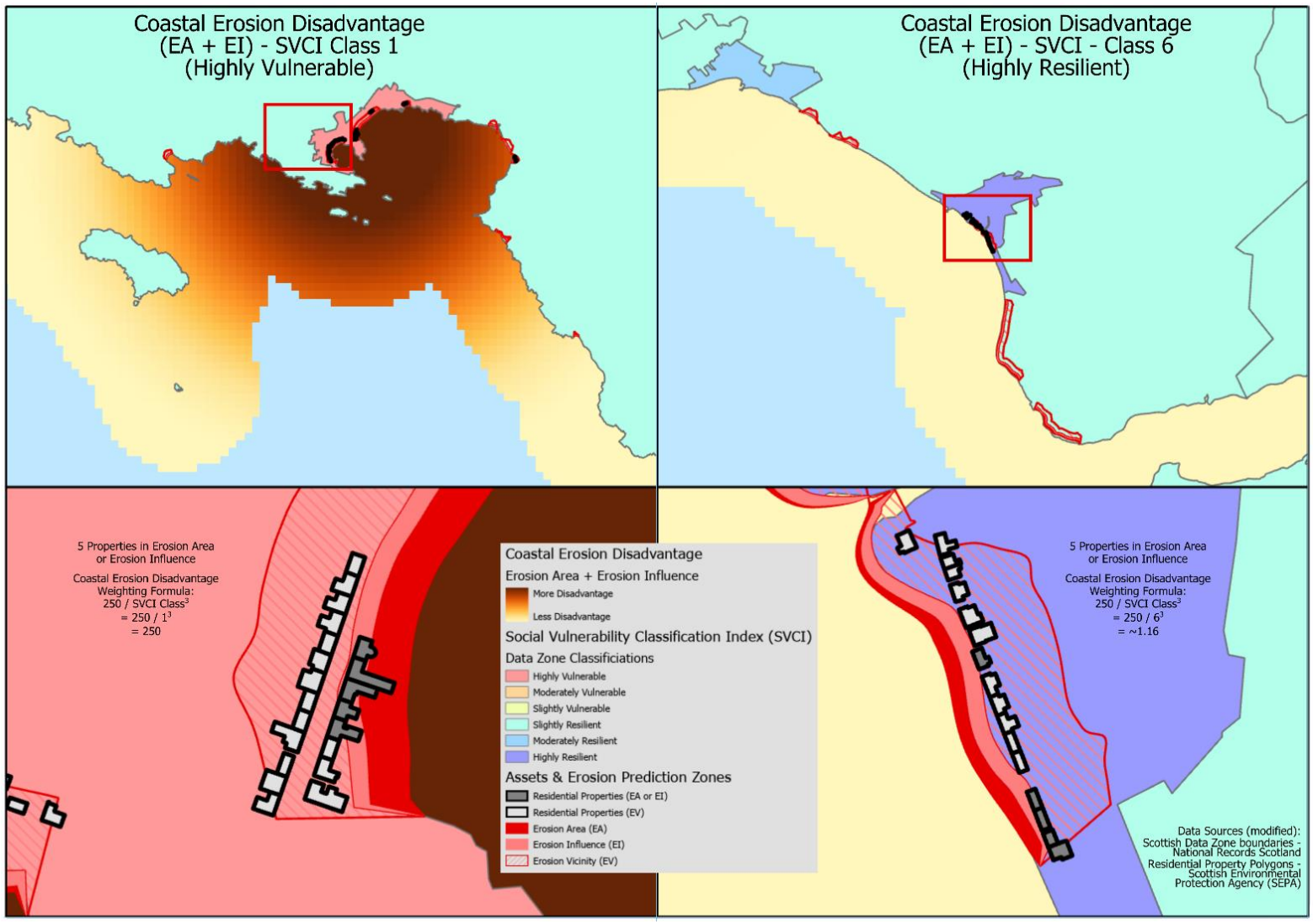

Figure 13: Hypothetical examples of Coastal Erosion Disadvantage mapping. ***Top left****: beige to brown shading along coastal strip indicates greater 'Disadvantage' (ie brown colour) where erosion area and erosion influence (red polygons in bottom left) intersect with a Social Vulnerability class of 6 (highly vulnerable).* ***Top right****: beige shows a similar number of properties affected by erosion but less 'Disadvantage' with a Social Vulnerability class of 1 (Highly Resilient).*

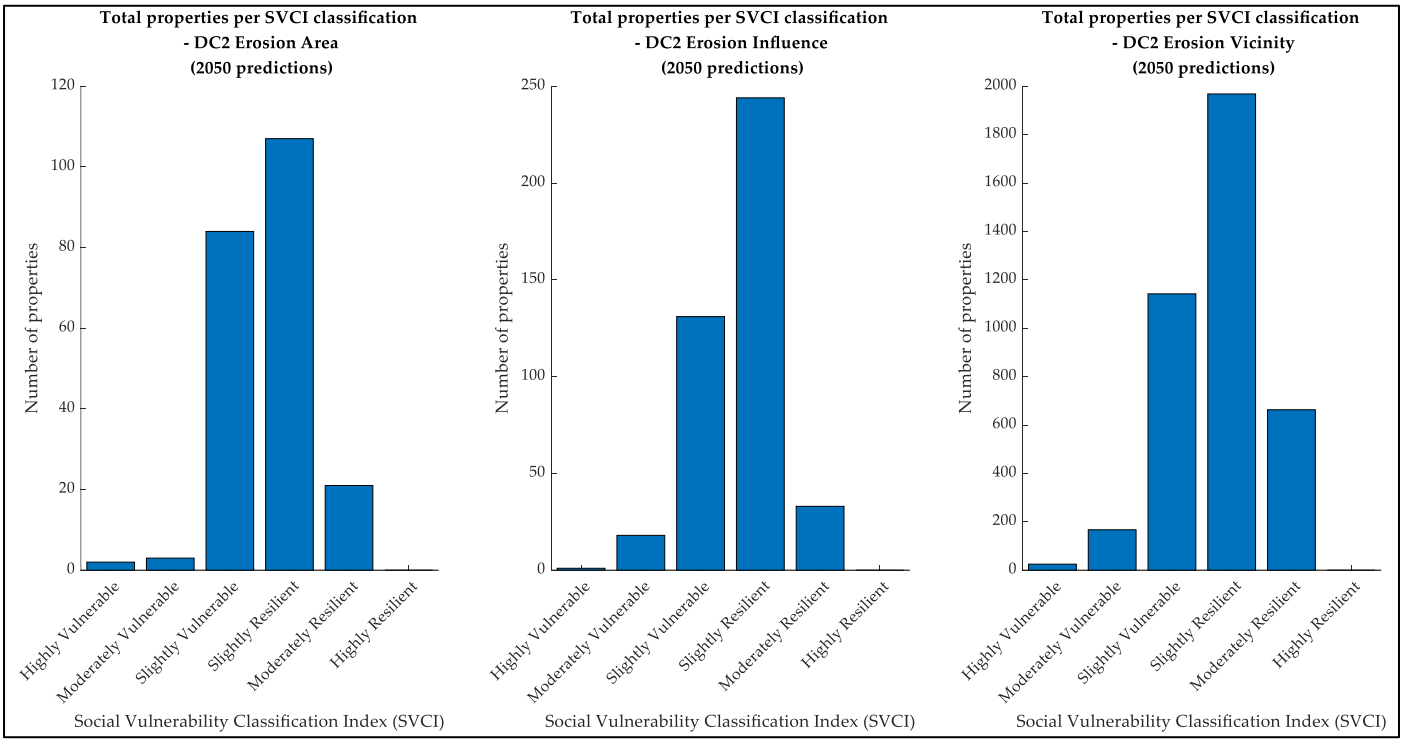

Figure 14: Dynamic Coast 2 erosion zones; distribution of the number of properties in each of the SVCI grouping. Note that whilst Erosion Area and Erosion Influence identify areas likely to be affected by erosion by 2050, Erosion Vicinity relates to adjacent areas not directly impacted.

Table 6: Number of properties in each of the SVCI grouping for the Dynamic Coast 2 2050 erosion prediction areas. Note that whilst EA and EI identify areas likely to be affected by erosion by 2050, EV relates to adjacent areas not directly impacted.

Class Number	SVCI Group	Erosion Area (EA)	Erosion Influence (EI)	Erosion Affected (EA + EI)	Erosion Affected (EA + EI)	Erosion Vicinity (EV)
1	**Highly vulnerable**	2 (0.9%)	1 (0.2%)	3 (0.5%)	239 (37.1%)	25 (0.6%)
2	**Moderately vulnerable**	3 (1.4%)	18 (4.2%)	21 (3.3%)		167 (4.2%)
3	**Slightly vulnerable**	84 (38.7%)	131 (30.7%)	215 (33.4%)		1142 (28.8%)
4	**Slightly resilient**	107 (49.3%)	244 (57.1%)	351 (54.5%)	405 (62.9%)	1968 (49.6%)
5	**Moderately resilient**	21 (9.7%)	33 (7.7%)	54 (8.4%)		663 (16.7%)
6	**Highly resilient**	0	0	0		0
TOTAL[3]		**217 (0.01%)**	**427 (0.02%)**	**644 (0.03%)**		**3965 (0.15%)**

[3] Total percentages calculated from total number of residential properties in Scotland (OS Residential Footprints) = 2,582,346 properties

Noting the caution above, coastal erosion affects a small, but critically important, proportion of the Scottish coast and as such the distribution of social vulnerability in the 2050 Dynamic Coast 2 erosion prediction zones appears much more optimistic than the initial MHWS proximity analysis presented above, which considers the whole coast. As expected, the greatest number of properties identified in this analysis are located within the anticipated Erosion Vicinity (EV) sub-section, which is the 50 m buffered area not directly impacted by erosion and which lies inland of the anticipated Erosion Area and Erosion Influence areas (EA and EI, see Figure 14). Smaller proportions of properties are located in the Erosion Area and Erosion Influence areas which are more likely to be impacted directly before 2050. However, the analysis also identified that many properties in the more at-risk areas fell into the slightly vulnerable & slightly resilient categories (see Figure 6). Figure 16 shows that, particularly for the immediate Erosion Area (EA), detached and semi-detached properties are most at risk. Whilst these may be perceived as more affluent property types, they are also the property types that are more common in rural and semi-rural settings.

Figure 15: Erosion Area (Red) anticipated to be seaward of MHWS in 2050, Erosion Influence (Pink) 10 buffer landward of MHWS 2050 and Erosion Vicinity (Pale Pink) a further 50m landwards. Non- and Residential Property shown & water infrastructure.

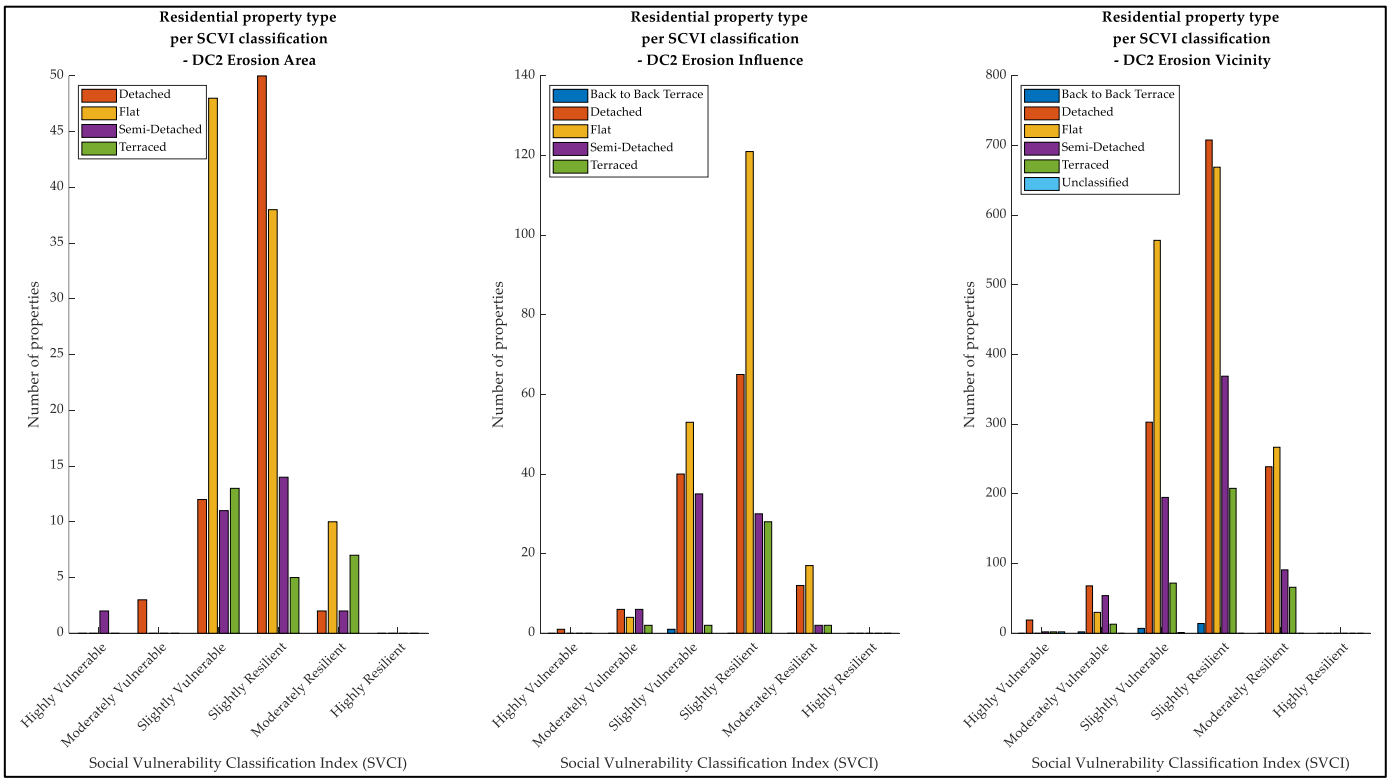

Figure 16: Number of properties per SVCI by residential property type (Dynamic Coast 2 2050 anticipated erosion zones). Spatial distribution of vulnerable Data Zones and risk properties. Regional spatial distribution – Scottish Local Authority (Council) Areas

With local authorities being the main administrative bodies in Scotland and the coast protection authorities (i.e. local authorities empowered under the Coast Protection Act (1949)), it is appropriate to explore the spatial distribution of

social disadvantage at this regional scale. The approach taken in Part 3 is layered as seen in Figure 17, firstly, to include all properties irrespective of social vulnerability classification or coastal defence, secondly, to include all socially vulnerable properties regardless of coastal defence and, thirdly, inclusive of all socially vulnerable properties that are/are not defended by coastal structures. It is also important to note that not all inner coasts and their urban shores are included within our analysis, for example, the Glasgow city region and the heavily defended parts of Edinburgh are excluded from the coastal erosion disadvantage maps as the anticipated erosion mapping deployed in Work Stream 2 (ie modified Bruun rule method used) is not applicable for these settings.

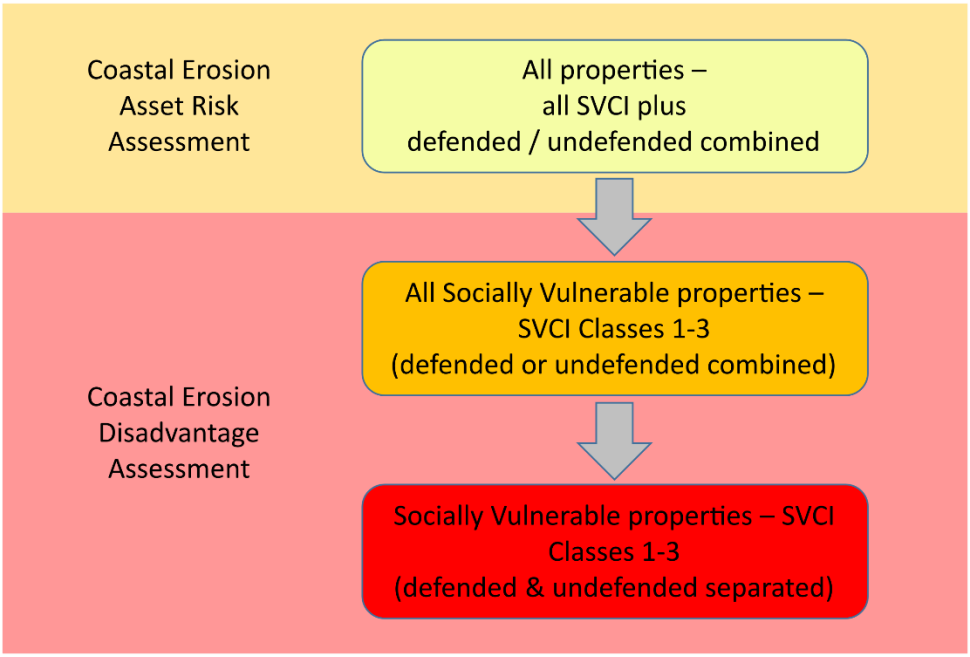

Figure 17: Illustrating how the data and analysis types used in this report differ from each other.

In the figures and tables below, several local authority areas are either missing (tables) or shown as "no properties" (figures), dependent on the layer of the analysis. In the subsequent figures, a reminder is denoted by an asterisk(s), which refers to the following conditions:

* - non-coastal local authority areas (see footnote 5) or coastal LA area with no residential properties identified in an erosion prediction zone (see footnote 6).

** - reasons above (*), plus none of the previous selected properties are classified as socially vulnerable (SVCI classes 1–3; see footnote 7).

*** - reasons above (* & **), plus none of the previously selected socially vulnerable properties are undefended (i.e., all are defended).

After analysing all three erosion prediction zones, plus a combination of Erosion Area (EA) and Erosion Influence (EI) across three layers of processing (all properties, socially vulnerable properties, and defended/undefended socially

vulnerable properties), several local authority areas are highlighted (see Figure 18, Figure 19 & and Table 7, Table 8 & Table 9 respectively).

The two local authorities with the highest Coastal Erosion Disadvantage are East Lothian and South Ayrshire. Both repeatedly identified in the highest classifications on the regional scale maps and across all analyses, indicating not only a significant quantity of properties in these areas at risk, but also the social vulnerability and undefended nature of a large proportion of these areas. The details of the quantity and status of these properties is explored below. It must be noted that this concern does not extend to the whole coastal boundary of these areas. Another general consideration is that despite Highland Region being identified in several of the analyses due to its substantial spatial extent (nearly 1/3 of Scotland's land area) and its long and indented western coast and sparse population, the issues are likely to be significantly less dense than in smaller local authority areas. Note that the results have not been normalised.

All properties – regional scale analysis

At a regional scale, North Ayrshire, East Lothian and South Ayrshire have some of the highest numbers of properties anticipated to be at immediate risk in the next 30 years (Erosion Area + Erosion Influence, in bold in table 7). However, North Ayrshire ranks highest at this stage, mainly due to properties in the zone of "Erosion Influence". When the "Erosion Vicinity" zone is examined, three local authorities have more than 500 properties identified, with a further six having over 200 properties at anticipated risk.

Table 7: Numbers of all properties, irrespective of SVCI grouping or defences, identified in erosion prediction zones by 2050 for each Scottish Local Authority area (top three local authority areas affected in bold). Note null returns have not been included for reasons of brevity.

Scottish Local Authority Area [4] [5]	LA Code	Erosion Area (EA)	Erosion Influence (EI)	Erosion Affected (EA + EI)	Erosion Vicinity (EV)
Aberdeenshire	S12000034	0	37	37	257
Angus	S12000041	1	2	3	40
Argyll and Bute	S12000035	25	35	60	521
City of Edinburgh	S12000036	2	17	19	284
Dumfries and Galloway	S12000006	11	21	32	142
Dundee City	S12000042	2	1	3	9
East Lothian	S12000010	33	51	**84**	369
Falkirk	S12000014	0	13	13	27
Fife	S12000015	41	21	62	504
Highland	S12000017	21	43	64	557
Inverclyde	S12000018	0	18	18	23
Moray	S12000020	19	26	45	132
Na h-Eileanan an Iar	S12000013	0	0	0	32
North Ayrshire	S12000021	13	79	**92**	490
Orkney Islands	S12000023	8	26	34	204
Scottish Borders	S12000026	0	2	2	62
Shetland Islands	S12000027	0	3	3	45
South Ayrshire	S12000028	41	31	**72**	265
West Lothian	S12000040	0	1	1	2
Totals		**217**	**427**	**644**	**3,965**

[4] Five Scottish Local Authority areas do not have a coastal margin – East Ayrshire, East Dunbartonshire, East Renfrewshire, Midlothian & North Lanarkshire. A further six Local Authority areas (Clackmannanshire, Glasgow City, Perth & Kinross, Renfrewshire, South Lanarkshire & Stirling) are deemed only tidal/estuarine. None of these 11 Local Authority areas will be displayed in any of the Local Authority area tables. Other results with zero values indicate no selection, even with a coastal margin.
[5] Two Local Authority areas (Aberdeen City & West Dunbartonshire) have no residential properties selected in erosion prediction zones, even though they are coastal.

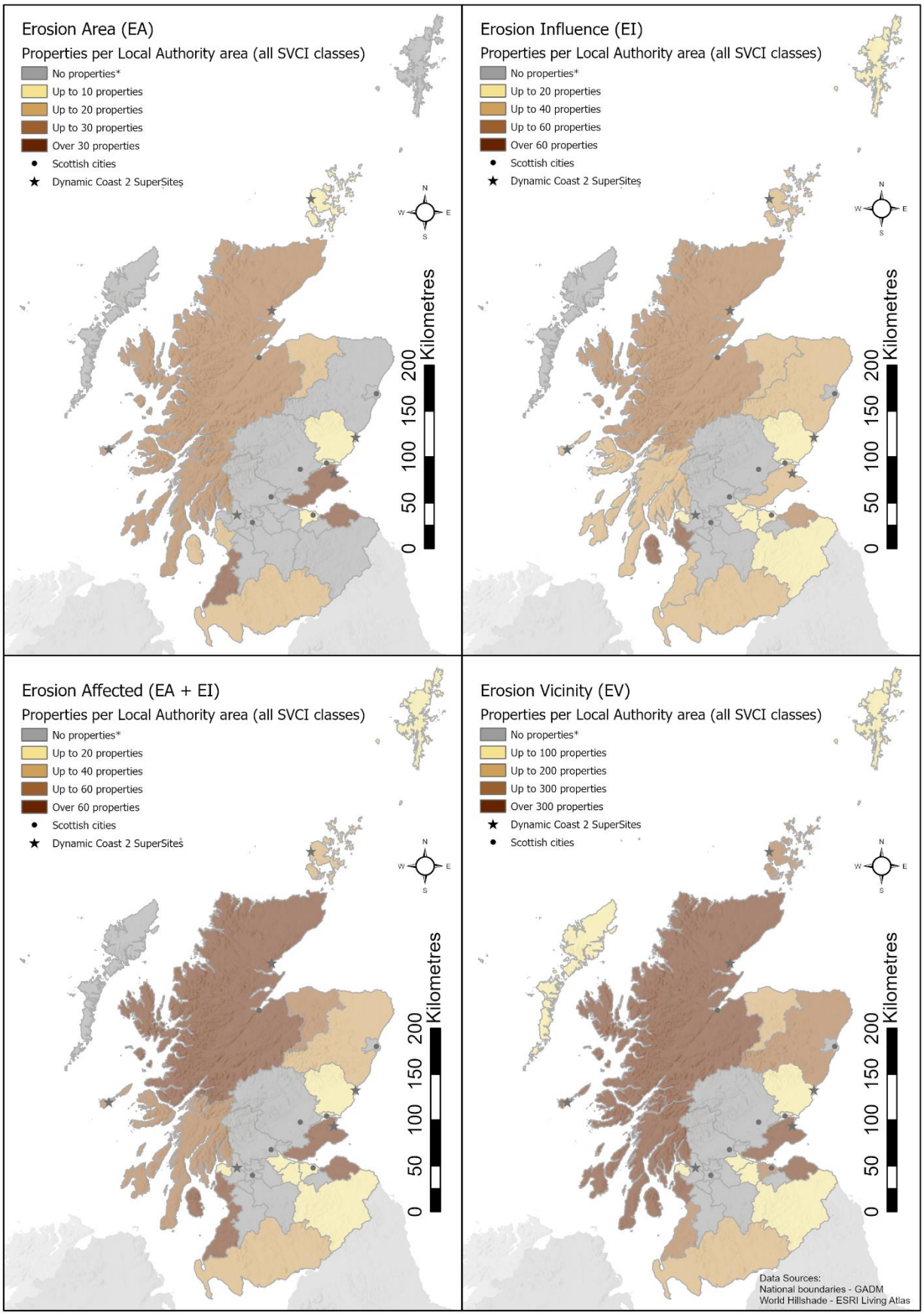

Figure 18: Regional scale analysis with local authority areas showing the number of properties identified within each of the three 2050 erosion prediction zones (EA, EI & EV). Note, this does not account for SVCI groupings (all groups included) or any differentiation between properties that are defended (by artificial structures) or undefended.

Vulnerable properties – regional scale analysis

The second layer of the analysis examined a subset of properties classified as being within socially vulnerable areas (most socially vulnerable i.e. groups 1–3 in the SVCI). This process removed Fife Local Authority area; the first layer of analysis showed 62 Fife properties at immediate risk (EA + EI), however, only 1 of these properties was classified as socially vulnerable in the second layer of analysis. This does not suggest that Fife's coastal communities are immune to the physical hazard risk, but rather that those properties anticipated to be affected are likely more resilient when compared to others in the Scottish coastal community. This demonstrates the benefit of using a layered approach to the analysis, since working from the general to the specific adds variables that identify particular circumstances of concern.

Unpacking the issues in East Lothian and South Ayrshire show both with over 50 socially vulnerable properties at immediate risk (EA + EI), and at least 30 of those in the Erosion Area zone. Four other local authorities (Aberdeenshire, Argyll & Bute, Highland & Orkney) have 20 or more socially vulnerable properties at immediate risk (EA + EI), a substantial proportion of all their properties at risk, together with some in Erosion Area.

Table 8: More socially vulnerable properties (Groupings 1–3) in each local Authority area, identified with 2050 erosion prediction zones. The percentages are relative to the corresponding Local Authority and erosion prediction zone.

Scottish Local Authority Area [5] [6]	LA Code	Erosion Area (EA)[7]	Erosion Influence (EI)[8]	Erosion Affected (EA + EI)[8]	Erosion Vicinity (EV)[8]

[6] No properties within an erosion zone (EA, EI or EV) in Inverclyde are classified as socially vulnerable (CEVI Classes 1, 2 or 3).
[7] Percentage of Total Properties per Local Authority Area identified in the various erosion zones (refer to

After analysing all three erosion prediction zones, plus a combination of Erosion Area (EA) and Erosion Influence (EI) across three layers of processing (all properties, socially vulnerable properties, and defended/undefended socially vulnerable properties), several local authority areas are highlighted (see Figure 18, Figure 19 & and Table 7, Table 8 & Table 9 respectively).

The two local authorities with the highest Coastal Erosion Disadvantage are East Lothian and South Ayrshire. Both repeatedly identified in the highest classifications on the regional scale maps and across all analyses, indicating not only a significant quantity of properties in these areas at risk, but also the social vulnerability and undefended nature of a large proportion of these areas. The details of the quantity and status of these properties is explored below. It must be noted that this concern does not extend to the whole coastal boundary of these areas. Another general consideration is that despite Highland Region being identified in several of the analyses due to its substantial spatial extent (nearly 1/3 of Scotland's land area) and its long and indented western coast and sparse population, the issues are likely to be significantly less dense than in smaller local authority areas. Note that the results have not been normalised.

Aberdeenshire	S12000034	0	22 (59%)	22 (59%)	133 (52%)
Angus	S12000041	1 (100%)	0	1 (33%)	4 (10%)
Argyll and Bute	S12000035	9 (36%)	17 (49%)	26 (43%)	163 (31%)
City of Edinburgh	S12000036	0	0	0	97 (34%)
Dumfries and Galloway	S12000006	0	0	0	31 (22%)
Dundee City	S12000042	0	1 (100%)	1 (33%)	0
East Lothian	S12000010	32 (97%)	29 (57%)	61 (73%)	245 (66%)
Falkirk	S12000014	0	13 (100%)	13 (100%)	27 (100%)
Fife	S12000015	1 (2%)	0	1 (2%)	40 (8%)
Highland	S12000017	5 (24%)	21 (49%)	26 (41%)	194 (35%)
Moray	S12000020	0	7 (27%)	7 (16%)	35 (27%)
Na h-Eileanan an Iar	S12000013	0	0	0	11 (34%)
North Ayrshire	S12000021	1 (8%)	1 (1%)	2 (2%)	86 (18%)
Orkney Islands	S12000023	1 (13%)	19 (73%)	20 (59%)	91 (45%)
Scottish Borders	S12000026	0	2 (100%)	2 (100%)	62 (100%)
Shetland Islands	S12000027	0	3 (100%)	3 (100%)	4 (9%)
South Ayrshire	S12000028	39 (95%)	14 (45%)	53 (74%)	109 (41%)
West Lothian	S12000040	0	1 (100%)	1 (100%)	2 (100%)
Totals		**89 (41%)**	**150 (36%)**	**239 (37%)**	**1,334 (34%)**

All properties – regional scale analysis

At a regional scale, North Ayrshire, East Lothian and South Ayrshire have some of the highest numbers of properties anticipated to be at immediate risk in the next 30 years (Erosion Area + Erosion Influence, in bold in table 7). However, North Ayrshire ranks highest at this stage, mainly due to properties in the zone of "Erosion Influence". When the "Erosion Vicinity" zone is examined, three local authorities have more than 500 properties identified, with a further six having over 200 properties at anticipated risk.

Table 7).

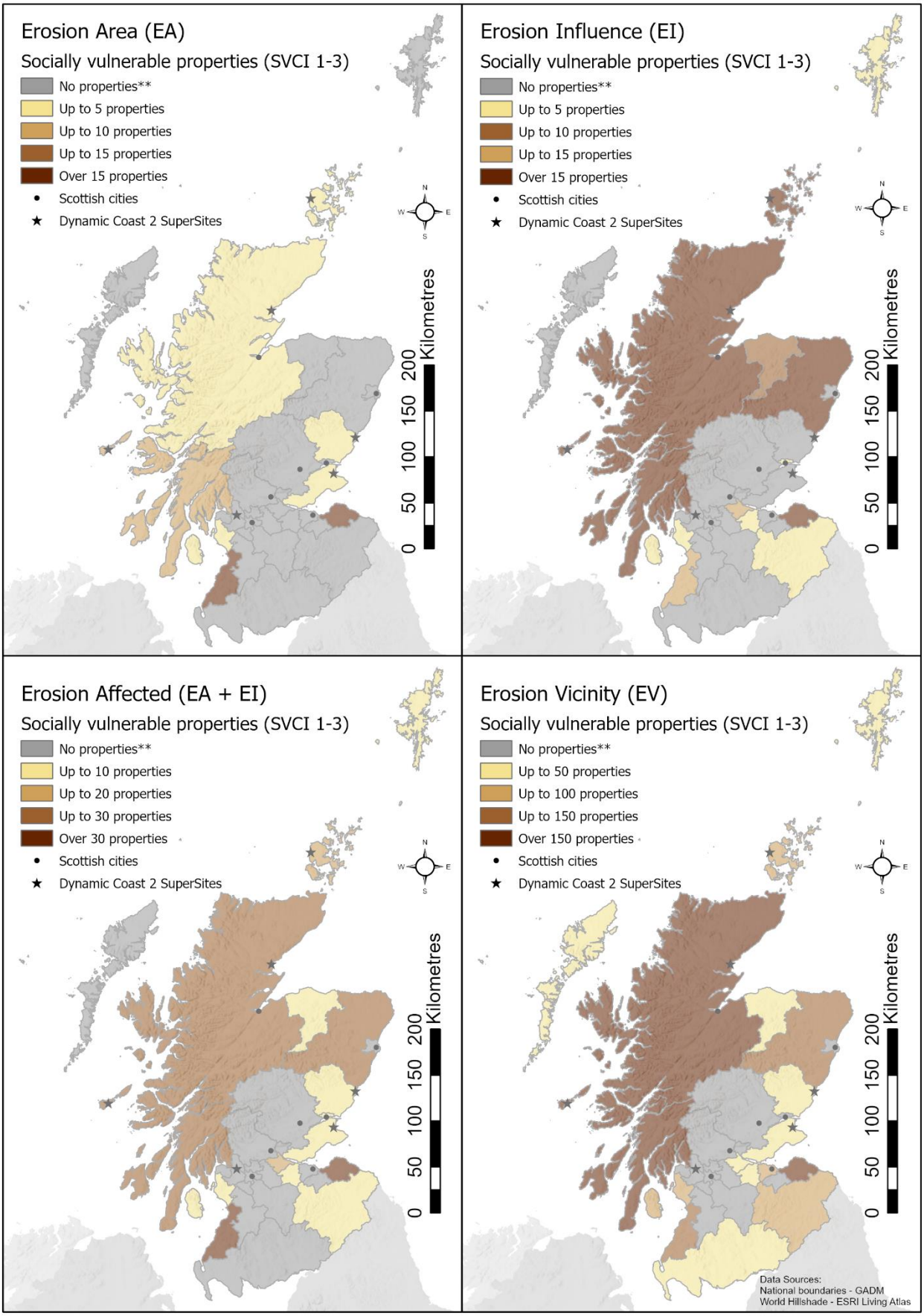

Figure 19: Regional scale analysis with Local Authority areas showing the number of socially vulnerable properties (SVCI Groups 1, 2 & 3) identified within each of the three 2050 erosion prediction zones (EA, EI & EV). Note, this does not differentiate between properties that are defended (by artificial structures) or remain undefended.

All vulnerable properties (defended & undefended) – regional scale analysis

The final layer of this analysis assessed the current location of artificial or structural defences in relation to any socially vulnerable properties identified in the second layer of the analysis above. East Lothian and South Ayrshire stand out again with 30 and 50 undefended and socially vulnerable properties classed at risk by 2050 (EA + EI) respectively, with at least 30 of these in the Erosion Area. Argyll & Bute is also of concern with 96% of properties within the EA and EI zone that are undefended are socially vulnerable. All 22 socially vulnerable households in Aberdeenshire are defended, with the opposite being the case in Falkirk, with all 13 socially vulnerable households currently undefended. Orkney has 19 undefended properties, with only 1 defended by artificial structures.

Overall, 67% of socially vulnerable properties that are at risk by 2050, are currently undefended. Furthermore, the proportion is greater for those socially vulnerable properties beyond predicted immediate risk, with only 18% of properties in the Erosion Vicinity zone being classified as defended. However, some of this may also be a function of the limited buffer zone width applied behind defences.

Table 9: Socially vulnerable properties (SVCI Groupings 1–3), both defended (i.e., with artificial defences) and undefended (natural coastal defences) in each local authority area identified within 2050 erosion prediction zones. The percentages are relative to the corresponding total number of socially vulnerable properties in each Local Authority and anticipated 2050 erosion zone in Table 8, therefore, both defended and undefended are the inverse of each other.

Scottish Local Authority Area[5 6 7]	LA Code	Erosion Area (EA)		Erosion Influence (EI)		Erosion Affected (EA + EI)		Erosion Vicinity (EV)	
		Defended	Undefended	Defended	Undefended	Defended	Undefended	Defended	Undefended
Aberdeenshire	S12000034	0	0	22 (100%)	0	22 (100%)	0	67 (50%)	66 (50%)
Angus	S12000041	0	1 (100%)	0	0 (100%)	0	1 (100%)	0	4 (100%)
Argyll and Bute	S12000035	1 (11%)	8 (89%)	0	17 (100%)	1 (4%)	25 (96%)	15 (9%)	148 (91%)
City of Edinburgh	S12000036	0	0	0	0	0	0	39 (40%)	58 (60%)
Dumfries and Galloway	S12000006	0	0	0	0	0	0	6 (19%)	25 (81%)
Dundee City	S12000042	0	0	1 (100%)	0	1 (100%)	0	0	0
East Lothian	S12000010	30 (94%)	2 (6%)	1 (3%)	28 (97%)	31 (51%)	30 (49%)	22 (9%)	223 (91%)
Falkirk	S12000014	0	0	0	13 (100%)	0	13 (100%)	0	27 (100%)
Fife	S12000015	1 (100%)	0	0	0	1 (100%)	0	16 (40%)	24 (60%)
Highland	S12000017	3 (60%)	2 (40%)	10 (48%)	11 (52%)	13 (50%)	13 (50%)	7 (4%)	187 (96%)
Moray	S12000020	0	0	1 (14%)	6 (86%)	1 (14%)	6 (86%)	3 (9%)	32 (81%)
Na h-Eileanan an Iar	S12000013	0	0	0	0	0	0	3 (27%)	8 (73%)
North Ayrshire	S12000021	1 (100%)	0	1 (100%)	0	2 (100%)	0	5 (6%)	81 (94%)
Orkney Islands	S12000023	0	1 (100%)	1 (5%)	18 (95%)	1 (5%)	19 (95%)	7 (8%)	84 (92%)
Scottish Borders	S12000026	0	0	2 (100%)	0	2 (100%)	0	18 (29%)	44 (71%)
Shetland Islands	S12000027	0	0	0	3 (100%)	0	3 (100%)	0	4 (100%)
South Ayrshire	S12000028	2 (5%)	37 (95%)	1 (7%)	13 (93%)	3 (6%)	50 (94%)	34 (31%)	75 (69%)
West Lothian	S12000040	0	0	0	1 (100%)	0	1 (100%)	0	2 (100%)
Totals		**38 (43%)**	**51 (57%)**	**40 (27%)**	**110 (73%)**	**78 (33%)**	**161 (67%)**	**242 (18%)**	**1,092 (82%)**

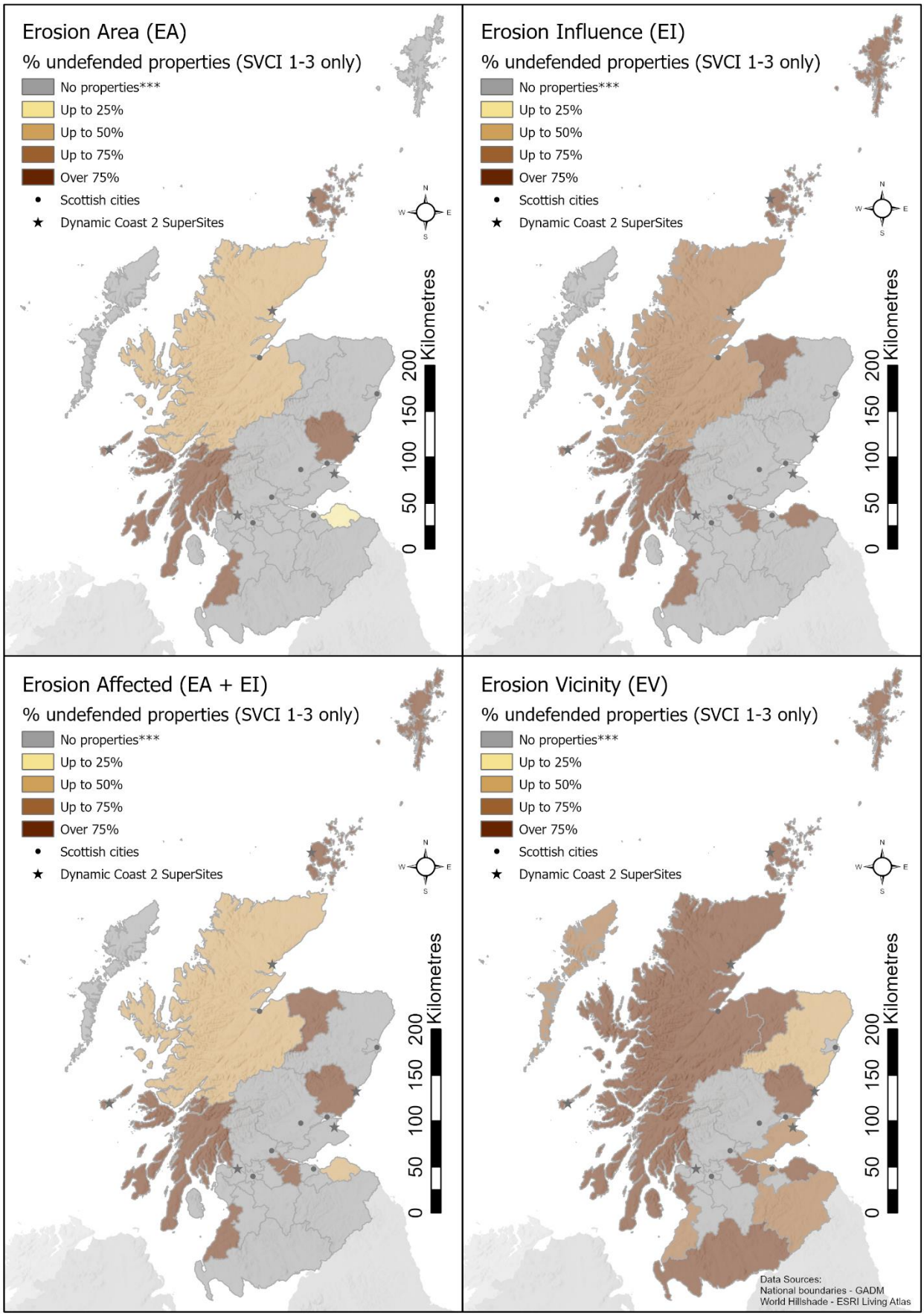

Figure 20: Regional scale analysis with Local Authority areas showing the number of socially vulnerable properties (SVCI Groupings 1, 2 & 3) identified within each of the three 2050 erosion prediction zones (EA, EI & EV) that are also undefended by artificial structures. Note resulting percentages in some Local Authority areas (Table 9) can be inverted to identify areas of socially vulnerable properties that are defended.

Localised spatial distribution – selected exemplar sites

This set of results demonstrate the localised spatial distribution of properties selected, together with the social vulnerability of their inhabitants to coastal change. Two correlated approaches have been taken. Firstly, a count of the number of properties within each Data Zone, along with consideration of the Social Vulnerability of the given data zones can be seen in Table 10. Here, particular attention has been paid to the three Social Vulnerability groupings (Groups 1, 2 & 3; Highly, Moderately & Slightly Vulnerable respectively). The second element of this analysis involved mapping, at national scale, the SVCI data, weighting towards those data zones with more socially vulnerable classifications (see methodology for more details). The coastal erosion disadvantage maps that follow (Figures 17 to 21) show data derived from properties affected by the Erosion Area (EA) prediction, as well as those identified in the Erosion Vicinity (EV) prediction. A coast-parallel "heatmap" demonstrates the relative level of coastal erosion and a range of sites emerge that would benefit from more detailed and localised investigation.

The two focus sites are used to exemplify the methodology:

1. South of Girvan, South Ayrshire
2. Prestonpans, East Lothian.

Both sites have been repeatedly identified as the most socially vulnerable Data Zones in the SVCI (Table 10) and the national "heatmap" for the various Dynamic Coast 2 erosion prediction zones (2050), and the wider regional scale local authority analysis. Girvan, there are alternative text for public version: less than five properties within the Carrick South 03 Data Zone (S01012419) which is classified as Highly Vulnerable (Social Vulnerability Class 1), and a further 37 properties in Carrick South 01 Data Zone (S01012417), classified as Slightly Vulnerable (SVCI Group 3) – all of which are within the Erosion Area predictions for 2050. In Carrick South 01, there are a further 13 properties in Erosion Influence, as well as a larger contingent (2 EA & 17 EI) within the southern Data Zone of Girvan Ailsa 01 (S01012429), classified as Slightly Resilient (SVCI group 4).

The Prestonpans focus site contains 22 slightly vulnerable properties (SVCI group 3) in the Erosion Area prediction zone located within IZ07 Data Zone (S01008203). A further 28 properties are located within Erosion Influence in the same area, the highest number for this combination of erosion zone and Social Vulnerability classification across the country. The results for this area also show over 500 properties within Erosion Vicinity prediction zones being identified across 15 km of coast toward the Edinburgh suburb of Musselburgh. The majority of Data Zones along this stretch are classified as either Slightly Vulnerable or Slightly Resilient (SVCI Groups 3 & 4).

Table 10: Data Zones of Concern within the Dynamic Coast 2 2050 prediction zones. In each box the top three rows in white show the Data Zones with most properties in the given erosion prediction zones (irrespective of SVCI grouping). The bottom three coloured rows indicate the Data Zones with most properties for that given SVCI grouping & 2050 erosion prediction zone. {Note this is the Full version of the table below, a revised table is copied on the next page for public release, where '<5 properties' is used and the Data Zone ID column is removed}

Dynamic Coast 2; 2050 predictions - Erosion Area (EA)			
	Number of Properties	**Data Zone Name (location)**	**Soc. Vuln. Class**
Most properties	37	Carrick	3
2nd most properties	22	Prestonpans	3
3rd most properties	20	Kinghorn North	4
Most properties in Highly Vulnerable	< 5	Carrick	1
Most properties in Moderately Vulnerable	< 5	Lunan	2
Most properties in Slightly Vulnerable	37	Carrick	3
Dynamic Coast 2; 2050 predictions - Erosion Influence (EI)			
	Number of Properties	**Data Zone Name (location)**	**Soc. Vuln. Class**
Most properties	62	Fairlie and Rural	4
2nd most properties	28	Prestonpans	3
3rd most properties	18	Inverkip and Wemyss Bay	4
Most properties in Highly Vulnerable	< 5	Cowal North	1
Most properties in Moderately Vulnerable	11	Isles	2
Most properties in Slightly Vulnerable	28	Prestonpans	3
Dynamic Coast 2; 2050 predictions - Erosion Vicinity (EV)			
	Number of Properties	**Data Zone Name (location)**	**CEVI Class**
Most properties	180	Largs	5
2nd most properties	133	Earlsferry	5
3rd most properties	105	Fairlie and Rural	4
Most properties in Highly Vulnerable	43	Cowal North	1
Most properties in Moderately Vulnerable	74	Arran	2
Most properties in Slightly Vulnerable	101	Musselburgh	3
Undefended Properties (DC2 EA + EI areas, undefended)			
	Number of Properties	**Data Zone Name (location)**	**CEVI Class**
Most properties	50	Carrick South	3
2nd most properties	29	Prestonpans	3
3rd most properties	16	Girvan Ailsa	4
Most properties in Highly Vulnerable	< 5	Cowal	1
Most properties in Moderately Vulnerable	11	Isles	2
Most properties in Slightly Vulnerable	50	Carrick	3

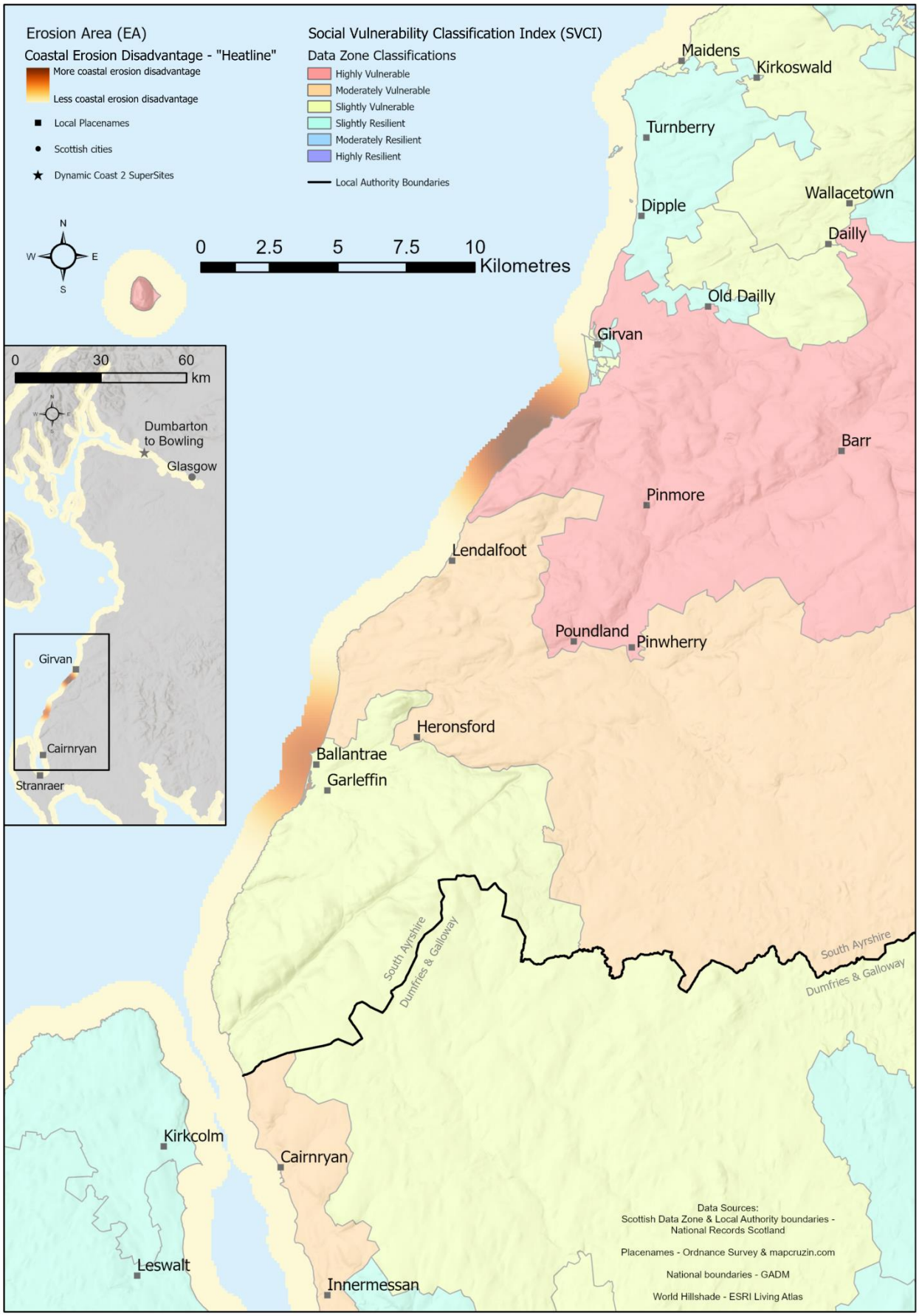

*Figure 21: Coastal Erosion Disadvantage "heatmap" showing coastal property areas identified in the 2050 **Erosion Area** prediction zone, alongside Social Vulnerability classification to the south of Girvan, South Ayrshire.*

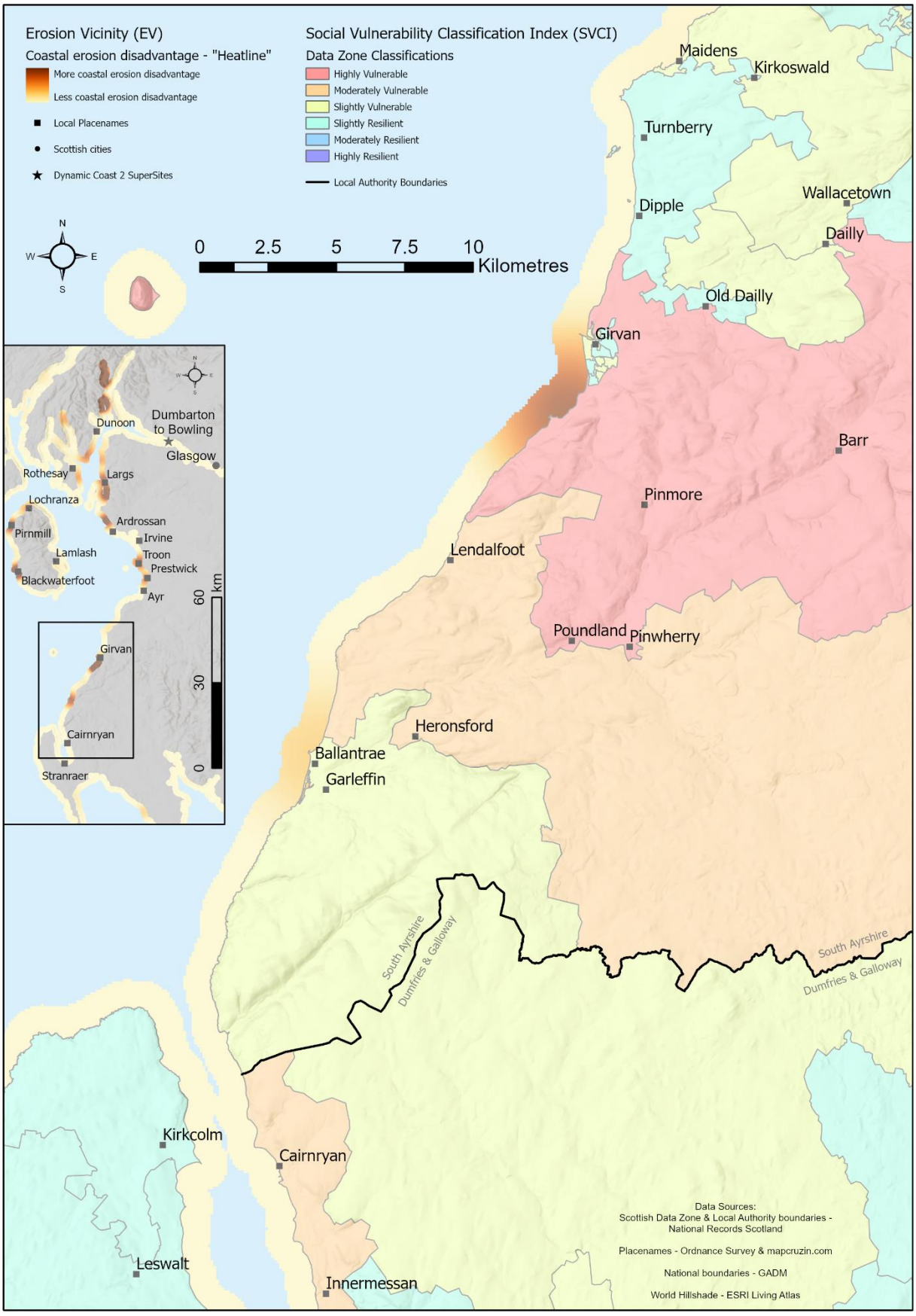

*Figure 22: Coastal Erosion Disadvantage "heatmap" showing coastal property areas identified in the 2050 **Erosion Vicinity**, alongside SVCI results for the south of Girvan, South Ayrshire. Note several other areas on the western side of Arran and into the Firth of Clyde (see inset map).*

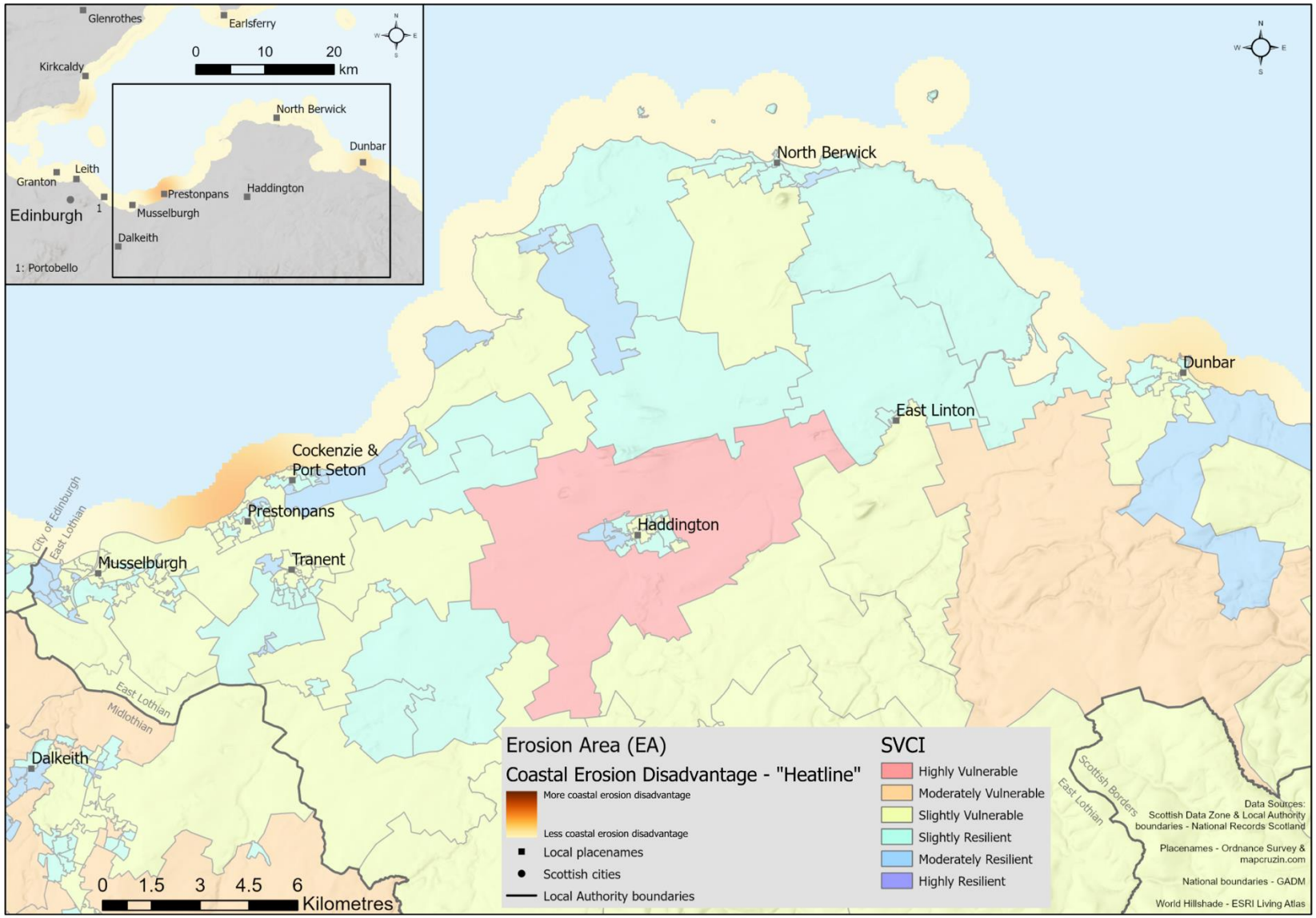

Figure 23: Coastal Erosion Disadvantage "heatmap" showing coastal property areas identified in the 2050 Erosion, alongside SVCI results for the East Lothian coast, most notably around Prestonpans.

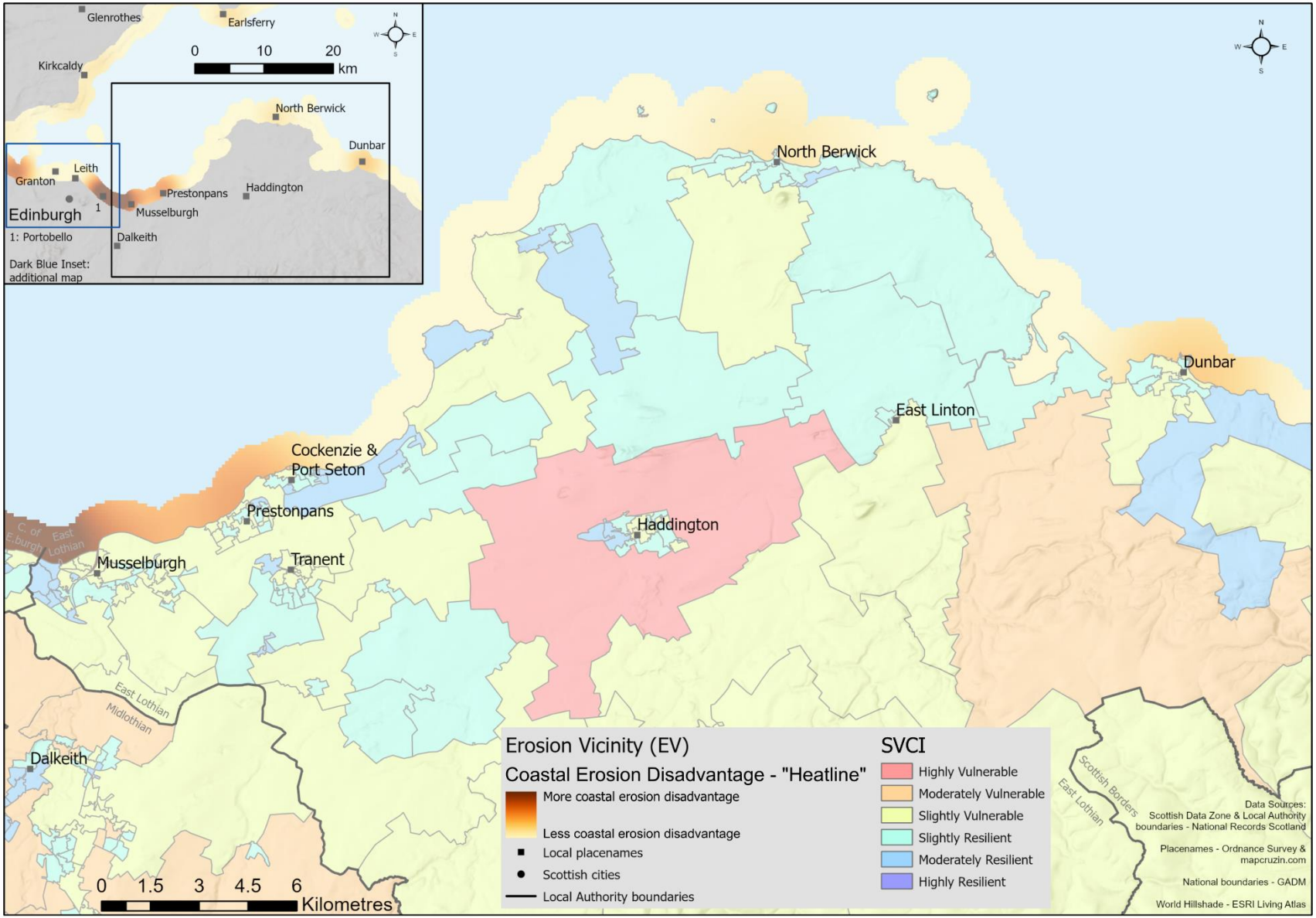

*Figure 24: Coastal Erosion Disadvantage "heatmap" showing coastal property areas identified in the **2050 Erosion Vicinity** prediction zone, alongside SVCI results for the East Lothian coast. Note the extension west T into the City of Edinburgh Local Authority area (see inset map).*

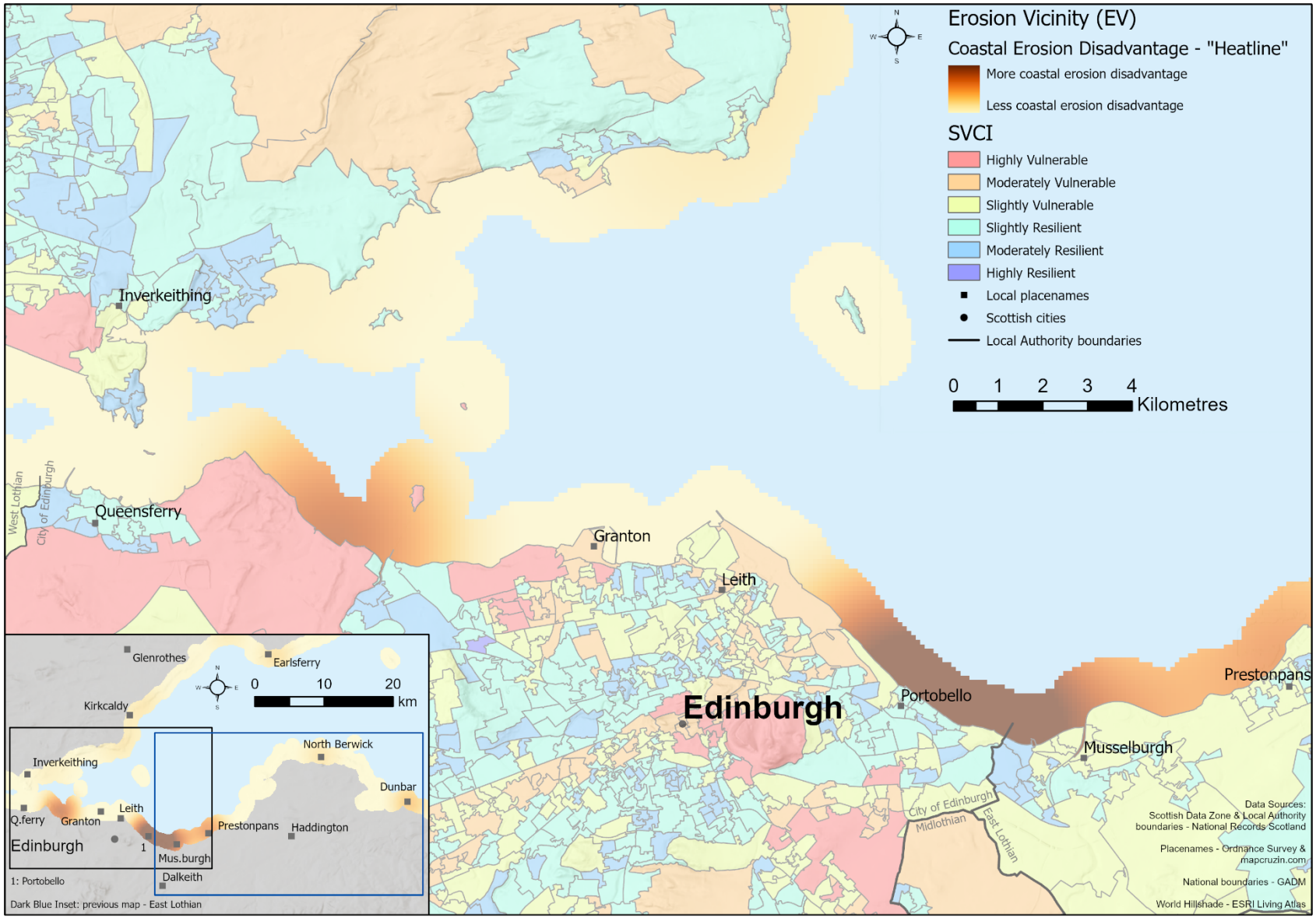

*Figure 25: Social vulnerability "heatmap" showing coastal property areas identified in the **2050 Erosion Vicinity** prediction zone, alongside SVCI results for the Edinburgh coast. The zone of concern peaks at Portobello with a smaller hotspot near the suburb of Cramond (Cramond Island west of Granton is uninhabited).*

Interactive web-map of DC2 WS6 analysis

See the link below for an interactive web-map of the Dynamic Coast phase 2 results, including Work Stream 6 (Social vulnerability to coastal erosion):

Browser link
www.dynamiccoast.com/webmaps.html

Discussion

Coastal social vulnerability and national social vulnerability in Scotland

Developing a Coastal Erosion Disadvantage map in Scotland, required inclusion of all national level Data Zones, regardless of proximity to the coast, to allow for the relative rates of social vulnerability on the coast to be compared with the overall national context (Figure 6 and Table 4). Lindley et al. (2011a) noted that 'the most socially vulnerable neighbourhoods in the UK tend to be in urban or coastal locations', yet Figure 5 suggests that the Scottish coastal locations covered by this analysis may have broadly similar social vulnerability levels, given that 39.1% of households in coastal areas are recorded as being within the top three socially vulnerable groups within the SVCI. This is in comparison to 44.2% of households at a national level. This may be attributable to the high density of households considered to be more socially vulnerable in Scotland's urban areas. It is also important to note that not all inner coasts and their urban shores are included here (for example, the inner Clyde, Glasgow city region and parts of Edinburgh) are excluded from our coastal erosion disadvantage maps). It is therefore important to note that levels of coastal erosion disadvantage would likely increase if these areas were included in future work.

Social vulnerability and risk – coastal proximity & erosion

National MHWS buffers

Stage one in the analysis involved identification of properties in proximity to the Scottish coast, irrespective of whether the coast at these given locations was eroding or not. Figure 9 and Table 5 show that 14,642 residential properties lie within 25 m of the current MHWS. So, a substantial number of properties lie in proximity to MHWS and are anticipated to be at increasing risk of erosion and flooding due to erosion and rising sea level, with 54% of these in the highly, moderately or slightly vulnerable categories. When the distance is doubled to 50 m from the current MHWS position, the number of properties affected increases by 151% to 36,759 with 50% of these households in the highly, moderately or slightly vulnerable categories. However, Table 5 suggests about 46% of coastal properties lie in the less vulnerable categories. It should also be noted that even minor changes in the socio-economic situation of households within the resilient categories may render them more vulnerable; no properties are identified as being highly resilient and only 10% as moderately resilient across the 25m and 50m from current MHWS zones.

Within this data, there is some expected auto-correlation between more socially vulnerable groupings (influenced by population density) and the presence of coastal defences (also influenced by the density of assets). The SIMD, from which much of our dataset is drawn, was designed to explore the social characteristics of the Scottish population as a whole and it will be strongly influenced by the characteristics of higher density (i.e. urban) areas. Similarly, the cost-benefit analysis for artificial coastal protection favours coastal areas with greater density of assets. We raise this here, not to undermine the association of greater social vulnerability of areas which have artificial defences, but to acknowledge that behind these average figures there are likely to be subtle variations which can be investigated in further research. Further to this, Figure 10 reveals that some of the most socially vulnerable groups (highly/moderately vulnerable) living along the Scottish coast are protected by artificial coastal defences. It does, however, appear that

the most socially vulnerable groups are less represented behind soft coasts. These findings emphasize the importance of current coastal defences in areas protecting some of Scotland's most vulnerable citizens, yet these results also suggest that broader consideration of alternative approaches to ongoing coastal change may need to be considered in order to reduce the potential risk to these highly/moderately vulnerable populations. Figure 12 gave insight into the potential for high density housing types to dominate patterns within the analysis (i.e., tenement flats), with several properties sharing the same footprint are the most numerous coastal property type across all classifications and buffer zones. The relative proportion of flats also appears greatest in the three most vulnerable classifications. The GIS data and analysis was such that a single building footprint with multiple properties (i.e., tenement flats) was identified by multiple overlapping polygons. However, if a single block of flats is damaged during an event, it is likely that many individuals would be affected, and it is quite likely those that are some of the most vulnerable or only slightly resilient.

Dynamic Coast 2 erosion areas – 2050 predictions

Using the anticipated erosion data from the Dynamic Coast 2 project, notably the Erosion Area (EA), Erosion Influence (EI) and the adjacent Erosion Vicinity (EV) data allows for the identification and assessment of the social vulnerability of current households close to known locations of active or highly probable coastal erosion anticipated over the next 30 years. Figure 12 and Table 6 indicate the level of social vulnerability in these areas of known or probable erosion is slightly less when comparing to the equivalent data related to the 25m and 50m MHWS buffer zones. 239 or 37% of all properties are identified in two most socially vulnerable groupings across two erosion prediction zones (EA& EI), with just over 50% classed as slightly resilient, 10% moderately resilient and none as highly resilient.

Figure 13 indicates that when the property data is disaggregated to housing type, then detached and semi-detached properties appear disproportionately represented in the Erosion Area (EA), Erosion Influence (EI) prediction zones Figure 16). Whilst these may be perceived as more affluent property types, they are also the residential property types that are more common in rural and semi-rural settings.

Considering the number of properties affected by coastal erosion related events and irrespective of associated social vulnerability of households, Table 7 indicates that, within the next 30 years, 644 properties across all local authority areas with erosion impacted coastline, are at immediate risk of exposure to coastal erosion related events (i.e. they are located within either the anticipated 'Erosion Area' or the 'Erosion Influence' area). This figure expands to 3,965 properties identified as being within the Erosion Vicinity. However, the spread of at-risk properties likely to be affected by coastal erosion related events within the next 30 years is not equally distributed; Table 7 and Figure 14 indicate that the areas with the highest numbers of affected properties within the Erosion Area or Erosion Influence Area are within North Ayrshire, East Lothian, Fife and South Ayrshire.

In addition, there are also significant numbers of properties sited within the Erosion Vicinity area, most notably in Argyll and Bute, Fife and Highland. Furthermore, another six local authority areas have over 200 properties at risk of coastal erosion related events (North Ayrshire, East Lothian, Aberdeenshire, the City of Edinburgh, South Ayrshire and the Orkney Islands). This suggests that, while the risk of coastal erosion related events may not be immediate, current

properties (and any future properties added to these zones as a result of future development) in a significant number of local authority areas across Scotland are likely to be exposed to erosional events in the longer term, where no action is taken to resist erosion within these local authority areas.

The SVCI analysis seeks to relate the numbers of properties at risk of exposure to coastal-erosion related events against levels of social vulnerability. Table 9 show that 15 of the 18 Scottish local authority areas presented include socially vulnerable households that are at risk of coastal erosion related events within the next thirty years. The areas likely to be most significantly affected, as identified within the results section of this report are East Lothian and South Ayrshire. Furthermore, a significant number of socially vulnerable households within an erosion vicinity area across almost all local authority areas – showing that vulnerability to anticipated erosion is widespread across Scotland.

A significant factor in determining the effects of coastal erosion is the presence and condition of existing coastal protection assets. Table 9 and Figure 16 show that, while the coast is currently defended in many of the local authority areas identified as having higher numbers of socially vulnerable households, several, notably East Lothian and South Ayrshire currently lack hard erosion resist assets.

This overall aim of this report was to identify areas of anticipated coastal erosion in relation to social vulnerability and to this end we developed a national scale Coastal Erosion Disadvantage Map (available online as an interactive web-map). Our conceptualisation of "Coastal Erosion Disadvantage" underpins these maps and considers both risks associated with geographical exposure, as well as the presence of households and communities considered to be experiencing a high level of social vulnerability now and in the future. This relative level of vulnerability is represented via a 'heatmap'. Exemplar heatmaps (Figures 17–21) serve to graphically represent the methodology used and highlight at risk areas. Figure 17 indicates, for example, that the area to the south of Girvan, in South Ayrshire is anticipated to experience a significant level of Coastal Erosion Disadvantage, within the next 30 years, due to the coincidence the immediate anticipated Erosion Area and an area experiencing a high level of social vulnerability according to our SVCI analysis. Figure 18 also shows the area of the south of Girvan, South Ayrshire, to have a number of socially vulnerable households within the anticipated 2050 Erosion Vicinity zone, further extending the implications of the levels of coastal erosion disadvantage likely to be experienced by the local households and communities of this local authority area. A similar context can be observed for the East Lothian coast, most notably around Prestonpans (Figure 19 and 20) where Coastal Erosion Disadvantage levels emerge as being high, due to the combination of the vicinity of households within the anticipated erosion area and the erosion vicinity and levels of social vulnerability, as identified within the SVCI. A final demonstration of the heatmap of Figure 21 indicates the presence of coastal disadvantage for areas of coast surrounding the city of Edinburgh where the modified Bruun rule approach could be used. Here there is evidence that households may be unequally affected by coastal erosion related events; due to the presence of hard erosion resist infrastructure limiting the geographical scope of analysis presented here, the underlying risks in this area are likely to be underestimated.

Finally, in the above discussion, it should be noted that that the heatmaps devised through the SVCI assessment reflect the fact that social vulnerability is most pronounced in the urban areas included in this analysis. This results from population density, as well as a range of factors concerning the characteristics of social deprivation in Scotland (SIMD 2020). Unsurprisingly, the heat-mapping exercise has highlighted the vulnerability of urban areas, where both a greater level of deprivation and higher densities of people and property occur. It is important, that we recognise that one limitation of the heat-mapping exercise is that the vulnerability of urban areas will appear to be more pronounced. The heat-maps are an effective visualisation of the interaction between social vulnerability and coastal erosion-based events at a range of spatial scales, but it is crucial that the context of individual areas, and, in particular, rural and isolated areas, are accounted for when appraisals of coastal defences are being considered: reading of the heat-maps is thus perhaps most effectively done at a local scale.

Conclusion and Future impacts upon coastal communities in Scotland

Coastal erosion is acknowledged to be a cross-cutting issue, expected to affect multiple aspects of Scottish society (Scottish Climate Change Adaptation Programme 2019–2024). For this reason, it is acknowledged within the Scottish Governments key policy statements, a recent example is the Economic Recovery Implementation Plan (August 2020) which states: *'Continuing to support Local Authorities to develop and implement flood protection schemes and will look to support future investment in coastal change adaptation measures'*. This report also acknowledges the importance of Natural Capital, and it is within this framework we acknowledge the essential role of natural defences protecting Scotland coastal assets. Whilst aspects of 'Just Transition' are focussed on mitigation pathways to NetZero, we argue that the outputs from this analysis (mapping coastal disadvantage) allows social justice aspects to be incorporated within resilience and adaptation also to be incorporated.

By 2043, the Scottish population is expected to grow by 2.5% to 5.57 million (NRS, 2019). There is also considerable uncertainty pertaining to levels of immigration to Scotland, following the departure of the UK from the EU (Scottish Government, 2019). Population growth is likely to place increasing pressure upon resources and services, both in terms of expansion and in responding to the needs of a more complex society. Simultaneously, the proportion of people of pensionable age is expected to increase from 19% currently to 23% of the population by 2043, while the proportion of those of working age is expected to fall in the same period (NRS, 2019). These are important factors to consider while working with the social vulnerability findings presented here, in that population growth as well as an aging population are factors that are likely to increase the vulnerability for coastal communities, and which are likely to place increasing pressure on national resources, including the National Health Service, as well as services for which local councils are responsible, for example, residential care. In addition, changes to coastal erosion and flood risk may be a factor influencing social vulnerability (e.g. affecting physical and mental health).

Alongside these social parameters that are likely to change, it is worth noting that the condition and design life of existing artificial coastal defences, helping to reduce current vulnerability in urban communities, is largely unknown

across Scotland due to insufficient data (both in terms of coverage and quality); although climate change risks are expected to dramatically increase the costs of repairs and maintenance of these artificial structures (Burgess et al. 2018). Consequently, although artificial coasts (much of it protecting made ground), accounts for only 3% of the total Scottish coast (Hansom et al, 2017), artificial coasts currently protect some of the most vulnerable properties and communities; the social vulnerability analysis shows the highest number of vulnerable properties to lie behind artificial coastal structures (Figure 10). In general, the greatest social vulnerability is present within urban areas where these structures are typically more prevalent. However, it should be noted that the inability of present models to anticipate erosion risk on urban shores (without fronting beaches) means that only a proportion have been modelled here, likely resulting in an underestimation of the full extent of social vulnerability to erosion. Together these are especially pertinent issues to consider given that six of the major Scottish cities are positioned on Scotland's coast and the communities within several of these cities, for example, Dundee, exhibit high levels of social vulnerability. Conversely, it emerges from the social vulnerability analysis that it will also be important to consider the impact of coastal erosion events on island communities, where resources may become compromised due to coastal erosion or coastal erosion related flooding events in future, leaving these communities less able to draw upon key services and employment opportunities, which increase the likelihood of such places already experiencing the effect of population decline (Bunting, 2017), becoming at risk to community blight (Fitton et al., 2018). These data, composed of the anticipated coastal changes and the social vulnerability of our society to these changes, provide an important evidence base on which to consider the exposure, maintained resilience and inherent resilience of our current and future coastal communities. Increased understanding of the condition of coastal defences helps enable an early and planned approach to adaptation and open up opportunities to develop flexible adaptation responses to deliver wider social, environmental and economic advantages for disadvantaged communities. For example, exploring opportunities to incorporate nature-based solutions in urban coastal management and development has the potential to contribute to wider social benefits.

Whilst there is stiff competition for the Scottish Government's existing flood defence spending and much interest in the new Coastal Change Adaptation Fund, we are now able to consider existing social vulnerability as we shape short-term resilience measures alongside longer-term adaptational strategies. Limiting new development planned for areas anticipated to be at risk of erosion will also allow future social vulnerability to be minimised. These results should also be placed within the wider Scottish socio-economic context. The Scottish Government is committed to addressing the climate emergency, as well as striving to tackle social inequalities (Fitton et al 2018), particularly in childhood (Scottish Government, 2019). It is important to note that the social vulnerability results reflect wider social inequality data, thus it is clear that coastal erosion is likely to most dramatically impact upon families, children and wider communities, as well as the elderly and those suffering from physical and mental health issues. Wider analysis (SIMD 2020) shows that such groups are already adversely affected by poverty and inequity within Scottish society, the gap in educational attainment within the most and least deprived areas of the nation continues to be severe, despite efforts to close this

gap (Scottish Government, 2019). Environmental threats, which are only likely to worsen due to climate change, therefore, pose a threat to Scottish Government goals to improve the health, wellbeing and life chances of all who live in Scotland, in-line with international objectives.

It is important to note that the creation of the SVCI and analysis of data emergent from the study highlights the importance of taking both current and future planned local contexts into account when exploring socio-economic factors in relation to coastal erosion. This is especially relevant when we consider the results of the super site analysis (see these reports for detail), when drawing comparisons between regions in Scotland and whilst being mindful of the areas (e.g. urban estuarine areas like Glasgow and highly defended areas within Edinburgh) which are beyond the scope of the modified Bruun rule method used here. The urban context does not devalue the significance of the SVCI findings, in that the SVCI is a set of indicators that seeks to go beyond consideration of deprivation related indicators as being the only factors that dictate social vulnerability. Rather, it is possible to imagine scenarios within which an affluent community may face different challenges (i.e. due to the presence of an aging population) compared to one with other vulnerability indicator (e.g. high unemployment and low educational attainment). Such considerations highlight the importance of both local level understandings of contextual situations, as well as local level planning in terms of consideration of adaptation approaches.

Finally, it is important to note that given the predicted population growth that Scotland expects in the next 25-year period (NRS, 2019), it is likely that the number of properties within coastal areas will also increase, although this analysis only considered existing dwellings. The initial analyses of social vulnerability to coastal erosion presented here can be built upon moving forward, potentially integrating further consideration of an increasing number of properties that are currently proposed for coastal areas, and other details that have been alluded to throughout this document. To extend this analysis two key areas are recommended. First, to assess erosion risks in estuarine and currently defended regions of Scotland would allow a more comprehensive geographic assessment of Coastal Erosion Disadvantage and secondly, to overlay currently approved and future development plans with these data to identify where Coastal Erosion Disadvantage may be increased via strategic development decisions. This report, its data, methodology and mapping are thus a first step to identifying coastal erosion disadvantage for current and future generations.

A more general strategic point is to highlight that the management of coastal erosion and flood risk should not be considered as a stand-alone issue, in isolation of other concerns. A more holistic and transformative view might be to address coastal erosion and flood risk, particularly for vulnerable communities, as part of applying the ‘place principle’ https://www.gov.scot/publications/place-principle-introduction/ . The place principle considers the issues facing whole systems and places rather than dealing with different challenges (such as coastal erosion and flood risk) in isolation and may prove to be a more helpful mechanism to create the conditions needed for more transformative change.

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Appendix

Table 11: Spatial datasets used during analysis

Spatial Extent	Acronym	Codes	Number in Scotland
Data Zone (or Data Zone)	DZ	S01006506 – S01013481	6976
Local Authority/Council Area	LA or CA	S12000005 – S12000046[8]	32
Detailed Characteristic Postcode Sector	DC	S28000001 – S28000866	866
SEPA Residential Properties	SEPA RPs	-	2,582,346

[8] Not continuously numbered

Table 12: Indicator source data and details (continued next page)

Domain	Variable *(variable name in Dynamic Coast data)*	Dataset	Location in source dataset	Raw data spatial extent
Population	Total population *(Total_population)*	SIMD 2020 - 2017 NRS small area population estimates	"Total_population"	Data Zone
	People under 5 years old *(age_4_less)*	Census 2011 Digimap[9]	"ons-age" – sum relevant age columns	Data Zone
	People 75 years or older *(age_75_over)*			
Health	Limited day to day activity *(Activ_limit_sum_adjust)*	Census 2011	DC3101: Columns 002 + 003 (sum)	Detailed Characteristic Postcode Sector
	No car *(no_car)*	Census 2011 Digimap[10]	"ons-car-availability" – no car	Data Zone
	Depression % *(HlthDprsPc)*	SIMD 2020	"DEPRESS"	Data Zone
Cohesive and Connected Communties	Single person households *(One person household)*	Census 2011	QS112[10]: Column 002	Data Zone
	Primary School Age children *(primary_school_child)*	Census 2011 Digimap[10]	"ons-age" – sum relevant age columns	

[9] DataZones referred to as Lower Super Output Areas in Digimap datasets.
[10] Note: not all variables not labelled as Data Zones needed to be adjusted to DZ units. Although named such, they were downloaded in DZ units.

Domain	Variable *(variable name in Dynamic Coast data)*	Dataset	Location in source dataset	Raw data spatial extent
	English language skills *(Limit_Eng_lang_adjust)*	Census 2011	DC2105: Columns 004 + 005 (sum)	Detailed Characteristic Postcode Sector
	Crime *(CrimeRate_2020)*	SIMD 2020	"crime_rate"	Data Zone
Skills, education and training	Education attendance *(EduAttend_2016)*	SIMD 2016[11]	"Attendance"	Data Zone
	No qualifications *(EduNoQuals_2016)*		"no_qualifications"	
Economic Prosperity	Long-term unemployed *(Longterm_unemploy)*	Census 2011	LC6116: Column 049	Data Zone
	Dependent children households no employed adult *(No_work_parent_tot)*		DC1601ca: Columns 161 + 273 (sum)	Council Area
	Employment deprivation *(Employment_rate_2020)*	SIMD 2020	"employment_rate"	Data Zone
Sustainable communities	Social rented households *(Social_rent_total_adjust)*	Census 2011	DC4404: Column 253	Detailed Characteristic Postcode Sector
	Private rented households *(Priv_RentFree_adjust)*		DC4404: Column 442	Detailed Characteristic Postcode Sector
	People working >30km from home *(Worktravel_30km_plus)*		LC7102[6]: Column 008	Data Zone

[11] SIMD 2016 used due to significant increase in "missing and suppressed data" in latest SIMD 2020.

Domain	Variable *(variable name in Dynamic Coast data)*	Dataset	Location in source dataset	Raw data spatial extent
	Public transport travel time to GP, Post Office, retail *(Ave_PT_Services_2020)*	SIMD	"PT_GP" + "PT_Post" + "PT_retail" (average)	Data Zone
	Building Density *(Building_Density_km2)*	Ordnance Survey & Alasdair Rae[12]	(Scotland only)	Data Zone[13]
Physical assets	Mobile home *(Mobile_home)*	Census 2011 Digimap[10]	"ons-accommodation" – mobile_home	Data Zone
	Overcrowded households *(overcrowded_rate_2020)*	SIMD 2020	"overcrowded_rate"	Data Zone

[12] Split into Scotland building footprints - http://ajrae.staff.shef.ac.uk/buildings/
[13] Spatial Join operation applied to associate building footprints (both residential and non-residential) to Data Zone spatial extents to determine density based on spatial area of each Data Zone.