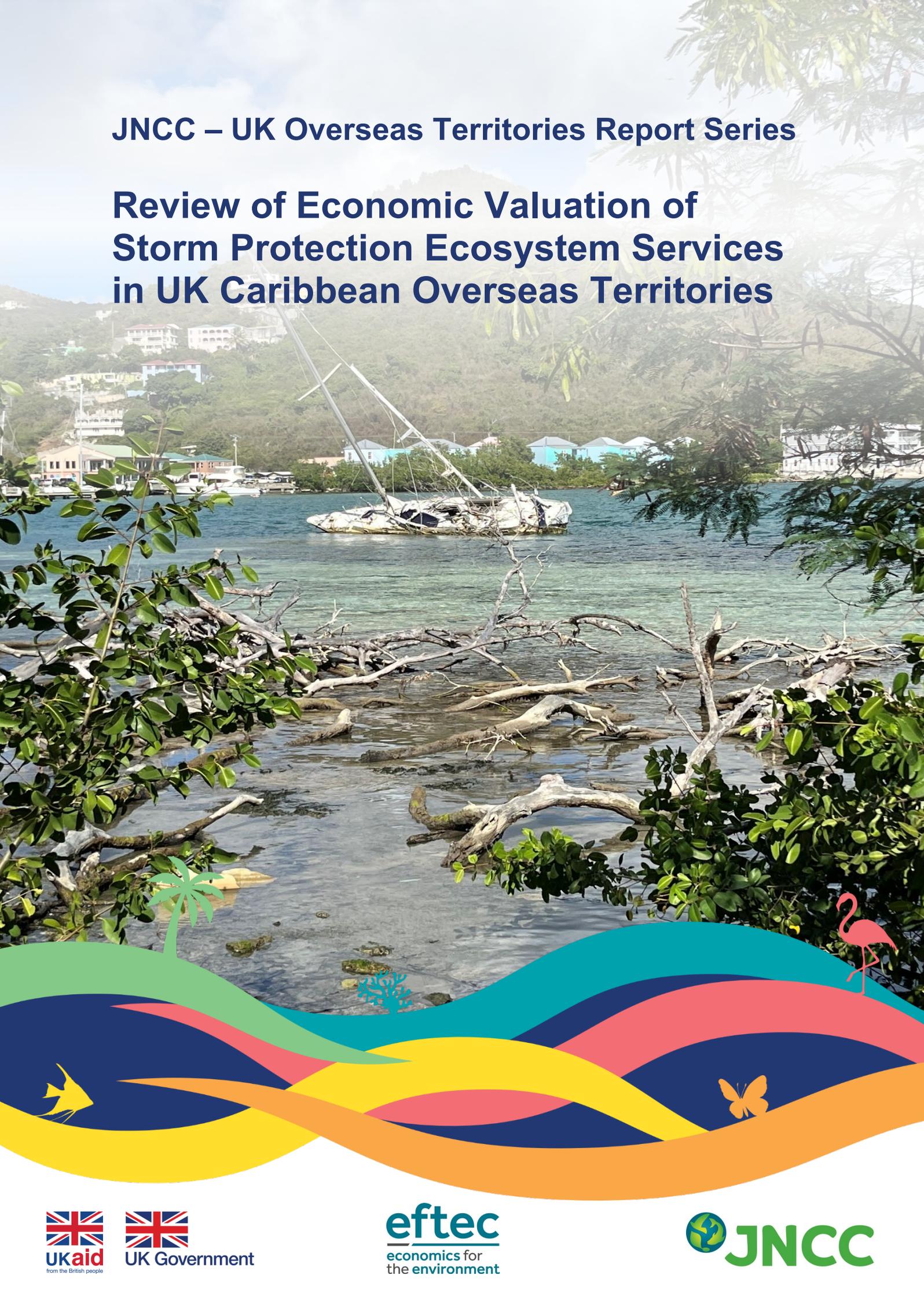# JNCC – UK Overseas Territories Report Series

# Review of Economic Valuation of Storm Protection Ecosystem Services in UK Caribbean Overseas Territories

## This document should be cited as:

## Acknowledgments:

## Evidence Quality Assurance:

This document is compliant with JNCC's Evidence Quality Assurance Policy.


The views and recommendations presented in this report do not necessarily reflect the views and policies of JNCC.

# Contents

# Summary

This is the evidence review report for the 'Review of Economic Valuation of Storm Protection Ecosystem Services in the UK Caribbean Overseas Territories' commissioned by the Joint Nature Conservation Committee (JNCC).

A rapid evidence assessment was undertaken using a search protocol developed in line with UK guidance (Collins *et al*. 2015). The review covered economic valuation approaches in storm protection models prepared separately for the five Caribbean Overseas Territories (OTs: Anguilla, the Cayman Islands, Montserrat, the Turks and Caicos Islands and the Virgin Islands) under the Conflict, Stability and Security Fund (CSSF), and in key literature pertaining to the roles of coastal and marine ecosystems in storm protection from an economics perspective.

The implementation of the defined search protocol resulted in eighteen documents being included in the evidence base. Most of this evidence is made up of government or government-commissioned reports. Notably, half of the ten documents shared directly by JNCC are in-draft (all dated 2022).

The reviewed sources cover a range of ecosystem assets and types in the Caribbean, with coral reefs, mangroves, and seagrasses the most frequently mentioned and/or studied across the evidence reviewed. While flooding was a central feature in many of the bio-physical models, there is a key difference between coastal and inland flooding. Coastal flooding relates to storm surge and is in the scope of this project. Inland flooding largely falls outside the scope, but an exception is made where it is difficult to distinguish hydrologically what is inland versus coastal for a particular setting.

The review identifies links between the storm protection benefit models and socio-economic data. The studies use a range of physical modelling and monetary valuation methods. In general, these are fit for purpose for understanding the ecosystem service, and therefore should be used in ecosystem accounting (in preference to not measuring and valuing storm protections services, which would be a significant omission for the five Caribbean OTs). The studies use a consistent logic chain, within an ecosystem services framework, which enable the inclusion of their results in the OTs' ecosystem accounts and other relevant decision-making processes (such as policy appraisal).

The review highlights the opportunities and challenges of integrating ecosystem service modelling and economic valuation into the SEEA-EA accounting framework. Links to the ecosystem accounts can help increase consistency of approaches and ensure full coverage of relevant habitats. However, the monetary valuations, such as those based on avoided damages, do not exactly follow the exchange value concept favoured by the SEEA-EA guidance (to align to GDP and other data from the Systems of National Accounts (SNA)). This is because, while they do use property values (which are exchange values), they do not reflect an annual transaction. Therefore, while they provide a useful comparison to other SNA data, they are reported within 'supplementary values' in the OTs' ecosystem accounts.

With more specific guidance, current and future modelling results can be presented in a way that makes their results easier for the OTs to use in their ecosystem accounts. Key steps for this include how an annual flow of benefits is derived and using SEEA-EA terminology such as ecosystem types and users/beneficiaries. Incorporating this modelling data into the ecosystem accounts can increase recognition of the value of vital ecosystem services, such as storm protection, in the OTs, including within Government and private sector decision-making.

# 1.    Introduction

## 1.1.    Project background

JNCC is supporting the governments of the UK Caribbean Overseas Territories (henceforth "OTs") across numerous, multi-disciplinary projects which seek to support the OTs' governments' capacity and capabilities with ecosystem accounting. JNCC, along with eftec, set up the Ecosystem Accounting Network, an association of professionals seeking to apply ecosystem accounting approaches to better value the benefits from natural capital.

Ecosystem accounts provide a framework for the collection, analysis, and communication of the links between the natural environment and societal wellbeing. Since 2017, eftec has been working across the five Caribbean OTs (Anguilla, Cayman Islands, Montserrat, Turks and Caicos Islands, and Virgin Islands) to support the development of their ecosystem accounting processes, and production of the Ecosystem Accounts (hereafter "the Accounts") themselves. The Accounts capture a wide range of evidence on the extent, condition, and provision of benefit attributable to the terrestrial and marine environments. The ecosystem accounting framework that has been applied to produce the OT Ecosystem Accounts is shown in Figure 1.
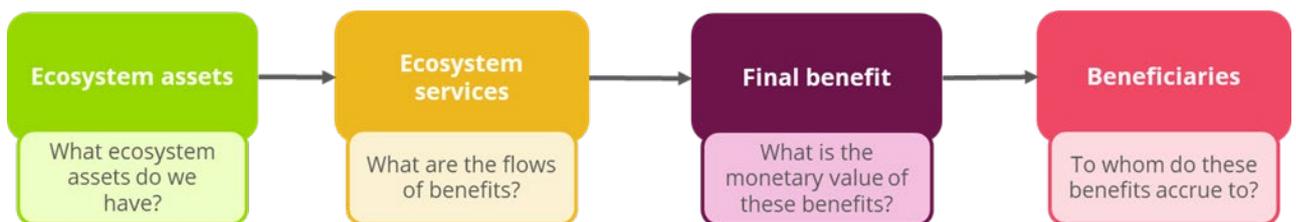


**Figure 1:** Ecosystem accounting framework.

The diversity and similarities across the OTs are reflected in their individual ecosystem accounts, showcasing the range of environmental assets within the region, but also the abundance of benefits to residents on the islands. This earlier work has demonstrated that the economic prosperity and wellbeing of the people of these islands is fundamentally linked to effective management of the environment and has helped communicate this value to different stakeholders. As part of a Darwin Initiative funded project (DPLUS108), the OTs have all developed 2020 Ecosystem Accounts and are part of a network dedicated to ecosystem accounting practitioners in the region.

Storm (and/or coastal) protection has been identified as a priority ecosystem service across the OTs in the 2022 series of Network meetings, particularly interpreting and using the storm protection models that they have access to. The storm protection models, prepared separately for specific OTs under the Conflict, Stability and Security Fund (CSSF) programme, are suitable material for knowledge transfer. Since each model is bespoke per territory, it is important to ensure consistency in how the outputs of the model are applied to OT-specific ecosystem accounts. Understanding compatibility and consistency across models, as well as key differences, will facilitate better communication across governments concerned with disaster management, and better promote the value of the natural environment in providing storm protection services.

## 1.2.    Project objectives

This project complements the completed JNCC internal peer-review of the bio-physical modelling of storm protection (Kovacevic *et al.* 2022). The bio-physical model review focused on the provision of evidence associated with storm protection (flood risk management from natural disasters), and how the natural environment supports this benefit. The review undertaken here aims to identify links between the storm protection benefit models and socio-economic data, to enable their inclusion in the OTs existing ecosystem accounts and other relevant decision-making processes (such as policy appraisal).

The conclusions and recommendations arising from the review will support inclusion of the quantification and valuation of storm protection benefits into the ecosystem accounting framework and ensuring consistency of approaches undertaken across the five OTs included in a previous Darwin Plus funded project (DPLUS108).

The overarching objectives of the project are to:

- Understand the extent to which existing storm protection benefit modelling approaches are standardised or differ across the OTs, from an environmental-economics perspective.
- Assess the potential to expand models to different habitats where possible.
- Support mainstreaming the use of storm protection models into ecosystem accounts, understanding how to interpret and use the key outputs from the models.

# 2. Review method

## 2.1. Approach

The evidence review undertaken as part of this work has used a rapid evidence assessment (REA) approach. It follows the Environment Agency, Defra and Natural Environment Research Council (NERC) guidance (Collins *et al.* 2015) which defines a REA as "a type of evidence review that aims to provide; an informed conclusion on the volume and characteristics of an evidence base, a synthesis of what that evidence indicates and a critical appraisal of that evidence" (p. xi).

The scope of the review was informed by discussion with JNCC and reflects the focus of this work on understanding whether the OTs' storm protection models can be developed further with appropriate valuation evidence. This work does not aim to provide a systematic review of storm protection valuation and evidence in the region.

The following steps were taken for collecting and collating available literature to establish an evidence base:

1. Develop a search protocol.
2. Search for evidence and produce a database.
3. Extract relevant evidence.

The search protocol and its implementation are discussed further in Section 2.3. The resulting evidence is then synthesised to identify common themes and trends, as well as gaps to understanding the roles of coastal and marine ecosystem assets in storm protection from an economics perspective.

## 2.2. Scope

Specifically, the review scope covers:

- The bio-physical models commissioned by JNCC and the respective OTs, or already known to the project team, to understand the storm-protection benefit models for each of the five OTs.
- Evidence reflecting valuation approaches to coastal and marine ecosystems in storm protection, interpretation of valuing these ecosystem services, use and/or applicability to ecosystem accounting (particularly the UN SEEA-EA), and use and/or applicability to policy appraisal.

The evidence review focuses on key literature that discusses the role which coastal and/or marine ecosystems play in storm surge protection from an economics perspective. Specific questions for review include:

- What is the value and valuation approach used (e.g. replacement costs, avoided damage cost) to assess storm protection benefits provided by marine and/or coastal ecosystem assets?
- How do the values of a particular ecosystem asset (e.g. coral reefs, mangroves) vary within the evidence base?

- How suitable are the identified valuation approaches for ecosystem accounting and/or economic appraisal?

## 2.3.   Search protocol

To understand the roles of coastal and marine ecosystems in storm protection from an economics perspective, a search protocol was developed in line with guidance on rapid evidence assessments (Collins *et al*. 2015). The search protocol, in addition to establishing the background, scope, and objective of the review, details the two-stage screening process by which literature in the evidence base is collated and analysed. This ensured that relevant literature was collected and collated consistently across multiple reviewers, and that the approach used was transparent and replicable. The full search protocol can be found in Appendix 1.

The implementation of the review protocol ultimately fed into the development of the 'evidence base' which includes relevant literature that reports sufficient information that can be used to understand the roles of coastal and marine ecosystems in storm protection from an economics perspective. This includes the identification of common themes and trends across the literature.

The evidence sources were divided into three categories, and reviewed in the following order:

1.   A list of core documents sent by the JNCC project team relating to storm protection modelling across the UK Caribbean Overseas Territories.
2.   Peer-reviewed journal articles identified through the Environmental Valuation Reference Inventory (EVRI), Ecosystem Services Valuation Database (ESVD) and National Ocean Economics Program's (NOEP) "Environmental & Recreational (Non-Market) Values - Valuation Studies Search" databases.
3.   Relevant sources that appeared in the bibliography or references sections of the core documents sent by the JNCC project team.

Documents in the second category were searched for using keywords for ecosystem service and geographic scope (see Appendix 1). The third and final set of documents were sourced through the references and bibliography sections of the JNCC documents. For these sources, the reviewer read the title of each document and any accompanying subtitle, abstract, summary or keyword(s) to determine whether it was sufficiently relevant to understanding the roles of coastal and marine ecosystems in storm protection from an economics perspective. The same search parameters, outlined in Appendix 1, were applied to these sources as well.

The first phase screening entailed the implementation of the evidence search strategy as defined in the search protocol. The following high-level summary information was recorded for each document:

- Author(s) or commissioning body
- Date of publication
- Document title
- Origin of source (e.g. JNCC project team or database)

- Study description (e.g. abstract or the reviewer's summary of the study's purposes and objectives)

The second phase screening entailed a more in-depth review of those documents collected during the first stage by applying the inclusion and exclusion criteria listed in the search protocol. The criteria are applied to ensure that documents collected are relevant for review, where the key inclusion and/or exclusion criteria relate to the geographic scope (i.e. Caribbean region) and temporal scope (i.e. published since 2016 inclusive) of the identified evidence.

The information that reviewers extracted, where possible, included:

- Relevant: Indicated with a "yes" or "no" based on inclusion and exclusion criteria in Appendix 1.
- Ecosystem asset(s): List of the ecosystem asset(s) mentioned in the source.
- Bio-physical model: Name(s) of the bio-physical model discussed.
- Benefit name: Describes the benefit(s) or core function(s) of the model in simple terms.
- Coverage: Describes whether the benefit(s) or core function(s) of the model is/are separate or combined in the context of the study.
- The good itself: Describes the advantages and benefits of using the model.
- The change: Specifies the counterfactual description of the model.
- Location: Provides the location of the study.
- Affected population: Lists the beneficiary groups (e.g. households and businesses) that benefit from modelled storm protection and any benefits arising from the natural capital or ecosystem assets or services studied.

## 2.4. State of the evidence base

Implementation of the search protocol resulted in eighteen documents being included in the evidence base. An overview of sources identified, and number reviewed is shown in Table 1.

**Table 1.** Potential sources identified and sources reviewed.

| Identified through | Number of sources | Duplicates | Number reviewed |
|---|---|---|---|
| JNCC | 10 | - | 10 |
| EVRI | 13 | - | 1 |
| ESVD | 13 | 1 (with EVRI) | 1 |
| NOEP | 5 | 1 (with EVRI) | - |
| Bibliographies | 6 | - | 6 |
| **Total** | **47** | **2** | **18** |

Despite providing more than half the sources identified, EVRI, ESVD and NOEP only provided two sources that met all criteria and were included in the evidence review, though neither directly related to a bio-physical storm protection model. Of the eighteen documents reviewed, ten were from the first category of sources directly sent by JNCC, and six were

collected from the bibliographies of the JNCC-sourced documents. There is some degree of cross-referencing between sources (particularly the JNCC documents referencing other JNCC documents within the set of reviewed documents).

Under the search protocol's inclusion and exclusion criteria, any document that did not specifically relate to the Caribbean and/or was dated prior to 2016 was ruled out and not reviewed. Of this set of excluded sources found in EVRI, ESVD and NOEP, it is possible that there is material pertaining to areas outside of the Caribbean that could cover other ecosystem assets and valuation approaches apart from the ones identified in the reviewed sources. Furthermore, sources prior to 2016 would make use of available knowledge prior to 2016 and would not incorporate the observed evidence form the 2016 severe hurricane season.

Most of this evidence base was constructed through literature shared directly by JNCC (approximately 56%) and as such, most are government or government-commissioned reports. Notably, half of the ten documents shared directly by JNCC are in-draft (all dated 2022). The reviewers were able to access all documents in full.

# 3.    Review findings

## 3.1.    Results

This section presents the project team's findings from the eighteen sources reviewed as part of the evidence review on storm protection models in the Caribbean.

### 3.1.1.    Physical coverage and modelling of change

The reviewed sources collectively cover a range of ecosystem types (i.e. habitats) in the Caribbean. Coral reefs, mangroves and seagrasses are the three most frequently mentioned or analysed habitats across the literature reviewed, particularly in the context of coastal protection and mitigation of flood risk. Within UN *et al*. (2021) an ecosystem type "reflects a distinct set of abiotic and biotic components and their interactions" (para. 2.11). Note that within SEEA-EA (UN *et al.* 2021) recommends the use of level of 3 in the IUCN Global Ecosystem Typology (i.e. Ecosystem Functional Group) as these definitions are consistent with CBD definition of ecosystems. Table 2 shows the frequency with which natural capital and ecosystem assets were mentioned across the reviewed literature.

It is useful to compare the ecosystem types covered in the studies identified for review, with those identified in the ecosystem accounts of the five Caribbean OTs. The aggregated 2020 OTs ecosystem account identifies extensive areas of mangrove, seagrass, and reef habitats (see eftec 2022). Under IUCN habitat codes MFT1.2 Intertidal forests and shrublands (31,000 ha), M1.1 Seagrass meadows (258,000), and M1.3 Photic coral reefs and M1.6 Subtidal rocky reefs (a combined 402,000 ha), respectively. It also identifies other areas of coastal habitat (e.g. coastal saltmarshes and reedbeds, subtidal sand beds). Where a marine or coastal ecosystem asset that is present in the OTs is not frequently mentioned or entirely absent from the reviewed sources, it is deemed that the study authors did not find it to be relevant to modelling storm protection in the context of that geographic area.

Therefore, the conclusion is that the asset does not play a significant role in storm protection services across the Caribbean. This may be partly explained by the limited geographic scope outlined in the search criteria in which a natural capital or ecosystem asset may not appear because it makes up a very limited or negligible extent (in terms of area) within an OT or other Caribbean location. For instance, it is possible that more literature looking at the storm protection benefits provided by other habitats (e.g. sand dunes) would have surfaced if the geographic scope of the evidence review was expanded beyond the Caribbean.

In terms of geographical coverage, the literature reviewed covered the UK Caribbean OTs (either individually or as groups) and other neighbouring Caribbean Islands including the Bahamas, Guadeloupe, Martinique, Puerto Rico, Saint Martin and the U.S. Virgin Islands. Fourteen of the reviewed sources related directly to one or more of the UK Caribbean OTs.

Fifteen of the reviewed sources introduced a bio-physical model as a primary topic or subject of research, while three did not directly relate to one. The bio-physical models discussed in the sources can be broadly categorised into four types: terrain, sediment, vulnerability, and resilience.

**Table 2:** Coverage of natural capital and ecosystem assets in the literature.

| Ecosystem asset | Number of sources (n = 18) |
|---|---|
| Mangroves | 13 |
| Coral reefs | 12 |
| Seagrass | 8 |
| Non-mangrove vegetation (e.g. forest, shrubland) | 4 |
| Salt ponds and marshes | 2 |
| Channels, ghauts, and rivers | 2 |
| Hollows/concavities | 1 |
| Wetlands | 1 |
| Lagoons | 1 |
| Beaches | 1 |

As the main area of focus of this project is on storm surge protection afforded by natural capital and ecosystem assets, it should be noted that storm surge (which includes coastal flooding) was not featured across all the models depending on the nature of the study. If a model directly related to storm surge or storm surge protection benefits, the model was either:

1) exclusively related to storm surge risk (coastal wave and flooding) or,
2) it was combined with inland flooding, as in the case of the TUFLOW/SWAN model which looks at both components under a combined model.

The bio-physical models varied in terms of coverage. Most sources reviewed were combined coastal and inland models while others were separate.

While flooding was a central feature in many of the models, there is a key difference between coastal and inland flooding. Coastal flooding relates to storm surge and is in the scope of this project while inland flooding largely falls outside the scope of this project (depending on the context and assuming it is reasonably easy to distinguish what is inland versus coastal for a particular setting).

Of the eighteen sources, eleven sources introduced at least one bio-physical model that directly considered storm surge or coastal flooding (either coastal, inland or both). A small number of reviewed sources introduced bio-physical models that did not relate to flooding. To measure the ecosystem service benefit, the sources reviewed employed various approaches to study the "change" that can be attributable to a particular natural capital or ecosystem asset. These methods ranged from multiple scenario and cumulative cost to refinement of vulnerability mapping and conditional probability. The most common experimental method ("the change" observed) was to compare a modelled ecosystem service outcome for a scenario, reflecting a change in the ecosystem (habitat), against a baseline. All else being equal, the change in the model outcome is taken as a measure of the ecosystem assets contribution to that service.

With respect to the affected populations (and stakeholders more broadly), local inhabitants were the most frequently mentioned affected group, appearing in seven of the sources,

followed by businesses (particularly the tourism, agricultural and fisheries sectors), which were mentioned in six sources. Another commonly mentioned affected group were overseas tourists, perhaps reflecting the importance of the tourism sector to the economies of the UK Caribbean OTs and neighbouring islands.

Physical indicators and metrics (as model inputs) largely depended on the nature of the specific model and the benefit it serves. As mentioned, the bio-physical models introduced in the reviews can be categorised into different types, such as sediment and vulnerability mapping. While some of the bio-physical models relied on both quantitative and qualitative data, most of the bio-physical models featured in the sources relied entirely on quantitative data inputs. The notable exception to this is the Bayesian Belief Network (BBN) model for Montserrat, which consists of nodes linking ecosystem processes and services to "*operationalise a natural capital framework to provide a practical tool for decision makers and stakeholders in Montserrat to manage natural capital, through an ability to explore the impacts of different policy and management options*" (McVittie *et al.* 2022).

## 3.1.2. Monetary valuation

This section considers uses of monetary values in both ecosystem accounting and economic appraisal.

### 3.1.2.1. Valuation methods

Economic valuation is used to estimate the value individuals place on the natural environment. A key distinction is between data that reflects the economic activity in markets ('exchange values') or data that reflects the benefit a person gets from something, including but not limited to consumption in markets ('welfare values'). Under some conditions exchange values are a good measure of welfare, but this is often not the case for environmental goods and services, nor in relation to public goods for which there are no exchange values because no market exists. For example, outdoor recreation or benefits to human health from better air quality can often be free to access, but nevertheless have high welfare.

Different types of value can be estimated for a specific 'marginal' change (e.g. an increase in purchases, or in visits to a recreational site), or in 'aggregate' (e.g. the total value of market purchases, or of all visits to a recreational site – which is equivalent to a change from zero - i.e. no market or no asset). While accounts use valuations of marginal change in their calculations, their main objective is to provide aggregate values.

Ecosystem services approaches are widely used to organise relevant qualitative and quantitative data, without which valuation would not be possible. Ecosystem accounts organise this physical data, enabling them to produce environmental values. They adopt the exchange value approach to monetary valuation.

Marginal or aggregate welfare or exchange values all have valid uses to inform policies and decisions:

- National ecosystem accounts (following UN SEEA-EA (United Nations 2021)) give aggregated measures of exchange values to enable comparability to other national economic data, such as GDP.

- Economic appraisal (typically cost-benefit analysis - CBA) compares the costs and benefits of achieving a given objective for the people affected (sometimes the entire society).

The UN guidelines (2021) favour the use of exchange values in Ecosystem Accounts. However, there are no exchange values for most environmental public goods because such goods are not exchanged in markets - this is often the case for annual storm protection services. Therefore, ecosystem accounts sometimes need to use other values, which are presented in the accounts as 'Supplementary Values'.

### 3.1.2.2. Storm Protection Values in the OTs' 2020 Ecosystem Accounts

The five UK Caribbean OTs' Ecosystem Accounts are designed in line with UN ecosystem accounting guidelines (United Nations, 2021). A review of wider marine and fisheries evidence captured in the 2020 OT Ecosystem Accounts looked at how storm surge (or coastal) protection was valued (eftec 2022).

For four of the five accounts, avoided infrastructure damage costs were calculated for commercial and residential buildings, other buildings, and/or transportation infrastructure where data was available. The exception was Montserrat, where the storm surge protection service (i.e. preventing coastal flooding) was not deemed a material service. Both the Virgin Islands and Cayman Islands accounts report monetary values as annual and asset values for protection, with Anguilla reporting the asset value of protection from a one-off storm event (eftec 2022).

From each of these models (for Anguilla, the Turks and Caicos Islands and the Virgin Islands) a different physical flow indicator serves as a basis for valuing storm protection services in monetary terms. These flow indicators and the associated values are shown in Table 3. It should be noted that these physical flow indicators are just one piece of data amongst the many used in the physical modelling. For instance, under an avoid damage cost approach, the number of avoided lost hotel room days or number of buildings protected may each be one of multiple physical units used in measuring and valuing storm protection services in their respective models.

**Table 3:** Storm surge protection service captured in the OT 2020 Ecosystem Accounts.

| OT | Ecosystem types | Physical units supporting monetary valuation | Annual value (US$m) | Asset Value (PV25, US$m) |
|---|---|---|---|---|
| Anguilla | Marine and coastal ecosystems | 1,124 avoided lost hotel room days | One-off storm event | 4 |
| Cayman Islands | Coral reefs | Physical flow not reported | 8.5 | 145 |
| Montserrat | | | | |
| Turks and Caicos Islands | Marine and coastal ecosystems | 11,370 properties at risk | Not assessed | Not assessed |
| Virgin Islands | Coral reefs | 2,234 buildings protected | 76 | 1,285 |

### 3.1.2.3. Other Storm Protection Valuation Evidence

Overall, all eighteen sources reviewed were relevant to ecosystem accounting as they either directly or indirectly referred to natural capital and ecosystem assets and their associated benefits. Twelve documents assessed the monetary value of storm protection services (either as an annual flow or asset value), of which two are models commissioned by JNCC (Calder-Neil *et al*. 2022; Carter *et al*. 2022). There was a mix of approaches used to valuing storm protection in the models reviewed:

- Avoided damages, based on the cost of damages to infrastructure – buildings and contents.
- Cost of business interruption.
- Stated preference methods (e.g. willingness to pay survey).
- Payments made to utilities companies for services not disrupted by storm hazard.

The most used valuation approach is avoided damage costs, coupled with scenario modelling to determine the attributable value to an ecosystem type (e.g. coral reefs). Within the evidence base, it is not always clear whether values produced are annual values (i.e. likely to be recurring) or avoided loss for a specific case (e.g. specific storm event). For example, Williams *et al*. (2017) specifically states that values produced reflect "the value associated with the low-probability event" (p. 36). Where annual values are produced, further review is required to know whether they can support asset valuation (i.e. estimating present value of benefits) and what the appropriate assumptions are (e.g. storm frequency).

Several studies also referenced the replacement costs method, but it was not directly applied. The replacement cost approach is a cost-based method for valuing ecosystem services. A replacement cost "considers the cost of providing a substitute good or engineering solution that performs a similar function to the environmental good." (Defra 2021). "In order for a replacement cost to not overstate the true economic value, three conditions must be satisfied:

1) estimate of the costs reflects the qualities of the ecosystem service being lost,
2) replacement is the least-cost alternative, and
3) replacement would be fully demanded in the absence of the asset" (abbreviated from Defra 2021).

It is not clear that it would be an appropriate method to adopt. This is because to provide a valid valuation, it needs to be clear that the replacement actions are or would be adopted. This is considered unlikely to be the case for all the ecosystem assets providing storm protection services on the OTs.

Generally, the sources reviewed were conducive to economic appraisal applications, though there were notable exceptions listed below:

- The bio-physical model for Montserrat (which is a Bayesian Belief Network model) (developed by McVittie *et al*. (2022)) is based on nodes and links between natural capital and ecosystem processes contributing to ecosystem services. As noted by Kovacevic *et al*. (2022), "the limitations of the BBN models are clear, and it is the outputs of a BBN model. They are limited to the probabilities of each node or variable, which has very limited practical meanings. Therefore, the extension or link to other models will increase the usability."

- Scotland's Rural College (2022) introduced a Hydrological Engineering Centre – River Analysis System (HEC-RAS) basic sediment model for Montserrat and strictly considered physical flows and did not provide any suggestion or guidance on how the ecosystem asset, services and processes in question could or should be appraised.
- Imbert (2018) on storm intensity and damage to mangrove vegetation in Martinique and Guadeloupe discussed the storm protection benefits of different species of mangroves following different hurricane events but did not cover monetary valuation or economic appraisal approaches of these benefits.
- Lastly, Joyce *et al*. (2019) was a highly scientific and technical study that focussed on predicting tides and hurricane-driven storm surge and waves adjacent to deep ocean islands and did not provide any indication of how to quantify or appraise the assets and services mentioned.

## 3.2.  Gaps

The evidence on storm protection in the Caribbean exists (through biophysical models on storm protection benefits), but not many sources made the link to monetary valuation of natural capital and ecosystem assets.

While some sources offered highly technical guidance on storm protection (e.g. through sediment modelling, bathymetry, simulation of waves and tides), there is a gap in terms of how economists can interpret and subsequently utilise this data to inform monetary valuation of the assets' ecosystem functions and services, and final benefits to people.

An obvious area of data gaps is the database source category, which is driven by the defined search protocol implemented within this project. Across known evidence repositories, EVRI, ESVD and NOEP, only two unique articles were identified as relevant for inclusion within the review evidence base. It should be noted that the primary reason for exclusion of sources was that they fell outside of the period (since 2016) specified in the search criteria (24 of 47 documents identified) as described above.

# 4. Discussion

## 4.1. Economic uses of storm protection model results

The bio-physical modelling approaches to storm protection within the OTs generally fit the structure and logic chains used in the SEEA-EA guidance (United Nations 2021), and in the existing OTs ecosystem accounts. They identify where ecosystem assets are providing a service, and the beneficiaries of that service. Based on the evidence reviewed, key points for ecosystem accounting are:

- The use of habitat areas as a basis for the studies align to the ecosystem accounts guidance on the extent of ecosystem assets and the asset registers used in the OTs' 2020 ecosystem accounts. The role of ecosystem condition in the modelling is more variable, but a minimum condition of habitats is implied in their provision of storm protection benefits, and some models reflect different condition of habitats in the different scenarios they use.

- The studies measure the total physical flow of the ecosystem service. In general, this takes a form of reduced risk to built assets or businesses because of the presence of the ecosystem assets. This is consistent with the requirements of the SEEA-EA.

- As noted, the measurement unit of physical flow of the ecosystem service of storm protection is different across studies. Sometimes this is appropriate for the circumstances on different OTs, but it can create a challenge for accounting, for example for validation of accounting data.

- The SEEA-EA identifies the users and/or beneficiaries of a service. In general, the models define users and beneficiaries clearly, but they do this in different ways, and this could create inconsistency in representation of the data in ecosystem accounts.

Despite not being produced with the specific purpose of providing data for ecosystem accounts (and often being commissioned prior to the publication of the UN standard in 2021), the model outputs can be aligned and incorporated within the OT ecosystem accounts. In terms of monetary valuation, the over-arching principle within SEEA-EA is the alignment to the System of National Accounts (SNA), and therefore favours the use of exchange values. The valuations within the evidence reviewed related to property values (e.g. avoided damage cost) is not strictly speaking an exchange value but does provide good comparability to other market-based values (e.g. GDP).

As reflected in Kovacevic *et al.* (2022) the JNCC commissioned bio-physical models have been reviewed to reflect training, support and maintenance. All CSSF-funded models have some elements of training materials and/or support, which is crucial for the ecosystem accounting process. To ensure that storm surge protection is captured within the OT accounts, the approach to modelling and valuation needs to be repeatable on a regular basis – therefore data and modelling but also organisational effort (i.e. resource needs) are important determinants of continued use.

In general, the economic values derived from the OTs' storm protection models align with requirements for use in economic appraisal to inform decision-making. There are some exceptions where models do not calculate, or link to parameters for calculating, economic

values. However, where economic values are produced, they provide marginal change values suitable for use in appraisal.

The suitability of many of the models' outputs for economic analysis reflects the utility of the ecosystem services approach. This provides a structure to link the physical measurement of services to economic analysis of their consequences for people and society. However, differences in the models used and the way they report results mean it is currently difficult to validate the models' economic outputs. These factors, in addition to the large context-specific variations in values for storm protection (e.g. due to different topography, ecosystems, and areas at risk), mean it is difficult to identify results that could be robustly transferred between different locations in the Caribbean.

## 4.2.  Future improvements

The current evidence base on storm protection modelling can make a long-term contribution to ecosystem accounts for the Caribbean OTs. To maximise this contribution, the following improvements are recommended:

- Modelling results can be regularly updated to provide annual inputs to the accounts. Not all data needs to be updated annually, and an efficient approach could involve:
    - Annual updates of data on the value of properties receiving storm protection services. This should be updated in line with annual property value (from other national statistics) and new spatial planning/development activity.
    - Other regular updates could use latest socio-economic data (e.g. from population surveys).
    - Complete re-running of the models should be undertaken periodically (e.g. three to five years), specifically when significant new data is available, for example on the extent and condition of habitats (ecosystem types), or on storm patterns and risks. Both have increasing importance given expected risks from climate change.
- Models can more explicitly use a SEEA-EA output structures (e.g. terminology and units) to enable the OTs to use them in their accounts.
- Data can be reported for both marginal values (e.g. per hectare of habitat per year) and aggregated value (annual and long-term asset).
- More consistent output formats in line with SEEA-EA will enable comparisons between different studies for the same location (e.g. a detailed comparison could be made of the Carter *et al.* (2022) results (forthcoming) with the current results used in the 2020 account for the Cayman Islands).
- Based on these comparisons, validation approaches can be developed for ecosystem accounting data, informed by ongoing development of validation guidance (e.g. by Eurostat, pers. comm.).
- Future specification of physical modelling and monetary valuation of storm protection (and other ecosystem services) should link to the asset register(s) for the relevant areas, helping to ensure full coverage of ecosystem types (including where they do not provide benefits) and reinforcing links to the ecosystem accounts.

# 5.    Conclusions

The evidence review completed as part of this work highlights that it was possible to compare different models and economic valuation approaches employed within modelling commissioned by JNCC and found in the wider literature for their use in the OTs Ecosystem Accounts. This was facilitated by using similar ecosystem service and/or natural capital frameworks where the means of valuing storm protection (either in physical terms and/or monetary terms) share a common logic chain (i.e. linking ecosystem types to change in ecosystem service provision and ultimately benefits). For this review, to enable establishing links to the OT Ecosystem Accounts, the framework considered is as defined within the UN SEEA-EA (2021) guidance.

The implementation of the defined search protocol resulted in eighteen documents being included in the evidence base. Most of this evidence base is made up of government or government-commissioned reports, and several are in-draft (all dated 2022). The reviewed sources cover a range of ecosystem types (i.e. habitats) in the Caribbean, with coral reefs mangroves, and seagrasses being the most frequently mentioned and/or studied across the evidence reviewed. Of the eighteen sources, eleven introduced at least one bio-physical model that directly considered storm surge or coastal flooding (as distinct from inland flooding, which is outside the review scope unless it is indistinguishable from coastal flood events).

With respect to monetary valuation of storm protection services, a range of approaches have been used within the evidence base, including avoided damage cost, and stated preference methods. Several studies reference the replacement cost method, but it was not usually directly applied. Of the eighteen sources, twelve provide a monetary assessment of the storm protection service (either as an annual flow or one-off assessment), of which two are models commissioned by JNCC. Note that these bio-physical models and monetary values are not included within the 2020 OT Ecosystem Accounts (see eftec 2022). However, they are suitable evidence to use as part of future updates to the accounts. Having measurement and valuation of storm protection within the accounts provides information that ensures this important ecosystem service is not omitted.

In general, the economic values derived from the OT storm protection models align with requirements for use in economic appraisal to inform decision-making. For example, they provide marginal change values suitable for use in appraisal.

The suitability of many of the models' outputs for accounting economic analysis demonstrates the effectiveness of the ecosystem services approach as a way to link the physical measurement of services to economic analysis. However, differences in the models and the large context-specific variations in values for storm protection mean results cannot be robustly transferred between different locations in the Caribbean. These reasons also mean that while further research could try to specify a value transfer function, it may not be able to give a sufficient level of accuracy.

## 5.1.  Recommendations

Aligning the evidence on measuring and valuing storm protection services in the OTs to ecosystem accounting requirements will increase its use in those accounts and raise its

visibility with decision makers. Key areas of alignment include SEEA-EA terminology, providing annual values, and enhancing repeatability, updates, and validation.

The best models for each OT should be updated regularly, due to the expectation that climate change will alter storm frequency (a parameter in the models) and the extent and condition of ecosystem assets over time. Some aspects of modelling can readily be updated annually (e.g. property values). For others it will be more efficient to update less frequently as data is gathered, or modelling processes are repeated (e.g. three to five years).

With the number of models that are available, and with greater consistency of model outputs and their use in accounts over multiple years, validation processes should be developed for storm protection (and other key data) in the OTs' ecosystem accounts.

The key points from this review on how the models link to the OTs' ecosystem accounts should be used to help specify future storm-protection modelling work. More broadly they can be used to enhance multi-disciplinary working on ecosystem services.

Academic research is needed to better understand the opportunity for meta-analysis to deliver a value transfer function (e.g. to derive value per hectare of different habitats given the value of assets protected) that can be applied in accounting and economic appraisal across the OTs and Caribbean region.

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# Appendix 1: Search protocol

## Background

### Scope

The review scope covers:

- The work undertaken by JNCC and the respective OTs, or already known to, the project team in order to understand the storm protection benefit models for each of the OTs (Anguilla, the Virgin Islands, the Cayman Islands, Montserrat, and the Turks & Caicos Islands).
- The evidence reflecting valuation approaches to coastal and marine ecosystems in storm protection, interpretation of valuing these ecosystem services, use and/or applicability to ecosystem accounting (particularly the UN SEEA-EA), and use and/or applicability to policy appraisal.

In the project inception meeting (31 January), the project team explained the general purpose of a rapid evidence review and why it is appropriate for this project. The review summary report will present findings from relevant sources, where some restrictions on publication timing and habitat types have been defined as part of the 'Evidence Search Strategy'.

### Objectives

The aim is to get a better understanding of the extent to which storm protection benefit modelling approaches are standardized or differ across the OTs. The review will focus on key literature that discusses the role which coastal and/or marine ecosystems play in storm protection from an economics perspective.

Questions for review:

- What is the value and valuation approach used (e.g. replacement costs, avoided damage cost) to assess storm protection benefits provided by marine and/or coastal ecosystem assets?
- How do the values of a particular ecosystem asset (e.g. coral reefs, mangroves) vary within the evidence base?
- How suitable are the identified valuation approaches for ecosystem accounting and/or economic appraisal?

## Evidence search strategy

### Evidence sources

Priority sources: The review will consider reports provided by JNCC including:

- JNCC Peer Review of OT storm protection models *(in-draft)*
- OT storm protection modelling reports (*in-draft*)

Supplementary evidence: In addition to the JNCC provided documentation, the review will consider literature from known databases and bbibliographic searches of the JNCC commissioned reports. The databases and search order are as follows:

- Environmental Valuation Reference Inventory (EVRI): https://www.evri.ca/en
- Ecosystem Services Valuation Database (ESVD): https://www.esvd.net/
- National Ocean Economics Program (NOEP) Non-Market Valuation: https://www.oceaneconomics.org/nonmarket/

The search strings used to conduct searches within the evidence databases are:

- For EVRI:
    - Keyword: 'coastal protection'; Region: Caribbean; Environmental Assets: any
    - Keyword: 'storm protection'; Region: Caribbean; Environmental Assets: any
- For ESVD:
    - Country: all Caribbean Islands; CICES: 'Hydrological Cycle and water flow regulation (including flood control and coastal protection)'
    - Country: all Caribbean Islands; TEEB ES services: 'Storm protection'
- For NOEP:
    - Keywords: 'coastal protection' and 'storm protection'; Location: 'Caribbean'
    - Keyword: 'coastal protection'; Location: 'Caribbean'

The bibliographic searches were conducted through a title screening exercise to determine whether referenced evidence was sufficiently relevant to understanding the roles of coastal and marine ecosystems in storm protection from an economics perspective.

All results were recorded regardless of their title or how relevant they initially appear to be. It is expected that there will be overlapping results between the evidence databases and JNCC reports. Therefore, only unique search results will be added to the evidence base. If a single source appears in search results across multiple combinations of keywords, it shall only be logged once.

## Methods

Relevant evidence sources are documented in an evidence base which contains summary information of the piece of evidence such as title, authors, date of publication, and other parameters of interest pertaining to the biophysical model(s) and the respective physical flow measure, monetary value, application and use, and quality and transferability.

The first stage of the screening process will collect high-level summary information about the documents such as the author, year of publication, type of source, the keywords/phrases used to find it and the origin of the source (e.g. provided by JNCC or EVRI).

The JNCC documents provided are reviewed in detail. All other evidence sources were subject to a second stage screening in line with the defined inclusion and exclusion criteria below. This stage determined whether an evidence source is relevant.

## Inclusion and exclusion criteria

During the second stage screening process, sources were identified as being relevant according to the following criteria:

Inclusion Criteria (both):

- One or multiple coastal/marine ecosystem assets are present in the UKOTs (as defined by OT asset registers).
- Model and/or valuation approach pertains to storm and/or coastal protection in some form.

Exclusion Criteria (any one of):

- File cannot be accessed (unless the relevant information can be found in the abstract or any other available part of the study.
- File published prior to 2016.
- File covers an area outside of the Caribbean region.
- Model and/or valuation approach solely pertains to inland flooding.

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# Appendix 3: Types and uses of economic values

Economic valuation is to help assess the impacts of decisions. It estimates the value individuals place on the natural environment – in other words, their preferences for changes in the environment. Different valuation methods represent different aspects of the individuals' preferences. Their commonality is that the results are expressed in monetary terms.

The key distinction is between data that reflect the economic activity in markets ('exchange values'); or data that reflect the benefit a person gets from something, including but not limited to consumption in markets ('welfare values'). Under some conditions exchange values are a good measure of welfare, but this is often not the case for environmental goods and services, nor in relation to public goods for which there are no exchange values because no market exists. For example, outdoor recreation or benefits to human health from better air quality can often be free to access, but nevertheless have high welfare.

Both these types of value can be estimated for a specific 'marginal' change (e.g. an increase in purchases, or in visits to a recreational site), or in 'aggregate' (e.g. the total value of market purchases, or of all visits to a recreational site – which is equivalent to a change from zero – i.e. no market or no asset).

Applying any economic valuation method to the environment is a three step process:

1. Qualitative assessment (understand the environmental goods and services and the change in these to be valued).
2. Quantitative assessment (measure the change to be valued in biophysical or socio-economic terms).
3. Monetary valuation (collect and analyse economic value data).

Ecosystem services approaches are widely used to organise relevant qualitative and quantitative data, without which valuation would not be possible to undertake and interpret.

Marginal or aggregate welfare or exchange values all have valid uses to inform policies and decisions:

- National ecosystem accounts (following UNSEEA-EA) give aggregated measures of exchange values (as in GDP).
- Economic appraisal (typically cost-benefit analysis - CBA) compares the costs and benefits of achieving a given objective to the affected population (sometimes the entire society).

System of National Accounts (SNA) is primarily concerned with measuring market exchanges, whereas policy appraisal is also interested in changes in the welfare of the affected population. This is the main reason why the economic values used in accounts are different from those used in appraisal or CBA. It also means that GDP, which only measures the economic activity in the markets, is not a good measure of welfare (SNA 2008) even though it is often interpreted as if it were.

The UK OTs' Ecosystem Accounts are designed in line with UN system of environmental-economic accounting guidelines that favour use of exchange values to enable comparability

to other national economic data, such as GDP. There are no exchange values for most public goods because such goods are not exchanged in the markets, and the exchange values environmental goods would have if there was a market is not always known. Therefore, while these national accounts aim to use exchange values, they sometimes use welfare values as a proxy for exchange values. Non-market measures of welfare value are presented in the accounts as 'Supplementary Values'.

These two areas of work are doing different types of analysis and so use different methods. This difference is starkest for recreation because it has a major non-market element - this means that the estimated values from travel expenditures (e.g. within tourism) and recreation demand model (e.g. use by locals) methods may be very different. **As they each have limitations and give decision-makers different information, it is better to use both exchange and welfare values.** Using only exchange values increases the risk that benefits from non-market environmental goods will be missed in decision-making, resulting in under-allocation of spending or sub-optimal management of the environment. This leads to an under-provision of public goods.