

Review of climate vulnerability assessment of Scotland's marine environment and marine economy

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Executive summary

Aims

The impacts of climate change on Scotland's seas are expected to become more frequent and severe over the coming decades. Warming seas, reduced oxygen, ocean acidification and sea level rise are already affecting ecosystems in the North Sea, adding pressure to historically overexploited fish populations, and exacerbating invasive species and disease spread in aquaculture. Infrastructure too is at risk, with climate change bringing increased frequency and severity of storms and flooding, and sea level rise increasing rates of coastal erosion (MCCIP, 2020).

This research reviews climate vulnerability assessments (CVAs) of natural and socio-economic marine systems in Scotland and internationally to:

1. identify focus, spatial scale and gaps in CVAs relevant to Scotland;
2. identify examples of CVAs methodologies used internationally, including the strengths and weaknesses of these methodologies; and
3. suggest how to strengthen vulnerability assessments of the marine environment and marine economy in Scotland.

We use a definition of vulnerability as a function of exposure, sensitivity and adaptive capacity.

Key findings

Our review found that Scotland already has many of the foundations in place to conduct a full CVA for its marine environment. It is also evident that the strengths and weaknesses of Scottish marine CVA literature are similar to those which exist internationally.

- **CVAs relevant to Scotland** vary in their definition of vulnerability. Most studies focus primarily on the ecological or physical system rather than socio-economic considerations.

- Regardless of the definition of vulnerability applied, most studies presented only partial assessments of vulnerability, in that they only examine certain risks or impacts rather than how they in turn affect vulnerability outcomes.
- Of the climate impacts explored for Scotland, many studies were further limited to specific hazards or sectors.
- While some sectors (e.g. fisheries, aquaculture) are well-studied, certain sectors at risk of climate impacts in Scotland are lacking in literature or are limited to site-specific studies
- **The international CVAs** that cover exposure, sensitivity and adaptive capacity focus on a specific species, region, or sector rather than covering the full scope of the marine environment.
- Other sources are more limited in their coverage of the conceptual framework of vulnerability, looking primarily at climate risks or impacts, stopping short of presenting full socio-economic vulnerability outcomes.
- International literature covers a range of sectors, but few studies consider multiple sectors, reducing their ability to provide a comprehensive overview of climate vulnerability in the marine environment.

Addressing the identified gaps requires an understanding of the effects of climate change across the range of sectors that are relevant to the marine economy. This is challenging for a number of reasons, including:

- climate data limitations,
- the complexities of analysing climate data across all the hazards relevant to the marine environment,
- the diversity of climate impacts relevant to the marine sector, ranging from infrastructure damage to species depletion,
- the range of stakeholders involved, and
- funding limitations and the challenges of collecting data at regular intervals.

Recommendations

To strengthen CVAs for the marine environment in Scotland we propose to:

- **engage with experts and stakeholders in Scotland**, starting with those in MCCIP and those engaged in the UKCCRA process to facilitate a cross-sectoral discussion of climate vulnerability in Scotland's marine environment;
- **identify priority sectors where additional research is needed and those deemed important for Scotland's marine environment** in order to gain a complete picture of climate vulnerability in the marine environment in Scotland;
- **identify robust studies included in this review which would potentially benefit from being updated** and develop a plan for funding priority research activities; and
- **draw from robust sources** such as those identified through this study to expand on the existing CVA work in Scotland.

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1. Introduction

1.1 Background and context

An iconic maritime nation, Scotland's seas cover nearly six times its land area and approximately 63% of the total UK Exclusive Economic Zone (EEZ) (Scottish Government, 2022). They also support several sectors crucial to Scotland's economy, from oil and gas and aquaculture to fishing and marine tourism, collectively forming what is known as the "marine economy", defined in Scotland's Marine Economic Statistics 2018 as "economic activity linked to the oceans, seas, bays, estuaries and other major water bodies, and the ecological and physical systems associated with them" (Scottish Government, 2020a). Together, these sectors form an industry of over £4.3 billion (Scottish Government, 2020a), and remain a key focus for the Scottish Government, as emphasised throughout the recently published Fairer, Greener Scotland Report 2021 (Scottish Government, 2021b). The importance of the marine economy is likely to be further emphasised in the upcoming Blue Economy Vision, which aims "to support a green recovery and just transition, with sustainable growth of the blue economy underpinned by environmental protection" (Scottish Government, 2021).

The impacts of climate change on Scotland's seas are expected to become more frequent and severe over the coming decades (MCCIP, 2020). Warming seas, reduced oxygen, ocean acidification and sea level rise are already affecting ecosystems in the North Sea, adding pressure to historically overexploited fish populations, and exacerbating invasive species and disease spread in aquaculture. Infrastructure too is at risk, with climate change bringing increased frequency and severity of storms and flooding, and sea level rise increasing rates of coastal erosion (MCCIP, 2020). Consequently, it is of crucial importance for the Scottish Government to have a clear understanding of the climate vulnerability of Scotland's marine environment and marine economy to better support the prioritisation of adaptation planning.

This review of climate vulnerability assessment (CVA) literature will form part of the evidence base informing the climate change theme within Scotland's Fisheries Management Strategy (Scottish Government, 2020b) and will subsequently contribute to the policy discussion around the Blue Economy Vision.

1.2 Project aims

This research project brings together information on existing climate vulnerability assessments (CVAs) of natural and socio-economic marine systems in Scotland and internationally to answer three main research questions:

1. What CVAs exist relating to the marine environment at a level relevant to Scotland, and what focus/spatial gaps can be identified?
2. What examples exist in the UK and internationally of use of CVAs methodologies relating to the marine environment, including the strengths and weaknesses of these methodologies?
3. How may the above methodologies be applied to strengthen vulnerability assessments of the marine environment and marine economy in Scotland?

Based on the findings, this report makes recommendations on next steps for developing a methodology for Scotland to track the vulnerability of the marine environment and marine economy.

1.3 Report structure

The report is structured as follows. First, the conceptual framework within which the review of CVAs is undertaken is presented. Second, key findings and insights from the reviewed studies are outlined and discussed, initially for Scottish-related studies (research question 1) then for international studies (research question 2). Following that, recommendations for how methodologies can be applied to strengthen vulnerability assessments in Scotland (research question 3) are offered. Concluding remarks are then provided.

2. Conceptual framework

2.1 Climate vulnerability assessments

CVAs are commonly used to evaluate the potential effects of climate change on a system. Originating from climate impact assessments, CVAs use existing biophysical and social scientific information to guide and evaluate strategic policy options, with the primary goal of reducing risk related to climate change (Dudley *et al*, 2021). The CVA definition in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) is the most widely used and considers both external changes (exposure) and internal vulnerabilities to those changes (sensitivity and adaptive capacity) when attempting to predict impacts (McCarthy *et al*, 2001). This implies that a change is important (i.e. high risk) if nature or society is exposed to and affected by it *and* if nature or society is unable to adapt to this change. In this way, CVAs enhance the understanding of how a sector and its dependent economies and communities are impacted by existing and projected climate changes, thus informing action to support human and ecosystem well-being.

The use of CVAs has resulted in new insights into the causes and consequences of vulnerability to climate change. However, the scale of a CVA depends on the research question being asked and who is conducting the assessment. Given the range of possible research questions, climate data limitations, and geographic and sectoral complexities, constructing and developing CVAs that address the marine environment in its entirety is particularly challenging (Füssel and Klein, 2006). As such, CVAs for the marine environment and associated marine economy are less prevalent in general; this is also the case in Scotland, despite a growing evidence base of the impacts of climate change on the nation's marine environment and the sectors which depend on its health (e.g. MCCIP, 2020; Moffat *et al*, 2020).

Insights from CVAs of marine systems could provide direction on how policies relating to the marine environment within the Scottish Climate Change Adaptation Programme (SCCAP) could be strengthened in the future. This will ensure that the marine environment sectors at highest risk of the negative impacts of climate change can be prioritised for adaptation planning.

2.2 Key definitions

In order to effectively evaluate what constitutes a robust CVA in the context of the marine environment, this report references the aforementioned definition of climate vulnerability, based on the IPCC definition (McCarthy *et al*, 2001). It is within this common definition, which defines vulnerability as a function of exposure, sensitivity, and adaptive capacity (**Error! Reference source not found.**), that reviewed literature has been assessed for strengths, weaknesses, and gaps.

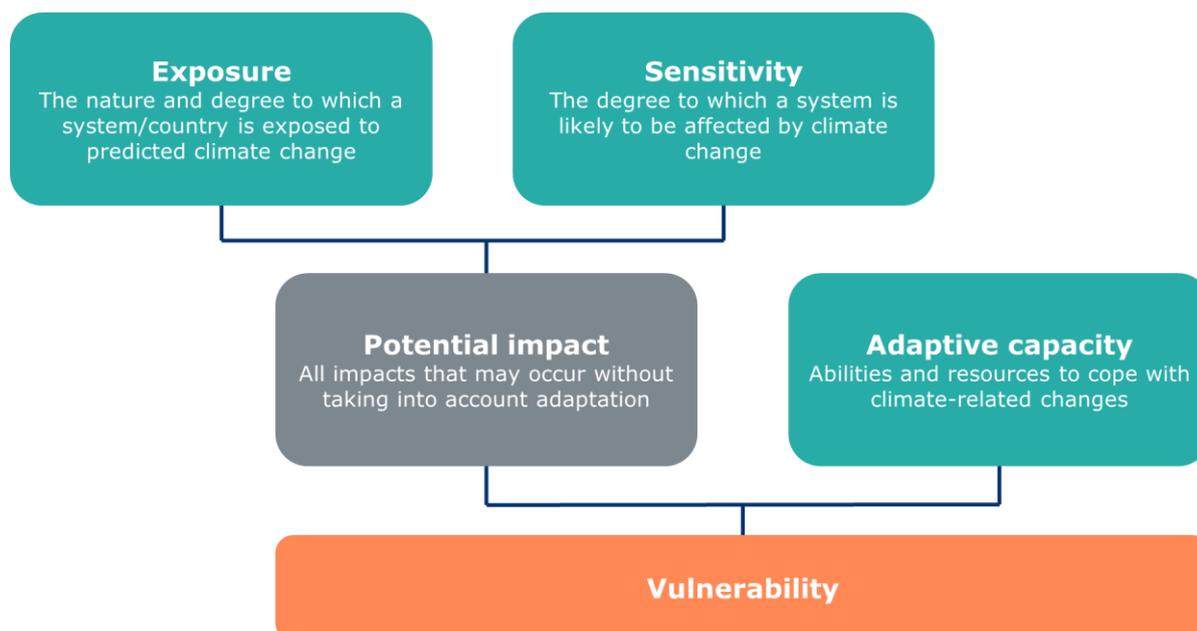


Figure 1: Common CVA definition

At its broadest level, the vulnerability of the marine environment can be assessed from three key perspectives: the ecological or physical system; the socio-economic system; or an integrated ecological-social system. An ideal, all-encompassing marine-focused CVA would account for all components and inter-relationships within an integrated ecological-social system. However, as indicated in sections 4.2, 4.3 and 5, such an ideal CVA approach does not exist. This research project focuses instead on existing approaches being used which cover some aspects of an ideal CVA, whilst noting the gaps and limitations of these approaches.

As a result, the critical assessment of existing marine-focused CVA methodologies is undertaken across four key assessment criteria:

- Scottish replicability: the degree to which Scottish-specific data can be drawn from the study, or the ease at which the study could be replicated in a Scottish context.
- Data and detail: the extent of the study's marine climate vulnerability focus (ideally including an integrated ecological-social view), its use of primary data, and its appropriate level of detail, in addition to assessment against the CVA definition listed in Figure 1.
- Regularly updated: is the study regularly updated, and if not, does it have potential to be easily replicated?
- Cross sectoral: are multiple sectors covered in the analysis, or is the study relevant solely to a single sector?

Each criterion is assessed on a scale from one to five, with a blue line connecting each of the four criteria scores, as illustrated in **Error! Reference source not found.** below.

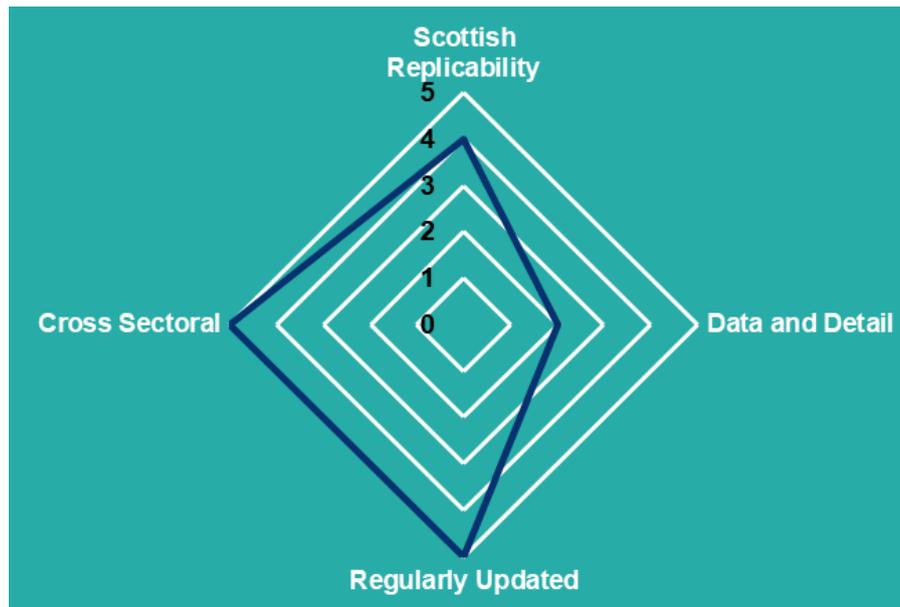


Figure 2: Example of critical assessment criteria visual presentation

3. Methodological approach

The foundation of this project’s methodology centres around a robust desk-based literature review of existing CVAs of the marine environment. The overall approach has been developed according to an iterative four-step process (**Error! Reference source not found.****Error! Reference source not found.**). Further details of these steps can be found in ‘

Appendix A: Methodological approach’.



Figure 3: Methodological approach

Literature sources were prioritised according to the following inclusion criteria.

- Date of publication: Recent literature sources were prioritised, with a focus on 2010 onwards for Scottish literature, and 2015 onwards for international literature, unless considered to be highly relevant.

- Topic relevance: Literature sources were required to cover marine or climate vulnerability at a minimum.
- Geographic scope: Priority was given to literature focusing on or including Scotland in order to inform research question 1. Literature focusing on other geographic scopes was included to inform research question 2, but each source was also assessed to ensure it met the topic relevance inclusion criteria.
- Methodology provided: If the geographic scope was outside of Scotland, the document required at least a partial overview of its methodological approach which was replicable in a Scottish context.

It should be noted that studies are assessed against the research aims of this paper, not against their own research aims. Many of the studies assessed, while partially relevant to our study, focused on specific aspects of vulnerability, such as environmental impacts or exposure. As such, identified limitations of each source are not criticisms *per se*, but rather limitations with respect to how each source aligns with this paper's assessment parameters and research questions.

4. Key findings

4.1 Literature overview

Overall, 109 documents were identified with potential relevance to the current study. These sources were reassessed in line with the inclusion criteria by CXC and Ramboll, and a shortlist of 57 of the most relevant documents was identified. This shortlist, summarised in [Appendix B](#), provides a spread of recent literature covering multiple geographies; a breakdown is presented in Figure .

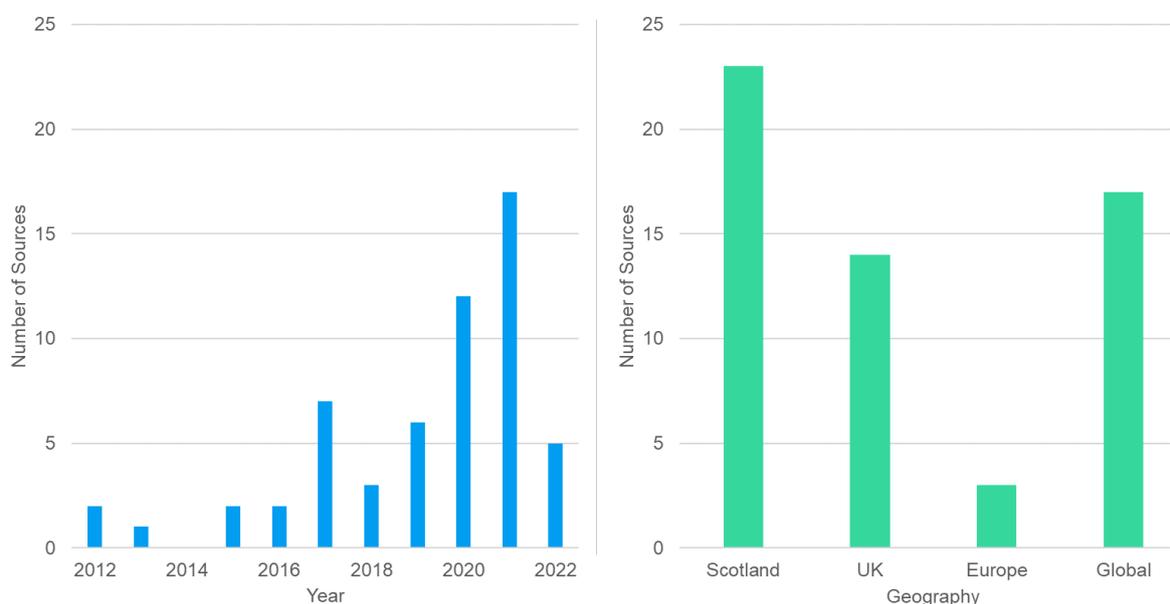


Figure 4: Number of literature sources in the shortlisted documents by year and geography

The literature reviewed revealed considerable existing work on CVAs. A range of public and private sector organisations, as well as independent research organisations and NGOs, were found to be conducting research on the topic, yielding different types of documents, including national-level assessments driven by Government, academic

studies focusing on a specific species, and guidance documents on vulnerability methodologies.

4.2 What CVA literature exists in Scotland?

What climate vulnerability assessments exist relating to the marine environment at a level relevant to Scotland, and what focus/spatial gaps can be identified?

In order to define “a level relevant to Scotland” for this question, all studies relating to climate vulnerability which either used Scottish data exclusively or include Scotland within the scope (e.g. through a UK-wide study) were considered. Thirty-seven studies were subsequently identified and analysed according to the four key assessment criteria (sufficiently replicable; data and detail; cross-sectoral; and regularly updated), including their adherence to the CVA definition in Figure 1. A wide array of approaches addressing many different aspects of climate vulnerability relevant to Scotland were identified, with strengths and weaknesses across the assessment criteria observed within each study.

Many CVAs are high-level, often UK-wide public sector studies

At the broadest geographic level, studies relevant to Scotland are high-level, UK-focused climate risk assessments and reviews, such as the UK Climate Change Risk Assessment (UKCCRA - CCC, 2021; Sniffer, 2021; DEFRA, 2022). As these studies are often not exclusively focused on Scotland, for use in a Scottish context one must extract those sections or chapters relevant. For example, the UKCCRA3 report has a ‘Summary for Scotland’ study which offers detailed and useful insights and data that can be used for future Scottish CVAs (Sniffer, 2021).

Public-sector studies, whether they were published by the UK or Scottish Government, were found to be the **most likely to be subject to regular updates and republication**. This is likely due to the availability of a consistent funding source or a statutory requirement. Work from the Marine Climate Change Impact Partnership (MCCIP – see Case Study Box 1, and Collins *et al*, 2020; Harkin *et al*, 2020; MCCIP, 2020) is regularly updated, while others such as the UK’s dolphin and porpoise conservation strategy (Scottish Government, 2021a) are one-off studies which have potential to be conducted regularly if additional funding was secured. Updates were found to typically occur every five years for UK Government documents (as well as MCCIP), and every nine years for those linked to UKCP09/18.

However, the primary benefit of these assessments is their **typically cross-sectoral nature**. Documents that offer a higher-level analysis, such as the UKCCRA3 (CCC, 2021; Sniffer, 2021; DEFRA, 2022), other DEFRA or CCC documents (DEFRA, 2018, 2020; CCC, 2022) or Scottish marine economic assessments (Moffat *et al*, 2020; Scottish Government, 2020a) all provide cross-sectoral views, with some providing important economic data (e.g. Moffat *et al*, 2020; Scottish Government, 2020a; Met Office, 2022). This data, although rarely covering all aspects of vulnerability exhibited in Figure 1, allows a cross-sectoral view of the entire marine environment or economy, something difficult to capture in other forms of study. A good case study is that of MCCIP (Case Study Box 1 **Error! Reference source not found.**), which provides the rare example of a regularly updated body of literature covering several key marine sectors and their climate risks and projections.

Case study: MCCIP's marine report cards and supporting reviews

Established in 2005, the Marine Climate Change Impacts Partnership (MCCIP) is “the primary independent source of marine and coastal climate change impacts evidence and adaptation advice in the UK”. MCCIP: publishes regularly updated reviews and summary report cards focusing on marine and coastal climate change impacts across the UK, Ireland, and UK overseas territories; works with conservation and industry bodies across sectors; and provides the marine and coastal evidence base supporting the UK Climate Change Act and other legislation.

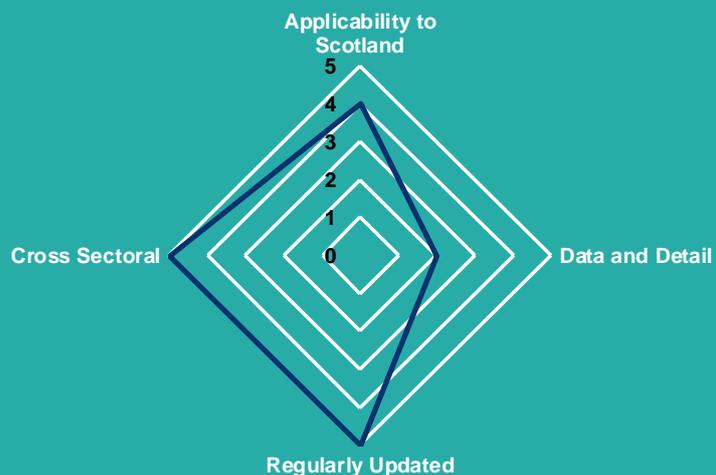
The reviews behind MCCIP's report cards, all published in 2020, cover Scottish marine economic sectors such as fisheries, tourism and recreation, and transport and infrastructure. As with their report cards, each review is structured as follows: introduction; what is already happening; what could happen in the future; confidence assessment; and key challenges and emerging issues.

For the purposes of this study's aims, MCCIP's literature carries certain limitations; in particular, their literature review format lacks a detailed, transparent methodology. In addition, socio-economic vulnerability outcomes are not considered (an upcoming MCCIP paper on the key challenges and emerging issues of climate change may yet address this gap; however, its focus appears to be evidence needs).

Overall, MCCIP's work provides useful input into a Scottish marine CVA. By providing cross-sectoral, regularly updated reviews on Scotland's marine environment and its climate-related impacts, it provides an important bridge between highly-specific, one-off studies and regularly updated but high-level overviews.

Key takeaways:

- Balance between highly-specific one-off studies and regularly updated but high-level overviews.
- One of the few organisations with detailed, cross-sectoral knowledge of the Scottish marine environment's vulnerability to climate change and the capability to input into a CVA.
- Perhaps lacking in socio-economic vulnerability analysis.



Case Study Box 1: MCCIP

Scotland-specific collections of resources with relevance to marine CVAs are another category of CVA literature relevant to the marine economy in Scotland

Collections of resources, presented individually rather than in a literature review format, were more frequently found in the assessment of international literature (and thus assessed in greater detail in section 4.3.4). Scotland-relevant literature of this type include:

- Public sector climate readiness toolkits of Adaptation Scotland (2019a, 2019b). These documents provide policy guidance, templates and toolkits – to public sector decision makers on understanding climate change adaptation capabilities, and to organisations wishing to undertake climate change risk or vulnerability assessments, respectively.
- The Shellfish Water Protected Areas website of SEPA (2021), a collection of 85 summary documents for different shellfish water protected areas and their quality around Scotland.

Sector-specific studies

While there were many cross-sectoral studies, the review also yielded several examples of studies focusing on **specific marine environment sectors**:

- Aquaculture and Fisheries – Cheung *et al*, 2012; ClimeFish, 2020
- Coastal studies – Fitton *et al*, 2018; Hansom *et al*. 2017; DEFRA 2020
- Heritage – HES, 2016; 2017; Graham *et al*, 2017; CREW, 2021
- Housing and Infrastructure – Fitton *et al*, 2018; SEPA, 2018; Adaptation Scotland 2019a, 2019b; Climate Ready Clyde, 2020
- Transport and ferry services – Coll *et al*, 2013; Orrey *et al*, 2019

Many of these sector-specific papers offered **highly detailed assessments**, presenting comprehensive, replicable methodologies supporting robust conclusions. Some papers (e.g. Fitton *et al*, 2018; CREW, 2021) went beyond the modelling of climate risks and hazards to investigate socio-economic outcomes (in these instances financial impacts) through the use of indicators (such as population density, socio-economic status, gender, ethnicity and age), making them more aligned with the IPCC definition of climate vulnerability (McCarthy *et al*, 2001) and Figure 1.

Several of these studies were found to focus on a **specific region**, for example Western Isles studies by Coll *et al*, (2013) and Billing *et al*, (2017), which focused on transport services and marine environment management, respectively. As a result, another commonality of these studies was the use of **primary data**, enabled by the focus applied to a specific sector or geography. A key example of region-specific academic literature which provides primary data is that of ClimeFish (2020), presented in Case Study Box 2.

Case study: ClimeFish.eu's Scotland-specific documentation

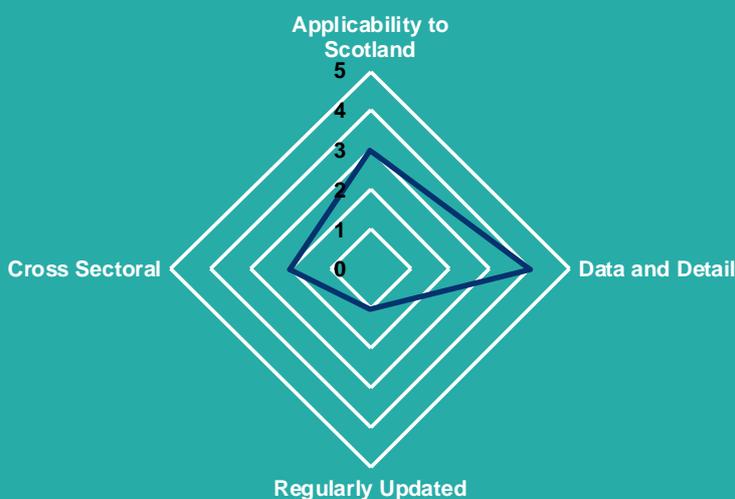
ClimeFish was an EU funded project aiming to ensure sustainable seafood production which benefits rural and coastal communities. From 2016 to 2020, ClimeFish published case studies, fact sheets and decision support frameworks on fisheries and aquaculture across Europe, with dedicated studies on both Scottish aquaculture and western Scotland fisheries.

Although focusing on Scottish shellfish aquaculture, ClimeFish results observed difficulties highlighted in this study – particularly that the “effect of climate change varies by location, so it is difficult to generalise impact and identify adaptation measures at a national scale”. The “West of Scotland Fisheries” case study also provides useful conclusions from model simulations, such as “warming seas in the west of Scotland will be detrimental to the abundance of cold-water species such as cod but might be beneficial to warm-water species such as whiting and hake”. Adaptation strategies and socio-economic outcomes are also highlighted, further increasing the relevance of these studies.

ClimeFish offers primary data (accompanied by useful, concise summaries) which links climate change vulnerabilities across two key Scottish marine economic sectors. However, their methodologies are unclear in describing the data requirements and assumptions, and as one-off case studies which are not linked to regularly updated data, ClimeFish projects (especially as funding ceased in 2020) would be difficult to rely upon should an overall Scottish marine economy vulnerability assessment be conducted.

Key takeaways:

- Two case study papers dedicated to Scotland's key marine economic sectors, backed by primary data and concise summaries.
- Difficult to gauge the data requirements, assumptions, and methodology.
- Potential issue with funding now expired.



Case Study Box 2: ClimeFish

4.3 Scottish CVA literature – key gaps

There is inconsistency in the definition of vulnerability (see Figure 1) applied across studies. Most studies focus primarily on the ecological or physical system yet lack socio-economic considerations (Cheung *et al*, 2012; Burden *et al*, 2020; Collins *et al*, 2020; Harkin *et al*, 2020; MCCIP, 2020; ClimeFish, 2021). On the other hand, studies Billing *et al.*, 2017; Fitton *et al*, 2018; Stewart-Sinclair *et al*, 2020 include the socio-economic dimension, with the former focusing on social vulnerability (in the form of community engagement methods) but lacking ecological considerations.

Regardless of the definition of vulnerability applied, **most studies presented only partial assessments of vulnerability**, in that they only examined certain risks or impacts rather than investigating how they in turn affected vulnerability outcomes. For example, Coll *et al.* (2013) and Monfries (2018) focus on the *impacts* of wave and wind and sea level rise, respectively. Moreover, of the climate impacts explored, **many studies were further limited to specific hazards** (e.g. soil erosion – Graham *et al.*, 2017; Hansom *et al.*, 2017; Fitton *et al.*, 2018; CREW, 2021 or sectors (e.g. transport – Orrey *et al.*, 2019).

The significant variation in research effort across sectors means that while some sectors (e.g. fisheries, aquaculture) are well-studied, **certain sectors at risk of climate impacts in Scotland are lacking in literature or are limited to site-specific studies** (e.g. housing and infrastructure – Fitton *et al.*, 2018; Adaptation Scotland 2019a, 2019b; Climate Ready Clyde, 2020; heritage – HES, 2016; 2017; Graham *et al.*, 2017; or ferry services Coll *et al.*, 2013). High economic impact sectors like oil and gas support, tourism and transport (particularly freight transport) are all under-represented in publicly available literature, in part due to the need to investigate the climate risks to infrastructure at a site-specific rather than cross-sectoral level. Similarly, sectors of growing importance, for example offshore wind, are also lacking in publicly available literature and do not feature in this literature review as a result.

4.4 Scottish CVA literature - conclusion

Overall, a trade-off emerges between high-level policy assessments and reviews, and the more site-specific sources. Higher-level studies (whether government policy documents or literature reviews), while providing cross-sectoral overviews with the potential to be regularly updated, seldom provide primary data, replicable methodologies or site-specific context. On the other hand, while more site-specific sources were found to often provide primary data and detailed methodologies, they tended to be one-off studies lacking the potential to be applied at a cross-sectoral marine environment level. For example, using the detailed approach used when undertaking a flood risk assessment (as per SEPA guidance) would not fulfil the objective of a CVA because it is too detailed to provide a good understanding of the vulnerabilities across the range of climate hazards relevant to a particular system. The gaps revealed above illustrate that our understanding of marine CVAs in Scotland is incomplete, and no individual study meets all of the assessment criteria highlighted in Section 2 of this report (including the Figure 1 definition of vulnerability). Whether these gaps are unique to Scotland, or are a common international observation, is explored in section 4.5.

4.5 What CVA methodologies exists outside Scotland?

What examples exist in the UK and internationally of the use of vulnerability assessment methodologies relating to the marine environment, including the strengths and weaknesses of these methodologies?

This section focuses on CVA literature relating to the marine environment (and in particular the methodologies of this literature) that has been conducted outside Scotland. Twenty studies were shortlisted for this section, including site-specific studies conducted elsewhere in the UK and wider international studies which did not specifically include Scotland in their analysis. This review was conducted to identify best practice approaches internationally which could potentially fill the gaps, or strengthen the understanding, of Scottish marine CVAs. As such, categories of document are similar, but not identical, to those presented in section 4.2.

As with the Scottish literature, many international CVA-related literature consists of high-level reviews and policy guides

The nature of international literature reviews and policy guides relating to this project's aims identified differ slightly compared to Scottish literature. In the international literature, policy pieces on climate vulnerability, or more specifically marine climate vulnerability, were more commonly authored by NGOs and intergovernmental agencies such as the FAO (Brugere *et al*, 2015; Comte, 2021; FAO, 2022). **Compared to Scottish literature, fewer direct government guidance documents were found** – although a study by Natural Resource Wales (2015), looking at the climate vulnerability of marine Natura 2000 protected features, is a notable exception.

Regardless of the nature of the document, **several similarities emerged between the international literature's reviews and policy guides**, which carried both methodological strengths and limitations. Several documents cover a global scope spanning multiple countries or sectors (Brugere and De Young, 2015; Weatherdon *et al*, 2016; Handisyde *et al*, 2017; Stewart-Sinclair *et al*, 2020; Comte, 2021; Fellman, 2021; Pham *et al*, 2021). Some contain global datasets, including the UK as part of a wider dataset (e.g. Stewart-Sinclair *et al*, 2020). **However, a cost of these documents' wider scopes is their level of detail.** In covering such a wide array of geographies and/or sectors, international reviews rarely contain a methodology detailed enough to replicate elsewhere, and few presented a CVA utilising the full conceptual definition of vulnerability outlined in Figure 1.

The reviews and policy guides which did present strong methodologies were those which offered guidelines for conducting CVAs. For example, Brugere and De Young (2015) present an eight-step process for fisheries and aquaculture CVAs, outlined by the FAO. Pham *et al*. (2021) also provide step-by-step guidelines for the same sector (see **Error! Reference source not found.**). These guidelines offer clarity on the definition of a CVA in a marine context and provide observations on stakeholder and actor inclusion in their implementation.

Case Study: Pham *et al*, 2021 – Guidelines for co-creating climate adaptation plans for fisheries and aquaculture

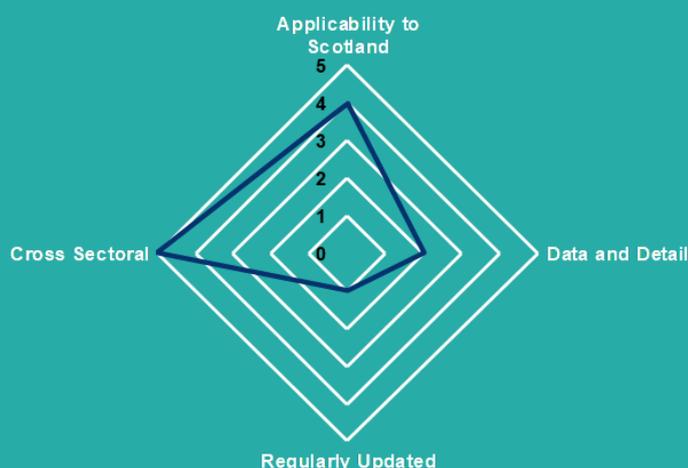
This paper presents practical, step-by-step guidelines for the development of fisheries and aquaculture climate adaptation plans (CAPs). While recognising and discussing organisations which have developed their own guidelines (e.g. FAO, Worldfish) and the nations pioneering detailed adaptation plans in seafood production sectors (UK, USA, Australia), this paper highlights the current research effort on biological impacts of climate change and relative lack of literature on their socio-economic consequences. As such, the guidelines presented in this paper, based on practical experience and emphasising stakeholder participation, provide a relevant and important stepwise approach which can be implemented directly for two of the Scottish marine economy's most important sectors (and indirectly implemented for several others).

The CAP guidelines are summarised below:

- Assess risk, opportunity, and vulnerability (evaluate status, biological forecast, risk and opportunity assessment to present to stakeholders for ranking.)
- Identify and assess adaptation measures (vulnerability assessment to identify main vulnerabilities, identify adaptation needs, identify, and assess adaptation measures to present to stakeholders for agreement).
- Implement, monitor and evaluate adaptation (operationalise CAP with implementation plan agreeing the key actor(s), resource estimation, funding source and timeframe).

Key takeaways:

- Clear, replicable step-by-step methodology.
- Utilises the full conceptual definition of vulnerability outlined in Figure 1.
- Sector-specific to fisheries and aquaculture but applicable at a cross-sectoral level.
- Useful blend of top-down implementation and bottom-up stakeholder engagement approaches.
- Lacks primary data or a data source applicable at a cross-sectoral level.



Case Study Box 3: Pham *et al*, 2021

International CVA literature also featured collections of resources such as toolkits

Four studies were identified as toolkits or collections of data sources and tools, presented together online without academic review:

- CAKEX (2017) – A US “Rapid Vulnerability Assessment Tool” published by the Climate Adaptation Knowledge Exchange.

- CCVATCH (2021) – A US Climate Resilience Toolkit for Coastal Habitats.
- NOAA (2021) – A collection of CVA resources and guidelines.
- World Bank Group (2022) – Climate and Disaster Risk Screening Tools.

Of the above studies, all except the World Bank Group (2022) were specifically American in origin, with both CAKEX (2017) and CCVATCH (2021) more specific in that they are intended to be used by American protected area land managers. **This specificity means their methodologies are difficult to assess**, as even when presented in detail (CCVATCH, 2021) they could not be directly replicated for the Scottish context. Nonetheless, these studies are useful and warrant inclusion for this study because they utilise, and can act as a source of, publicly available and cross-sectoral primary data and indicators. They also carry relevance for much of the marine environment, despite the World Bank Group's (2022) dataset website not being solely marine-focused, nor strictly intended to form the basis of a CVA.

Four international case studies were identified which offer a country-specific, primary data-driven view of a particular sector

These studies are presented below:

- Aragão *et al.* (2021) – A study looking at the importance of regional differences in vulnerability to climate change for demersal fisheries across Spain.
- Bueno-Pardo *et al.* (2021) – A detailed CVA of commercial fish and invertebrates in Portugal (further detailed in Case Study Box 4 **Error! Reference source not found.**).
- Dudley *et al.* (2021) – Presents a CVA framework for fisheries' social-ecological systems, looking at case studies in the United States.
- Farr *et al.* (2021) – An assessment of marine, estuarine, and riverine habitat vulnerability to climate change in the Northeast US.

Alongside being country-specific, **these studies share a utilisation of primary data and detailed descriptions of their analysis and methodologies**, giving them strong relevance to this study. For example, they use indicators to quantify the more complete definition of vulnerability, thus providing distinction between the vulnerability aspects of exposure, sensitivity, impact, and adaptive capacity detailed in Figure 1 (e.g. Aragão *et al.* (2021) uses 19 indicators that cover all these aspects).

A limitation of these papers to our study's aims is their focus of a single sector.

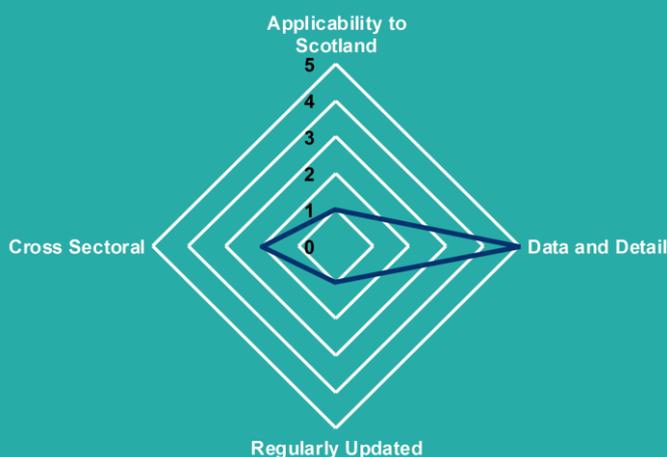
While this focus allows the aforementioned methodological detail, it restricts each paper's applicability to assessments that consider sectors across the marine economy. Similarly, as one-off academic studies, they are not intended to be maintained and regularly updated in the way a public sector database would be, compromising their ability to offer up-to-date and flexible assessments.

Case Study: Bueno-Part *et al.*, 2021 – Climate change vulnerability assessment of the main marine commercial fish and invertebrates of Portugal

This paper assesses the impacts of climate change on 74 commercial marine species of fish and invertebrates of commercial interest in Portugal, by assessing their vulnerability, exposure, sensitivity, adaptive capacity, and expected directional effects. Overall vulnerability scores were generally low, although the highest average vulnerabilities were identified for Central region species, as well as migratory and elasmobranch species. While undoubtedly a highly technical scientific paper limited in its cross-sectoral application, Bueno-Part *et al* provides a good example of a sector-wide analysis of climate vulnerability. Utilising the methodology presented in this paper alongside UK climate data, one would be able to assess Scottish fisheries' vulnerability to climate change and better understand commercially valuable species' predicted range shifts.

Key takeaways:

- Clear methodology
- Utilised primary data
- Vulnerability analysis was conducted for 74 commercial species across three Portuguese regions – north, central and south
- Vulnerability analysis included clear indicators covering the full conceptual definition of vulnerability.



Case Study Box 4: Bueno-Pardo *et al*, 2021

4.6 International CVAs - Conclusion

Considering the range of international studies reviewed across the various assessment criteria, **this review has identified gaps in our cross-sectoral understanding of marine CVAs, both at the national and international levels.** Many different types of literature sources were identified, each with their own methodological strengths and weaknesses, but no clear “best practice” example stands out which provides something beyond what currently exists in Scotland.

Some sources present the full conceptual framework of vulnerability outlined in Figure 1, but focus on a specific species, region, or sector rather than covering the full scope of the marine environment. Other sources were more limited in their coverage of the conceptual framework of vulnerability, looking primarily at climate risks or impacts, stopping short of presenting full socio-economic vulnerability outcomes.

International literature covers a range of sectors, but few studies consider multiple sectors, reducing their ability to provide a comprehensive overview of climate vulnerability in the marine environment. The sectors most frequently studied are by far fisheries and/or aquaculture. Other specific sectors include seaports, protected areas or Natura 2000 sites, and coastal habitat conservation.

As in the Scottish literature, high economic impact sectors like oil and gas support, marine tourism and to a lesser extent water transport (particularly freight water transport) are all understudied from a climate vulnerability perspective. Similarly, sectors of growing importance, for example offshore wind, are also lacking in the literature reviewed.

5. How can methods be strengthened?

How may the above methodologies be applied to strengthen vulnerability assessments of the marine environment and marine economy in Scotland?

5.1 Current state of play for marine CVA literature

The strengths and weaknesses of Scottish marine CVA literature are similar to those which exist internationally, demonstrating that Scotland is in line with other countries working to assess climate vulnerability of the marine environment. Addressing the gaps in this literature requires an understanding of the effects of climate change across the range of sectors that are relevant to the marine economy. This is challenging for a number of reasons, which include:

- climate data limitations,
- the complexities of analysing climate data across all the hazards relevant to the marine environment,
- the diversity of climate impacts relevant to the marine sector, ranging from infrastructure damage to species depletion,
- the range of stakeholders involved, and
- funding limitations and the challenges of collecting data at regular intervals.

As such, observed limitations are not criticisms of the studies per se, but an acknowledgment that climate vulnerability is a complex topic to assess across such a diverse sector.

It is clear from the literature review that **a complete methodology, using the full conceptual definition of vulnerability (going beyond impacts to include vulnerability outcomes, as outlined in Figure 1) and covering the entire marine sector is not currently available**. Despite this, there are specific insights that are well understood and emerge as strengths to consider when understanding how to improve marine CVA assessments in Scotland.

For instance, a strength of existing literature is the understanding of impacts, primarily climate and ecological impacts, within specific sectors. These are often measured using primary data and indicators, for example in the fisheries sector (e.g. Aragão *et al*, 2021; Buedo-Pardo, 2021). However, **there remains considerable variation in research efforts across sectors**, with many sectors relevant to the marine environment understudied or lacking information online unrestricted by paywalls or confidentiality agreements (e.g. site-specific infrastructure studies). Moreover, the typically one-off nature of these academic studies implies that sector-specific CVAs provide a snapshot in time, but potentially need to be updated given the rapidly evolving nature of climate change.

Given the lack of cross-sectoral research pieces utilising primary data, it is difficult to identify studies which could be replicated in Scotland to conduct a detailed assessment of the Scottish marine environment. The following sections provide recommendations for ways in which existing CVAs and research could be built upon in order to strengthen vulnerability assessments of the marine environment and marine economy in Scotland.

5.2 Practical requirements for strengthening existing vulnerability assessments

It is a conclusion of this paper that to develop a complete CVA of the marine environment and marine economy in Scotland, the following would be required:

- A **cross-sectoral view** of Scotland's marine economy, with detailed primary data sources as far as reasonably possible (whether collected through the study or not)
- A full, **well-defined scope** of vulnerability (including exposure, sensitivity and vulnerability outcomes)
- Clear environmental and socio-economic **metrics**, separated across exposure, sensitivity, impacts and vulnerability, to enable comparability across sectors and monitor changes in vulnerability to climate change.
- **Monitoring and evaluation**, with updates applied when needed to ensure that research is not a one-off, potentially out of date piece of work.
- An organisational body to **spearhead** the work and bring together relevant stakeholders and experts.

Scotland already has many of the foundations in place to conduct a full CVA for its marine environment. From a practical perspective, an important recommendation is to use existing expertise, data and resources to prioritise funding to those areas of the marine economy most vulnerable to the impacts of climate change.

Given the diversity of sectors relevant to the marine environment, building on existing networks will be critical to engaging with stakeholders across the marine environment. As shown, MCCIP engages a wide range of stakeholders and has a cross-sectoral understanding of the UK marine environment.

At a regulatory level, UKCCRA is a statutory and well-established process which encourages dialogue on high-level climate risks on a regular basis. Although the CCRA focuses on all sectors across the UK, rather than just marine sectors, the fact that the UK Government is required under the 2008 Climate Change Act to publish a CCRA every five years means that many climate experts across the UK provide contributions to the CCRA through consultation activities or at the request of the Committee on Climate Change. Identifying opportunities to build on the CCRA process and engage with the experts contributing to the CCRA from marine-relevant sectors in Scotland could help ensure that climate vulnerability discussions build on existing research and stay up to date with the latest developments.

5.3 Recommendations for next steps to strengthen CVAs of the marine environment in Scotland

In conclusion, the recommended next steps required to strengthen CVAs of the marine environment in Scotland are as follows:

Engage with experts and stakeholders in Scotland, starting with those in MCCIP and those engaged in the UKCCRA process to facilitate a cross-sectoral discussion of climate vulnerability in Scotland's marine environment.

Identify priority sectors where additional research is needed and those deemed important for Scotland's marine environment in order to gain a complete picture of climate vulnerability in the marine environment in Scotland. For sectors where limited CVA work has been identified (e.g. oil and gas infrastructure), determine whether this information does exist, but is possibly not publicly available. Identify stakeholders (such

as those involved in the planning process) who could potentially contribute expertise in climate resilience of infrastructure relevant to the marine environment.

Identify robust studies included in this review exercise which would potentially benefit from being updated and develop a plan for funding priority research activities.

Where additional research is required to fill a knowledge gap, draw from robust sources such as those identified through this study to expand on the existing CVA work in Scotland:

- Comte (2021), Pham *et al.* (2021) and ClimeFish (2021) for **conceptual guidance and step-by-step methodologies**
- Aragão *et al.* (2021) and Bueno-Pardo *et al.* (2021) for **detailed, sector-specific assessments using primary data**
- Stewart-Sinclair *et al.* (2020), for an approach which effectively **utilises indicators** to articulate a full definition of climate vulnerability.

Overall, this study has brought together information on existing marine CVA-related literature in Scotland and internationally, identified evidence gaps, and suggested how this evidence may be used to strengthen Scottish assessments in the future. Utilising the recommendations presented in this report will enable Scottish Government to develop a more complete understanding of the vulnerability of their nation's marine environment, and to determine areas and sectors most vulnerable to the worsening impacts of climate change. This in turn can help direct adaptation funding to the highest priority areas, building much-needed climate resilience into Scotland's vital marine economy.

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7. Appendices

7.1 Appendix A: Methodological approach

This study followed an iterative, step-by-step methodology, as outlined in Figure 4



Figure 4: Methodological approach

Step 1: Compilation of literature sources

Search terms

The literature review stage began by compiling a **long list** of documents and information sources potentially include in the review. The long list of literature sources included peer-reviewed journal articles, Government guidance documents and non-governmental organisation (NGO) reports. These were sourced via search engine platforms such as Google Scholar and SCOPUS.

A range of **search criteria** were used to find relevant documents and included the search terms listed below. The terms noted in **bold** were the search terms which yielded the most relevant literature:

- Climate change
- **Climate vulnerability**
- Climate vulnerability methodology
- Climate risk
- Climate risk assessment
- Climate impacts
- Vulnerability assessment
- Vulnerability assessment methodology
- **Marine**
- Marine risk assessment
- Marine environment
- Marine economy
- **Blue economy**
- **Scotland**
- United Kingdom
- Fisheries
- Aquaculture

Ramboll shared all literature reviewed with CXC, and CXC also shared with Ramboll any literature sources they deemed pertinent as the project progressed.

Step 2: Desktop-based literature review and summary

Following agreement of the list of literature sources, the project team undertook a preliminary review of each of the selected documents in the long list, which numbered 109 documents. The project team applied **inclusion criteria** to select those literature sources most relevant for this study.

Literature sources were prioritised according to the following inclusion criteria:

- **Date of publication**: Recent literature sources were prioritised, with a focus on 2010 onwards for Scottish literature, and 2015 onwards for international literature, unless considered to be highly relevant.
- **Topic relevance**: Literature sources were required to cover marine or climate vulnerability at a minimum.
- **Geographic scope**: Priority was given to literature focusing on or including Scotland in order to inform research question 1. Literature focusing on other geographic scopes was included to inform research question 2, but each source was also assessed to ensure it met the topic relevance inclusion criteria.
- **Methodology provided**: If the geographic scope was outside of Scotland, the document required at least a partial overview of its methodological approach which was replicable in a Scottish context. This inclusion criteria will be refined based on discussions with CXC, but a preliminary list is suggested as follows:

To ensure transparency in this selection process, Ramboll recorded whether the literature identified through the search criteria met the inclusion criteria and therefore warranted being taken forward for further analysis. This process was recorded in the excel-based Literature Summary Assessment Framework (LSAF). To ensure this review was done systematically and comprehensively, the LSAF – a single, centralised excel sheet with appropriate column headings covering relevant themes – was used to collate findings. Summarising the relevant documents in this way also allowed for easy reference to particular literature sources and identification of gaps.

For each of the documents in the long list, reference information as listed below was recorded, in addition to whether and to what extent the documents met the inclusion criteria:

- Document type (journal article, policy document, book etc.)
- Authors
- Year of publication
- Scope and sectors covered

Step 3: Literature assessment, evaluation and relevance to Scotland

Step 3a: Literature assessment & critical evaluation

Using the findings from the literature review, Step 3a involved critical evaluation of the short list of 57 literature sources based on their strengths, weaknesses and gaps. The output of this step was a clear understanding of which literature sources were most applicable for the Scotland marine context, and specifically which aspects of their methodological approach should be used (and/or adapted) for future application.

Step 3a saw the project team develop the findings of the previous steps and began with an analysis of the collated literature. Using the LSAF, this analysis involved a critical review of each document, to discover best practice, understand their relevance to the project context and identify gaps. In this regard, further headings within the LSAF were added to provide:

- Technical methodology-related information, such as:
 - Technical scope (details on methodological framework used)
 - Data requirements and assumptions
 - Key findings (structured according to exposure, sensitivity and adaptive capacity, for example)

Importantly, to facilitate the critical evaluation of literature sources, the LSAF included assessment parameters/headings such as:

- Applicability and relevance to the Scottish context
- Relevance to the marine environment or marine economy
- Strengths of the approach described
- Weaknesses of the approach described
- Robustness of findings
- Available data
- Ease of use (of methodological approach/framework)
- Scope/coverage
- Need for improvement

Step 3b: Evaluation for applicability to marine environment in Scotland

The final part of the literature evaluation process focused on a cross-literature assessment to understand how the existing methodologies could be applied to strengthen vulnerability assessments of the marine environment and marine economy in Scotland.

The focus of this step was to evaluate across the short-list of approximately 50 documents how complete existing work on the marine environment and economy in Scotland is, and how other work outside of Scotland could be applied to strengthen existing work. This evaluation identified relevant themes and lessons learned from previous work in this area.

Step 4: Reporting and Recommendations

A key component of the written report was communicating the results of the critical evaluation in order to provide CXC and the Scottish Government with a clear understanding of the existing information available on CVAs relating to the marine environment in Scotland, and recommendations for how existing methodologies can be applied to strengthen them. As such, the written report addresses each research question accordingly.

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