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Common Wadden Sea Secretariat

Agenda Item:	5.3
Subject:	Climate Vulnerability Index (CVI) phase 1 workshop report
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At WSB 28, a proposal by The Task Groups Climate (now: Expert Group Climate, EG-C), taking into account comments by the Task Group World Heritage (TG-WH) was endorsed, for the Wadden Sea World Heritage property to be a pilot site for development and application of a Climate Vulnerability Index (CVI). The CVI is a methodology to rapidly assess vulnerability through expert appraisal of the best-available climate science, applicable to all types of World Heritage properties (natural, cultural or mixed). The proposal entails an expert workshop CVI Wadden Sea.

This workshop "Climate Vulnerability Index (CVI) at UNESCO Wadden Sea - Phase 1: Outstanding Universal Value Vulnerability (OUV)" was successfully conducted on 10 – 11 February 2020 in Hamburg, Germany. Workshop participants prioritised three key climate stressors impacting the OUV of the Wadden Sea: sea level rise, temperature increase and extreme heat events. When considered over two time-scales (ca. 2050 and ca. 2100), the workshop assessed the OUV Vulnerability as High, indicating the potential for major loss or substantial alteration of attributes that convey the OUV.

This document contains the report of the workshop "Climate Vulnerability Index (CVI) at UNESCO Wadden Sea - Phase 1: Outstanding Universal Value Vulnerability" [Heron et as. 2020]

At WSB 31, the Board had acknowledged the successful work and generally supported the second phase of the CVI on Community Vulnerability. The workshop on Community Vulnerability is planned online on 16 – 17 February 2021 and will be facilitated by the CVI developers Scott Heron and Jon Day (Townsville, Australia). Preparatory to the workshop, the CVI developers provided video information on the CVI method and on outcomes of the Phase 1 Workshop. The latter includes material of a World Heritage Marine Programme site managers e-meeting, where the chairpersons of the Task Group World Heritage (TG-WH), Barbara Engels, and EG-C, Robert Zijlstra, and the CVI developers, presented the results of the CVI process in the Wadden Sea (see WSB32/5.1/1).

Both workshops will provide input to the single integrated management plan (SIMP) key topics tourism, fisheries, shipping, energy and coastal protection. Results of the second workshop and conclusions on the project CVI Wadden Sea will be delivered to WSB 33.

Proposal: WSB is invited to note the information.

Dunes at Langeoog, Germany. H.-U. Rösner

Workshop report: Climate Risk Assessment for Wadden Sea World Heritage property

Application of the Climate Vulnerability Index – Outstanding Universal Value (OUV) Vulnerability

Version: 1.0 (Final)

Authors: Heron SF, Day JC, Zijlstra R, Engels B, Weber A, Marencic H, Busch JA

United Nations Educational, Scientific and Cultural Organization

The Wadden Sea World Heritage Site since 2009

WADDEN SEA WORLD HERITAGE

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Executive Summary

Climate change is the fastest growing global threat to World Heritage. Many World Heritage properties around the world are already experiencing significant negative impacts, damage and degradation. These and many others are vulnerable to impacts from climate stressors such as rising temperatures, sea level rise and drought. Recently observed trends are expected to continue and accelerate as climate change intensifies.

The Wadden Sea World Heritage property includes the largest unbroken tidal flat system in the world and was inscribed on the UNESCO World Heritage List in 2009, in recognition of its Outstanding Universal Value (OUV).

This report describes outcomes of the first workshop of key international Wadden Sea experts representing different scientific and academic sectors centred around the OUV of the property, held in Hamburg, Germany (10–11 February 2020). This workshop applied the first phase of the Climate Vulnerability Index (CVI) for the Wadden Sea. The CVI is a methodology to rapidly assess vulnerability through expert appraisal of the best-available climate science, applicable to all types of World Heritage properties (natural, cultural or mixed).

The three identified key climate stressors impacting the Wadden Sea OUV are:

- Temperature trend (air and/or water);
- Extreme temperature events; and
- Sea level rise.

These were consistent across the two timeframes considered (ca. 2050 and ca. 2100) using a 'business-as-usual' climate scenario (RCP8.5), which represents the most likely consequence of current international policies linked to greenhouse gas emissions. **OUV Vulnerability was assessed as High** (the highest category) for both timeframes. Whilst the vulnerability associated with the two temperature-related climate stressors was assessed as High in both timeframes, the vulnerability to impacts from sea level rise escalated from Low in ca. 2050 to High in ca. 2100. Collectively and for both timeframes, there is potential for major loss or substantial alteration of the majority of the attributes that convey the OUV.

With respect to climate adaptation and response measures, there are limited possibilities currently known and ready to implement that support the system to acclimate and/or adapt to either increasing air and water temperatures or extreme temperature events. Improved knowledge of measures for adaption to temperature trends and extreme temperature events may inform additional management options. Adaptation strategies associated with sea level rise, which invoke local and regional management responses and build upon established scientific and technical support, might be of significant influence to the OUV (in particular during the latter part of this century). It was deemed important by the participants of the workshop to minimise other (localised) stressors on the ecosystem, thereby enhancing the natural resilience of the system.

Global actions to substantially reduce greenhouse gas emissions are essential, especially to reduce temperature impacts in the near term. The combination of actions to address climate change and support climate adaptation is critical to maintain the OUV of the Wadden Sea.

The second phase of the CVI process, to assess the vulnerability of the associated 'community' (local, domestic and international) is recommended for a subsequent workshop.

Resumé

Klimaforandringer er den hurtigst voksende globale trussel mod verdensarven. Mange verdensarvssteder overalt i verden oplever allerede betydelige negative påvirkninger, skader og forringelser. Disse og mange andre områder er sårbare over for klimaforandringer, så som stigende temperaturer, havvandsstigninger og tørke. De seneste observerede tendenser forventes at fortsætte og accelerere, når klimaforandringerne intensiveres.

Verdensarv Vadehavet inkluderer verdens største, ubrudte tidevandssystem, og blev optaget på UNESCOs verdensarvsliste i 2009, som en anerkendelse af dets enestående, universelle værdi (Outstanding Universal Value, OUV).

Denne rapport beskriver resultaterne fra den første workshop med vigtige internationale vadehavseksperter fra forskellige videnskabelige og akademiske sektorer. Workshoppen fokuserede på verdensarvens OUV, og blev afholdt i Hamborg, Tyskland d. 10.-11. februar 2020. Denne workshop anvendte den første fase af klimasårbarhedsindekset (Climate Vulnerability Index, CVI) for Vadehavet. CVI er en metode til hurtigt at vurdere klimasårbarheden for alle typer af verdensarvsudpegninger (naturlige, kulturelle eller blandede).

De tre identificerede, centrale klimastressorer, der påvirker Vadehavets OUV, er:

- Temperaturtrend (luft og/eller vand);
- Ekstreme temperaturbegivenheder; og
- Havvandsstigning.

Disse klimastressorer var forenelige inden for de to overvejede tidsnedslag (ca. 2050 og ca. 2100), hvor der blev anvendt et "business-as-usual" klimascenarie (RCP8.5), som repræsenterer de mest sandsynlige konsekvenser af de nuværende internationale målsætninger, der er forbundet med drivhusgasudledninger. **OUV-sårbarheden blev vurderet til at være Høj** (den højeste kategori) i begge tidsnedslag. Mens

sårbarheden, som er forbundet med de to temperatur-relaterede klimastressorer, blev vurderet som værende høj i begge tidsnedslag, havde sårbarheden fra påvirkningen af havvandsstigninger eskaleret fra lav i ca. 2050 til høj i ca. 2100. Både individuelt og fælles for begge tidsnedslag, er der potentiale for et stort tab eller væsentlig ændring af de egenskaber, der ledsager OUV.

Med hensyn til klimatilpasning, forståelse og responsmål, kan der være begrænsede muligheder for at hjælpe systemet til at akklimatisere sig og /eller tilpasse sig stigende luft- og vandtemperaturer eller ekstreme temperaturbegivenheder. Mere viden om tilpasningen til temperaturforløb og ekstreme temperaturbegivenheder, kan måske præge forvaltningsmulighederne. De tilpasningsstrategier, som er forbundet med havvandsstigninger, der kalder på lokal og regional styringssvar, og bygger på veletablerede videnskabelig teknisk viden, kunne påvirke OUV markant (særligt i den sidste del af dette århundrede). Deltagerne i workshopen betragtede det som vigtigt at minimere andre (lokaliserede) stressfaktorer på økosystemet for derved at forbedre systemets naturlige modstandsdygtighed.

Globale handlinger, der bidrager til væsentlig reduktion af drivhusgasudledninger, er vigtige, især for at reducere temperaturpåvirkningen på kort sigt. Kombinationen af handlinger til at tackle klimaforandringer og støtte til klimatilpasning er afgørende for at bevare Vadehavets OUV.

Det anbefales, at den anden fase af CVI-processen, der handler om at vurdere sårbarheden i det tilknyttede 'samfund' (lokalt, nationalt og internationalt), behandles på en efterfølgende workshop.

Zusammenfassung

Der Klimawandel ist die am schnellsten wachsende globale Bedrohung für das Welterbe. Weltweit sind viele Welterbestätten bereits erheblichen negativen Auswirkungen, Schäden und Verschlechterungen ausgesetzt. Sie sind, wie auch das Weltnaturerbe Wattenmeer, anfällig gegenüber den Auswirkungen des Klimawandels, einschließlich steigender Temperaturen, Anstieg des Meeresspiegels und Dürre. Es wird erwartet, dass sich die derzeit beobachteten Trends fortsetzen und beschleunigen werden, wenn sich der Klimawandel verschärft.

Das Weltnaturerbe Wattenmeer umfasst das größte zusammenhängende Gezeitensystem der Welt und wurde 2009 in Anerkennung seines außergewöhnlichen universellen Wertes (Outstanding Universal Value, OUV) in die Liste der UNESCO-Welterbestätten aufgenommen.

Dieser Bericht beschreibt die Ergebnisse des ersten Workshops internationaler Wattenmeer-Experten aus verschiedenen wissenschaftlichen und akademischen

Bereichen, die die Aspekte des OUV umfassen der Welterbestätte (10.-11. Februar 2020, Hamburg). In diesem Workshop wurde die erste Phase des Climate Vulnerability Index (CVI) für das Wattenmeer angewendet. Der CVI ist eine Methode zur schnellen Bewertung der Klimavulnerabilität für alle Arten von Welterbestätten (Natur, Kultur oder gemischt).

Als die drei zentralen Klimastressoren, die sich auf die OUV am Wattenmeer auswirken, wurden identifiziert:

- Temperaturanstieg (Luft und/oder Wasser);
- Extreme Temperaturereignisse; und
- Meeresspiegelanstieg.

Diese drei Stressoren waren konsistent für zwei Zeithorizonte (ca. 2050 und ca. 2100) unter Verwendung eines „Business-as-usual"-Klimaszenarios (RCP8.5), welches die wahrscheinlichste Folge der derzeitigen internationalen Politik im Zusammenhang mit Treibhausgasemissionen darstellt. **Die OUV-Vulnerabilität wurde für** beide Zeiträume **als Hoch** (die höchste Kategorie) **bewertet**. Während die Vulnerabilität im Zusammenhang mit den beiden temperaturbedingten Klimastressoren in beiden Zeiträumen als hoch bewertet wurde, stieg die Verwundbarkeit gegenüber den Auswirkungen des Meeresspiegelanstiegs von niedrig um 2050 auf hoch um 2100. Insgesamt und für beide Zeiträume ist das Verlust- oder Änderungspotenzial für die Mehrzahl der Attribute, die den OUV vermitteln, enorm.

In Bezug auf Klimaanpassung, Verständnis und reaktive Maßnahmen sind nur begrenzte Möglichkeiten, das System bei der Anpassung an steigende Luft- und Wassertemperaturen oder extreme Temperaturereignisse zu unterstützen bekannt. Verbesserte Kenntnisse über Maßnahmen zur Anpassung an Temperaturtrends und extreme Temperaturereignisse können zusätzliche Managementoptionen liefern. Klimaanpassungsstrategien können dann den größten Nutzen bringen, wenn sie sich auf Maßnahmen im Zusammenhang mit dem Anstieg des Meeresspiegels konzentrieren, die lokale und regionale Managemententscheidungen einschließen und auf etablierter wissenschaftlicher und technischer Unterstützung aufbauen. Die Teilnehmer des Workshops hielten es für wichtig, andere (lokal begrenzte) Stressfaktoren im Ökosystem zu minimieren.

Globale Maßnahmen zur wesentlichen Reduzierung der Treibhausgasemissionen sind unerlässlich, insbesondere um die Auswirkungen auf die Temperatur in naher Zukunft zu verringern. Die Kombination von Maßnahmen zur Bekämpfung des Klimawandels und zur Unterstützung der Klimaanpassung ist für die Erhaltung des OUV des Wattenmeeres von entscheidender Bedeutung.

Die Anwendung der zweiten Phase des CVI-Prozesses zur Bewertung der Vulnerabilität der mit dem Weltnaturerbe Wattenmeer assoziierten „Community" (lokal, regional und international) wird für einen anschließenden Workshop empfohlen.

Samenvatting

Klimaatverandering is de snelst toenemende wereldwijde bedreiging voor werelderfgoedgebieden. Werelderfgoed-locaties over de hele wereld hebben al met aanzienlijke negatieve invloeden, schade en achteruitgang te maken. Deze en vele andere werelderfgoederen zijn kwetsbaar voor de effecten van klimaatstressoren zoals stijgende temperaturen, zeespiegelstijging en droogte. Recent waargenomen trends zullen naar verwachting doorzetten en versnellen naarmate klimaatverandering aan intensiteit toeneemt.

Het Werelderfgoed Waddenzee bestaat uit het grootste aaneengesloten getijdensysteem ter wereld en werd in 2009 in de UNESCO-Werelderfgoedlijst opgenomen vanwege haar Outstanding Universal Value (OUV).

Dit rapport beschrijft de resultaten van de eerste workshop waar belangrijke internationale Waddenzee-experts met expertise uit verschillende wetenschappelijke en academische sectoren rondom de OUV van het Werelderfgoed Waddenzee bij elkaar kwamen. De workshop vond plaats in Hamburg, Duitsland (10-11 februari 2020). In deze workshop werd de eerste fase van de Climate Vulnerability Index (CVI) voor de Waddenzee toegepast. De CVI is een methodologie om snel de kwetsbaarheid voor klimaatverandering in kaart te brengen en is toepasbaar op alle soorten werelderfgoederen (natuurlijke, culturele of gemengde). De op de workshop aanwezige deskundigen beoordeelden de kwetsbaarheid van de Waddenzee op basis van de best beschikbare klimaatwetenschappelijke inzichten.

Als drie belangrijkste klimaatstressoren die van invloed zijn op de OUV van de Waddenzee werden geïdentificeerd:

- Temperatuurstijging (lucht en/of water);
- Gebeurtenissen met extreme temperaturen; en
- Zeespiegelstijging.

Deze uitkomst was consistent voor de twee onderzochte tijdframes (ca. 2050 en ca. 2100) , waarbij uitgegaan werd van een 'business-as-usual' klimaatscenario (RCP8.5), wat het meest waarschijnlijke gevolg is van het huidige internationale beleid voor de uitstoot van broeikasgassen. **De overall kwetsbaarheid van de OUV werd** voor beide tijdframes **als Hoog beoordeeld** (de hoogste categorie in de CVI methode). Dit betekent dat er voor beide tijdframes kans is op een groot verlies of substantiële veranderingen van de waarden van het gebied zoals beschreven in de OUV. De kwetsbaarheid voor de twee temperatuur gerelateerde klimaatstressoren werd in beide tijdframes als Hoog beoordeeld. De kwetsbaarheid voor zeespiegelstijging veranderde van Laag rond het jaar 2050 naar Hoog rond het jaar 2100.

Er lijken beperkte mogelijkheden om het Waddensysteem te ondersteunen om zich aan te passen aan de stijgende lucht- en watertemperaturen en aan gebeurtenissen met extreme temperaturen. Meer onderzoek zou aanvullende beheersopties kunnen opleveren. Adaptatiestrategieën voor zeespiegelstijging, die een beroep doen op lokale en regionale beheersmaatregelen en gebaseerd zijn op gevestigde wetenschappelijke en technische ondersteuning, zouden van grote invloed op de OUV kunnen zijn (met name in het laatste gedeelte van deze eeuw). De deelnemers van de workshop benadrukten dat het van belang is om andere (lokale) stressfactoren op het ecosysteem te minimaliseren en zo de natuurlijke veerkracht van het systeem te verhogen.

Wereldwijde maatregelen zijn noodzakelijk om de uitstoot van broeikasgassen aanzienlijk terug te brengen, vooral om de effecten van de temperatuur op korte termijn te verminderen. De combinatie van deze maatregelen om wereldwijde klimaatverandering te beperken en acties om klimaatadaptatie in de Waddenzee zelf bevorderen is van cruciaal belang om de OUV van de Waddenzee in stand te houden.

Voor de tweede fase van het CVI-proces, waarin de kwetsbaarheid van de bijbehorende ‘gemeenschap’ (lokaal, nationaal en internationaal) kan worden beoordeeld, wordt een volgende workshop aanbevolen.

1. Introduction

1.1 Background to this report – why the Wadden Sea?

Climate change is the fastest growing global threat to World Heritage properties (Osipova et al. 2017) many of which – natural, cultural and mixed – are already being impacted. The severity of current climate impacts on individual World Heritage properties varies, as do the range of climate drivers causing those impacts (see Sections 3 and 4), and the rate at which they are occurring. In most cases, climate change impacts result in a degradation of the attributes[†] that collectively convey the Outstanding Universal Value (OUV). OUV is the central concept for World Heritage properties and the basis for its inscription on the World Heritage List.

In 2019, the Wadden Sea World Heritage property celebrated its 10th anniversary of UNESCO World Heritage inscription. As other sites, the Wadden Sea is vulnerable to climate change effects. The extent to which a variety of climate change stressors will impact the OUV of the Wadden Sea is, however, not yet clear, nor is it clear which of these stressors should be considered the most significant.

In September 2018, a presentation about a then-new methodology (the Climate Vulnerability Index or CVI) was given to key members of the Common Wadden Sea Secretariat (CWSS) and the Trilateral Task Group-Climate (TG-C, since 2019 Expert Group-Climate Change Adaptation, EG-C), including the Acting Chair and Secretary of the EG-C. The CVI is designed to assess the impacts of climate change in World Heritage properties and the Wadden Sea World Heritage property was considered a good candidate for a workshop given:

- the fact the Wadden Sea World Heritage property is a transboundary tri-national property posing an additional challenge for managing climate change adaption,
- the existing expertise on climate change within the TWSC; and
- the need to identify priority issues for climate change adaptation and to consider a broader globally-consistent approach to assessing climate change.

There was widespread support by those present for trialling the CVI in the Wadden Sea and to gain experience with the CVI process, and for the Wadden Sea to become an exemplar for other World Heritage properties with similar values being impacting by similar climate stressors.

The trilateral Wadden Sea Board (WSB), as governing body of the Trilateral Wadden Sea Cooperation (TWSC), adopted a proposal prepared by the EG-C and the Task Group-

[†]The attributes are the specific features that convey the Outstanding Universal Value (OUV); they may be tangible or intangible but are identified at the level at which management occurs within the property

World Heritage (TG-WH) to pilot the CVI as a transnational tool to get a comprehensive view on possible impacts of climate change on the values of the Wadden Sea. The CVI process can also help identify research questions with respect to climate change and adaptive management for World Heritage properties. The subject of climate change in the Wadden Sea is complex and the diverse group of stakeholders provides additional complexity, so it was decided to limit the application of the CVI to the first phase (assessment of OUV Vulnerability).

On 10–11 February 2020 the CWSS organised an international expert workshop in which the impacts of climate change upon the OUV of the Wadden Sea World Heritage Site were discussed (phase 1). The trilateral EG-C and TG-WH supported the workshop preparation and the workshop was facilitated by the CVI lead developers.

The objective of this workshop was to assess the OUV Vulnerability of the Wadden Sea World Heritage property to climate change focussing on the key World Heritage attributes most likely to be impacted. The steps for the workshop were:

(1) Understand the CVI framework and its application in the Wadden Sea World Heritage property;
(2) Understand the key values that comprise the OUV, plus any additional values for the Wadden Sea World Heritage property that are significant to local and regional stakeholders but that do not form part of the (globally-significant) OUV;
(3) Understand future climate change scenarios facing the Wadden Sea World Heritage property and agree on the scenario to be used for the rapid assessment;
(4) Assess the range of potential climate stressors impacting the Wadden Sea World Heritage property and select three climate stressors considered most important;
(5) Evaluate the vulnerability of the OUV to the selected key climate stressors, considering the potential impact (based on exposure and sensitivity) and the adaptive capacity; and
(6) Briefly discuss the CVI phase 2 which will subsequently assess the Community Vulnerability in one or more future workshops; this would consider the economic, social and cultural dependencies and adaptive capacities of the (human) community associated with the World Heritage property.

The CVI outcome should help managing the World Heritage property, reporting to UNESCO on the status of the area and provide guidance on prioritising research questions. The results of the workshop will be also used to further elaborate the CVI and the experience gained will be used to improve the methodology. By considering the results of phase 1 (reported here), the Wadden Sea Board will decide whether phase 2 (Community Vulnerability) will be undertaken in the near future.

1.2 Overview of the Climate Vulnerability Index (CVI)

The Climate Vulnerability Index (CVI) is a rapid assessment tool to systematically assess climate change vulnerability of all types of World Heritage properties. Developed in Australia, it is a comprehensive vulnerability assessment approach that balances scientific robustness and credibility with a level of practicality. The CVI is increasingly becoming acknowledged, both within Australia and internationally, as a systematic way to assess the impacts of climate change upon World Heritage properties in a transparent and repeatable way. The CVI framework (Figure 1.1) builds upon the vulnerability framework approach described in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007). However, the CVI differs from many vulnerability assessments because it comprises two distinct phases and can be applied across all types of World Heritage properties, assessing:

- Phase 1: **OUV Vulnerability** - this assesses the exposure, sensitivity and adaptive capacity of key World Heritage attributes that convey the OUV of the property, assessing how they will be impacted by three key climate stressors (Figure 1.2) chosen to be the most relevant for that property; and
- Phase 2: **Community Vulnerability** based on the economic, social and cultural connections of the community associated with the World Heritage property, the dependency of the community upon the property, and the capacity of the community to adapt to climate change.

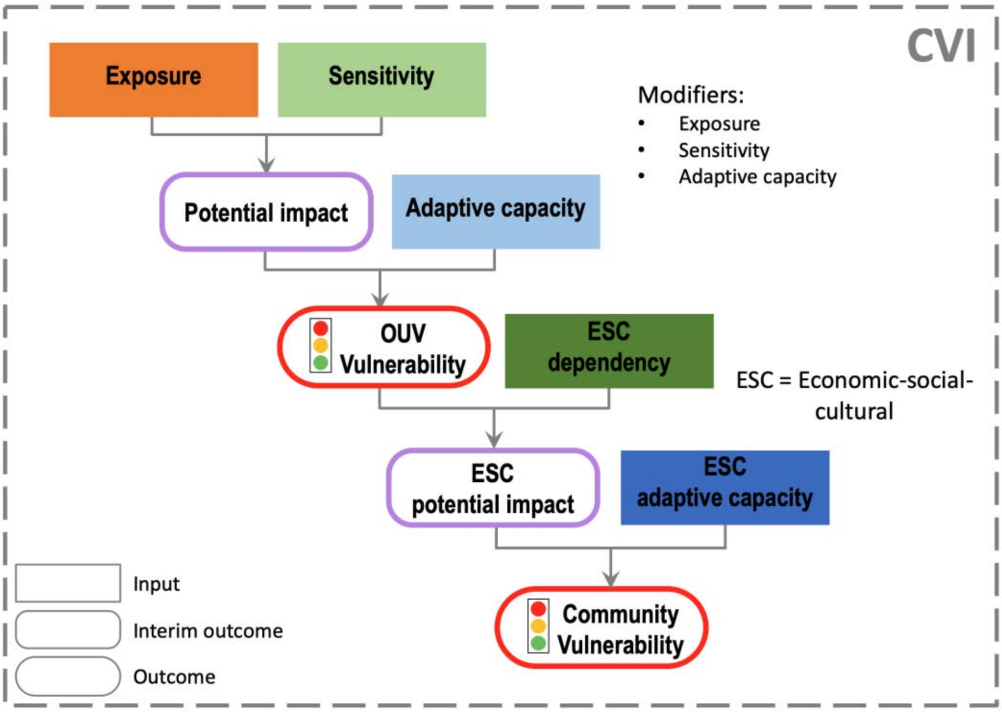

Figure 1.1. The CVI framework to undertake rapid assessment of climate change vulnerability of World Heritage properties and associated communities (Day et al. 2020).

	Climate Stressor	Synonyms	Timeframe
Temper-ature	**Temperature trend (air and/or water)**	*warming; hotter than average weather; increased evaporation; desiccation; sea-surface temperature; ocean warming*	chronic
	Extreme temperature events	*heatwaves; bleaching; hot spell; desiccation; marine heatwaves*	acute
Water cycle	**Precipitation trend**	*rainfall; rainstorms; showers; drizzle; heavy dew; hailstorms; sleet; snow*	chronic
	Intense precipitation events	*rainstorms; tropical cyclones; blizzard; storminess; extreme rainfall*	acute
	Flooding (fluvial, pluvial)	*runoff; soil absorption; intermittent waterways; flash flood*	acute
	Drought (severity, duration, frequency)	*aridity; dehydration; below average rainfall; prolonged water shortage; soil moisture*	chronic
Wind & Storms	**Mean wind trend**	*gale; gusts; change in wind direction*	chronic
	Storm intensity and frequency	*tropical cyclones; tornado; lightning strikes; blizzard*	acute
Snow & Ice	**Sea/lake ice change**	*ice extent; ice thickness; age of ice*	chronic
	Snow cover change	*snowpack; snow thickness; snow compaction; perennial snow; age of snowpack*	chronic
Coastal	**Sea level rise (trend)**	*flooding; subsidence; post-glacial rebound; ocean heat content; thermal expansion*	chronic
	Coastal flood	*coastal vulnerability; nuisance flooding*	acute
	Storm surge	*storm floods; storm tides; significant wave height; wave setup*	acute
	Coastal erosion	*currents; waves; sediment transport; accretion; deposition*	chronic
Context-specific	*e.g., Ocean acidification*	*pH; saturation state; acidity; calcification rate; ocean chemistry*	*chronic*
	e.g., Radiation change	*surface radiation; cloud fraction; long-wave radiation; short-wave radiation*	*chronic*
	...		
	...		

Figure 1.2. Climate stressors used in the Climate Vulnerability Index (CVI) methodology (after Day et al. 2020). Note that not all 14 listed climate stressors used generally across World Heritage properties (shown with coloured background) necessarily apply in the Wadden Sea; however, there may be one or more additional "context-specific" stressors that are applicable (see Section 4.3).

Results of both OUV and Community Vulnerabilities are highly relevant for many groups including the site managers, the responsible management agencies, the businesses that are dependent on the property and the local communities around each World Heritage property, especially as the CVI assesses the extent to which they may be able to adapt.

The foundation for the CVI process is the Statement of OUV for a property, from which key World Heritage attributes are summarised. A preliminary assessment of the current condition and trend in the condition of the key attributes was undertaken in the workshop. The key climate stressors most likely to impact the key attributes are identified for a defined and agreed time scale (e.g. by 2050). With this foundation established, the CVI process is initiated (see cvi-heritage.org/about)

The CVI process is best undertaken through a workshop of diverse stakeholders (including site managers, researchers, community representatives, dependent business owners, management agency representatives, and other stakeholders) and systematically works through the steps outlined in Section 4 (see also Day et al. 2020).

Developed in Townsville, Australia, the CVI has subsequently benefited from input and guidance from many experts around the world including from the International Council on Monuments and Sites (ICOMOS) and the International Union for Conservation of

Nature (IUCN), two of the advisory bodies for the World Heritage Committee. The ICOMOS Climate Change and Heritage Working Group (CCHWG) has included the development of the CVI in its current work plan, as has the IUCN Protected Areas Climate Change Specialist Group; the UNESCO World Heritage Centre is also supportive of the CVI.

The CVI methodology is now established but continues to evolve with every application. The Wadden Sea workshop, along with a series of other workshops occurring nationally and internationally over the next 18 months involving different types of heritage properties, will be used to help improve and refine this methodology.

The initial workshop for the Wadden Sea only assessed the OUV Vulnerability (Phase 1), which is the first important outcome of the CVI process. The second outcome, the Community Vulnerability, will assess the extent to which the community may be able to adapt, an aspect rarely considered in many assessments of climate impacts. A more detailed outline of the CVI process is provided by Day et al. (2020).

This Wadden Sea report, together with other CVI reports (e.g., Day et al. 2019, Heron et al. 2020), has implications for the assessment of other World Heritage properties and substantiates the value of the CVI process for assessing World Heritage properties, as well as assessing the vulnerability of other natural and cultural heritage properties around the world.

2. The Wadden Sea World Heritage property

2.1 Geography

The Wadden Sea is a serial tri-national World Heritage property, extending across the Danish Wadden Sea maritime conservation area; the German Wadden Sea National Parks of Hamburg, Lower Saxony and Schleswig-Holstein; and the Dutch Wadden Sea Conservation Area (Figure 2.1).

The Property covers an area of nearly 11,500 km² (CWSS 2012) between the land-sea interface and the offshore area of the three countries, with a coastal distance of roughly 500 km.

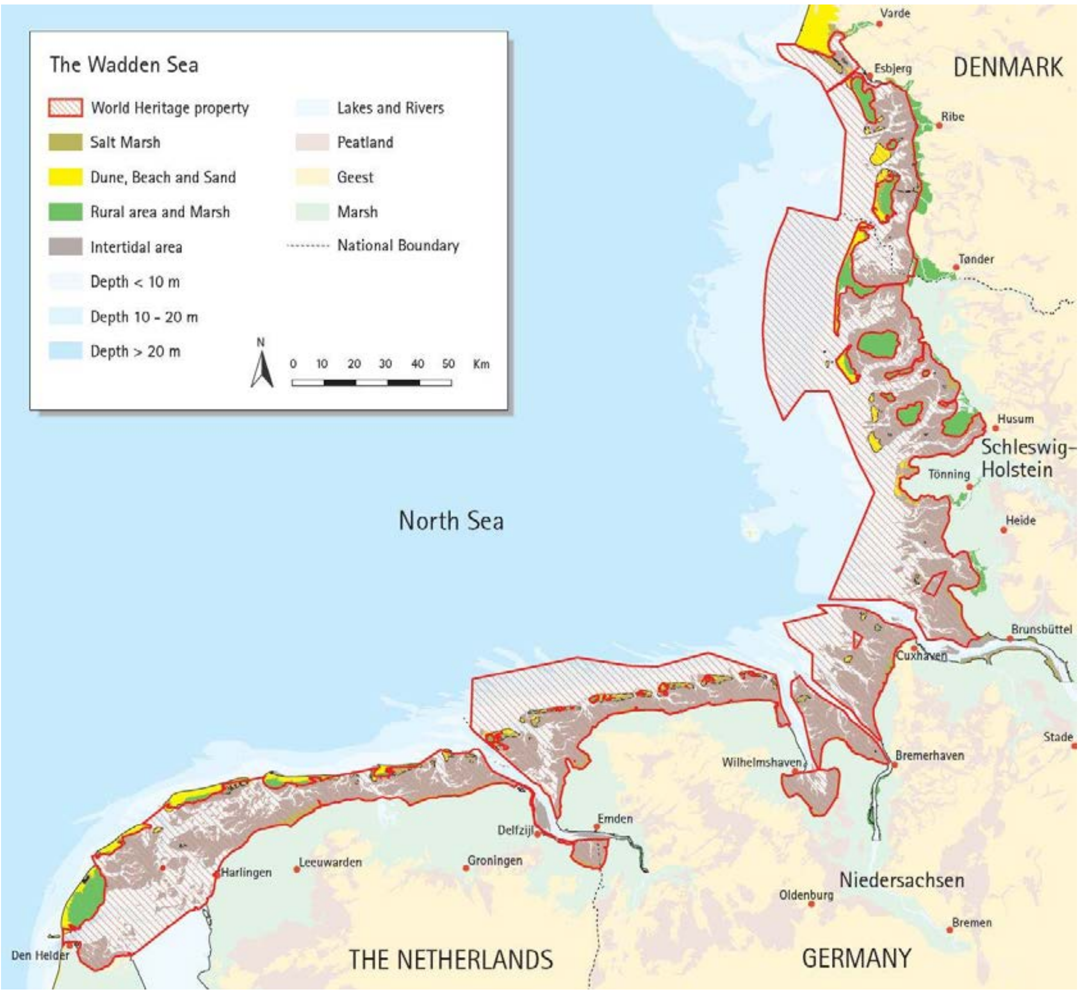

Figure 2.1. Map of the Wadden Sea (source: CWSS).

2.2 The World Heritage property

One Wadden Sea. One World Heritage.

The Wadden Sea was inscribed on the UNESCO World Heritage List in 2009, in recognition of the 'Outstanding Universal Value' (OUV) of the site (see Figure 1) and the progress made in protecting and managing it for future generations. The initial inscription included the Dutch and German Wadden Sea; the property was extended in 2011 (Hamburg) and in 2014 (Denmark).

The Wadden Sea is a large, temperate coastal sediment exchange system – one of the last remaining large-scale, intertidal ecosystems where natural processes continue to function largely undisturbed. It is a relatively flat coastal wetland environment formed by interactions between physical and biological factors. These contribute to a multitude of transitional habitats, such as tidal channels, sandy shoals, sea-grass meadows, mussel beds, sandbars, mudflats, salt marshes, estuaries, beaches and dunes, as well as offshore areas. The transitional environment between land and sea is characterized by the constant change of flood and ebb tides, fluctuations in salinity, high temperatures during summer and occasional ice cover in winter.

These dynamic circumstances have created numerous ecological niches, colonized by species that are adapted to the extreme environmental conditions. Three marine mammal species (harbour seal, grey seal, harbour porpoise), about 150 species of fish and more than 100 bird species are complemented by numerous molluscs, plants, and micro and macro flora and fauna (CWSS 2012).

2.3 Management of the World Heritage property

With the inscription of the Wadden Sea, the World Heritage Committee obligated the Trilateral Wadden Sea Cooperation (TWSC) to protect and manage the Wadden Sea and its OUV. Since 1978, the TWSC has provided the overall common framework for the protection of the property; its cornerstones are laid down within the Joint Declaration signed by the parties in 2010 (CWSS 2010a). At consecutive ministerial conferences and within the Wadden Sea Plan (CWSS 2010b) common principles, objectives and policies have been agreed upon. The Guiding Principle, as agreed at the 1991 Wadden Sea Conference, is "***to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way***". Further, a comprehensive set of primarily ecological Targets were agreed upon by the cooperation. These have been set in the Wadden Sea Plan (CWSS 2010b), which serves as the management plan for the property with complementary regulations, plans and programmes on the regional levels in each country.

While there are differences in how the relevant national legal protection instruments are composed within the overall framework, which naturally follows from the apparent differences in legal schemes, they are basically similar in objectives, protection regulations and enforcement. Most of the nominated property is state-owned (federal or state level) and only a very small part is privately owned. The Wadden Sea is subject to comprehensive protection, management and monitoring, in both the national perspectives and the international context (which is unprecedented in terms of its integrated and harmonized approach).

Danish Wadden Sea

The large majority of the reserve is state owned (almost 99%). The rest is owned by adjacent municipalities and private persons. This concerns predominately salt marsh areas and the northern part of the Margrethe Kog.

The Danish Wadden Sea Nature and Wildlife Reserve is divided into a number of zones, in which admission and use of the area are regulated. Access and hunting are strictly prohibited in around 10% of the reserve. These zones encompass the ecologically most valuable areas, such as breeding and resting areas for harbour seals, and breeding and roosting areas for birds.

Dutch Wadden Sea

The protection of the Dutch part of the nominated property, though similar in structure to the German protection, combines a unique national physical planning approach with a designation of the property under the Nature Conservation Act 1998 supported by additional designations.

The 'Key-planning-decision document Wadden Sea' (former PKB-Wadden Sea, now Structuurvisie Waddenzee) has the status of a law and its objectives and conditions are binding upon all state, regional and local authorities. The main objective is the sustainable protection and development of the Wadden Sea as a nature area and conservation of the open landscape. This explicitly includes the conservation of landscape qualities, in particular the quietness, openness and naturalness. This objective closely relates to the Targets of the Wadden Sea Plan. The local plans are binding legal documents with direct implications for the individual citizen or company. This approach was also chosen to engage and commit the regional and local authorities.

German Wadden Sea

The protection objectives of the German Wadden Sea National Parks, covering the German part of the property, are to protect the Wadden Sea and its natural development by enabling it to develop in a mostly undisturbed way. The conservation of nature by the national parks should also lead to an improvement of the living and working conditions of the human population living within the region through positive repercussions on tourism and the reputation of the region. This is currently a common Wadden Sea-wide understanding of the added function of the protection and management schemes for the nominated property also embraced by the Wadden Sea Plan (CWSS 2008).

The three national parks are protected by law, and each is divided into two or three protection and management zones with different levels of regulations.

The **Schleswig-Holstein National Park** (441,500 ha), protected since 1985, is divided into two zones, in which different activities are permitted. The core zone (zone 1) comprises coherent tidal basins and covers about 36% of the National Park, including the ecologically most valuable areas. Within the core zone, an area of 12,500 ha has been designated as a zone in which all resource use has been fully prohibited. The area covers about 3% of the National Park area. Zone 2 includes an area which is designated as a whale sanctuary.

The **Hamburg National Park** (13,750 ha), protected since 1990, is divided into two zones based on designated usage. Zone 1 is reserved for the establishment and succession of natural dynamics covering about 92% of the National Park. Zone II (about 8%) is reserved for recreation, sustainable tourism and nature experience activities which are in line with the National Park targets.

The **Lower Saxon National Park** (345,000 ha), protected since 1986, is divided into three zones. Zone 1 – the core zone – covers 68.6% of the total area and includes the ecologically most sensitive areas. Zone 2 – the intermediate zone – covers 31% of the total area. In general, the protection regime is similar to the core zone; exemptions for certain uses are made, provided that the protection aims are not jeopardized. Zone 3 – the recreational zone – covers about 0.5% of the total area. Only low-impact recreational activities are allowed there.

2.4 Implications of World Heritage status

The 1972 World Heritage Convention (UNESCO 1972) deals with the identification, protection and preservation of cultural and natural heritage around the world that is of outstanding value to all of humanity. The term Outstanding Universal Value (OUV) means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations.

The Convention has now been ratified by 193 governments, and in 2019 there were 1121 sites on the World Heritage List. With the listing of the Wadden Sea, the World Heritage Committee obligated the Trilateral Wadden Sea Cooperation to ensure the protection, preservation and transmission of the Wadden Sea and its OUV to future generations.

The Operational Guidelines for the Implementation of the World Heritage Convention list ten criteria which define OUV – six cultural and four natural criteria.

Each World Heritage property has a Statement of OUV (SOUV) which is the principal reference for protection and management of the property and a baseline for monitoring and reporting. The following brief description of how the Wadden Sea fulfils three World Heritage criteria is based on the SOUV for the Wadden Sea World Heritage property, adopted by the World Heritage Committee in 2009 and amended in 2014 (Annex 1):

- **Criterion viii - Geological processes**
  Nowhere else on the planet is there such a diverse and dynamic coastline of this scale, continually being shaped by wind and tides creating a variety of coastal and sedimentary features. The Wadden Sea is unique in that it consists entirely of a sandy-muddy tidal flat and barrier system under conditions of rising sea level, which contains examples of post-glacial coastal geomorphology and dynamic interactions of physical and biological processes.
- **Criterion ix - Ecological and biological processes**
  Nature has provided an invaluable record of past and ongoing dynamic adaptation of plants, animals and their coastal environments to global change. The productivity of biomass is the highest in the world and offers food availability widely; e.g., for fish, seals and birds.
- **Criterion x - Biodiversity**
  Despite its tranquil appearance, the Wadden Sea World Heritage is among the largest wildernesses in Europe and a one of the main hotspots of biodiversity in the world. It sustains over 10,000 species of plants and animals and it is one of the main hotspots of global biodiversity. In addition, it plays an indispensable role well beyond its borders: the richness of local species is crucial for up to 12 million migratory birds that make a stopover in the area on their journey to their wintering and/or summering grounds.

To be deemed of OUV, a property must also meet the conditions of integrity[‡] and/or authenticity and must have an adequate protection and management system:

- **Integrity**
  The Wadden Sea World Heritage property includes all the facets (species, habitats, processes) that constitute a natural and dynamic Wadden Sea. The area is large enough to ensure that these exceptional aspects of one of the world's first-class ecosystems of this kind are maintained and protected.
- **Protection and management**
  Protection and management of the World Heritage property are effectively secured. The Wadden Sea's supreme conservation state is the result of four decades of joint nature protection efforts of Denmark, Germany and the Netherlands, where the Wadden Sea is designated as national parks and nature reserves. Working together in the Trilateral Wadden Sea Cooperation, these countries ensure the integrated management of the area – the protection of one inseparable ecosystem that knows no borders – is a joint responsibility for the world community and for the benefits of present and future generations.

[‡] Integrity requires assessing if the World Heritage property is of sufficient size; if its components are sufficiently complete to demonstrate OUV; and assessing what pressures threaten the site and how they are being addressed.

2.5 Values of the World Heritage property

Prior to the CVI workshop, ten key values of the property (Figure 2.2) were identified from the SOUV by the CWSS and the trilateral Task Group-World Heritage (TG-WH) in their 27th meeting (May 2019). Each key value was associated with the relevant WH criterion (Annex 2). Given the broad descriptive nature of these key values, measurable attributes for each described key value were identified for the CVI application (see Sections 4.1 and 4.2). Together, these key values and attributes form the basis for assessments made using the CVI process.

In addition to the key values that convey the SOUV, there are other local, regional and/or national values that are still of significance. These Significant Property Values (SPVs; Annex 3) are also impacted by climate change. SPVs may be other natural or cultural features, scenery or some intangible values (e.g., meditative walks; sounds of lapping waves, birds calling and blowing wind/rain).

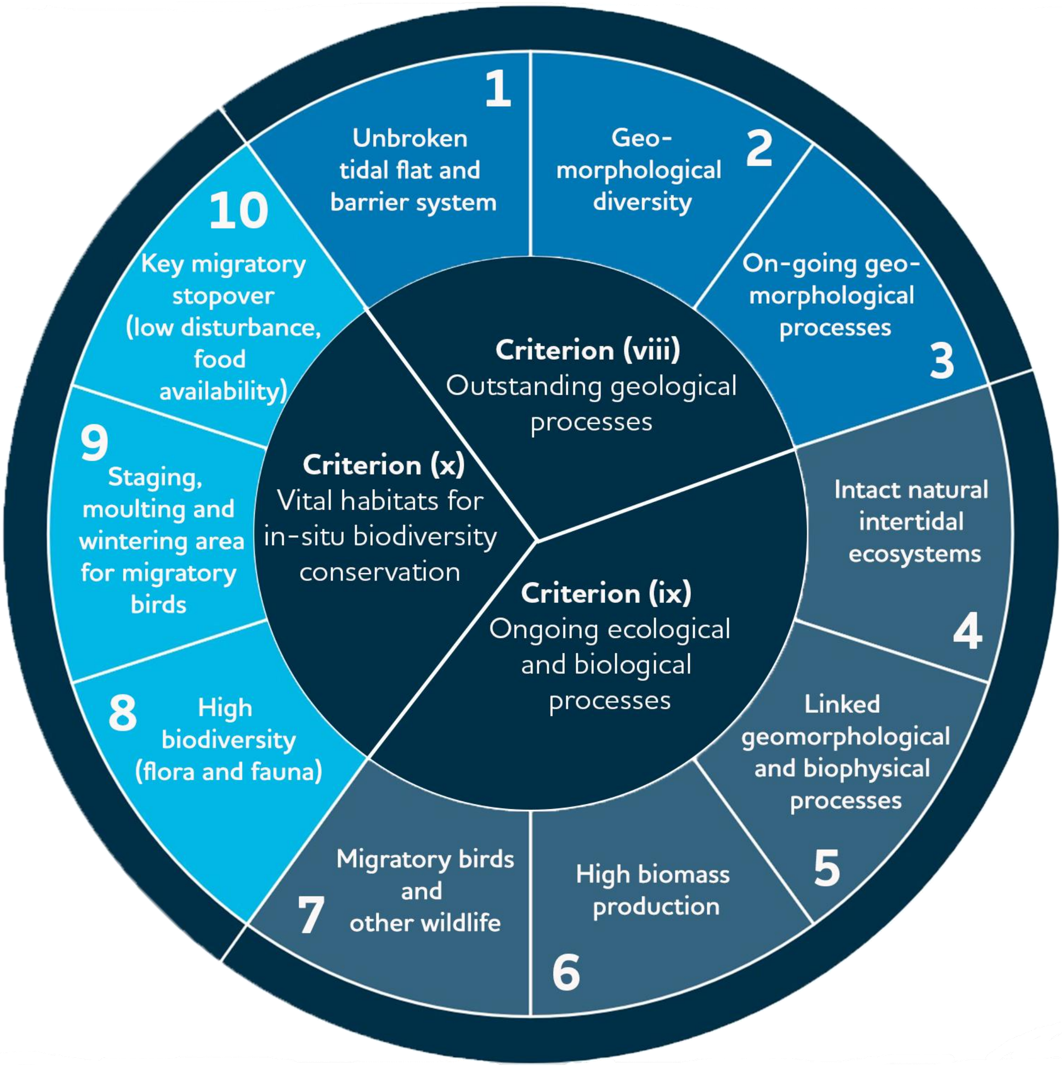

Figure 2.2. Key values derived from Statement of Outstanding Universal Value by the Common Wadden Sea Secretariat and the Task Group-World Heritage.

3. Climate change and its influence on the Wadden Sea World Heritage

3.1 Climate change and the Wadden Sea

Climate strongly influences the functioning of the Wadden Sea ecosystem. Factors like mean water and air temperature influence which species thrive, and have a significant effect on the primary productivity of the system. Extreme weather events – like storms or heat waves – also have impacts. Climate and weather events affect the movement of water and influence the distribution of sediments.

Changes in the climate and weather conditions will have significant effects on the ecosystem. Climate change influences abiotic factors (shaded blue in Fig. 3.1), geological parameters and morphological behaviour (yellow) and biological factors (green). Human interventions and management responses (orange) interact with the changes and also have consequences. Although substantial knowledge exists on responses of individual species to changes in abiotic factors, it is very hard to predict what will happen in a changing climate due to the complex interactions and feedback loops between species, and due to the many dynamic processes. Sea level rise is a key factor in the geomorphological development of the area, and therefore has a major impact on the ecosystem as it shapes the future habitats upon which species are highly dependent, especially in the long-term perspective (beyond 2050).

Insights into global climate change presented by the IPCC (2019) were considered in the CVI application for the Wadden Sea. The rate and extent of climate change strongly depends upon the CO2 emissions scenario (Representative Concentration Pathway, RCP, 2.6, 4.5 and 8.5) and the future time being considered (Figure 3.2). This chapter presents a brief overview of the current climate, the anticipated changes due to climate change and the potential changes in the Wadden Sea area.

3.2 Physical impacts of climate change on the Wadden Sea

Effects of climate change in the Wadden Sea region are widespread and diverse (Figure 3.1). They range from changes to the geomorphological system and the ecosystem to effects on human use, such as tourism, agriculture, flood safety and fisheries. It is noted that effects can be either negative or positive. As the Wadden Sea area consists of land and water, changes in both marine and atmospheric conditions will have impact. In this first phase of applying the CVI, focus was on the biotics and abiotics of the Wadden Sea itself. As such, aspects relating to the associated community (e.g., agricultural use and tourism) were not examined (but will be in the second phase of the CVI process, assessing Community Vulnerability).

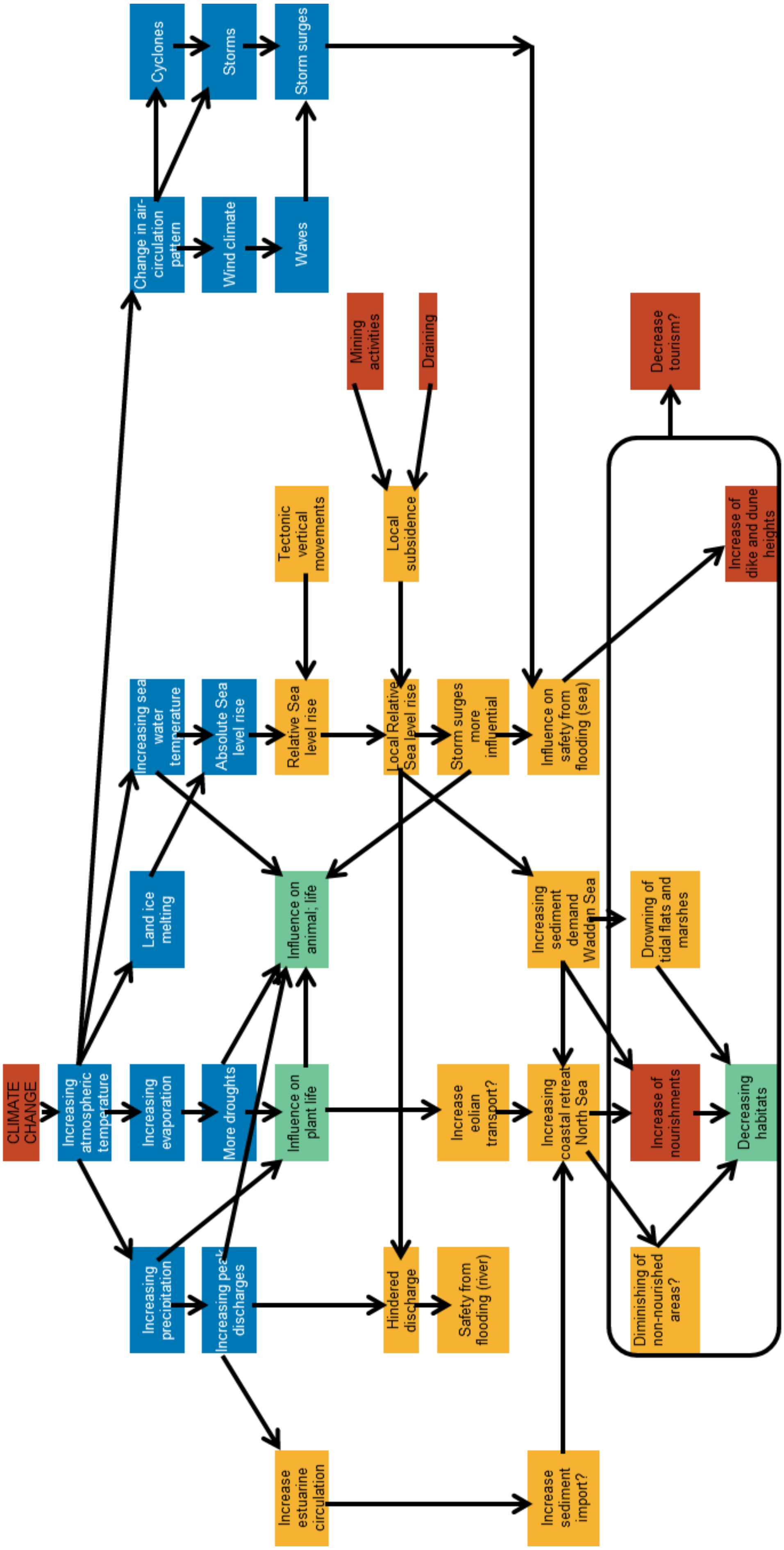

Figure 3.1. Cause-effect chain in the Wadden Sea due to climate change (Oost et al., 2017).

Full resolution image available online.

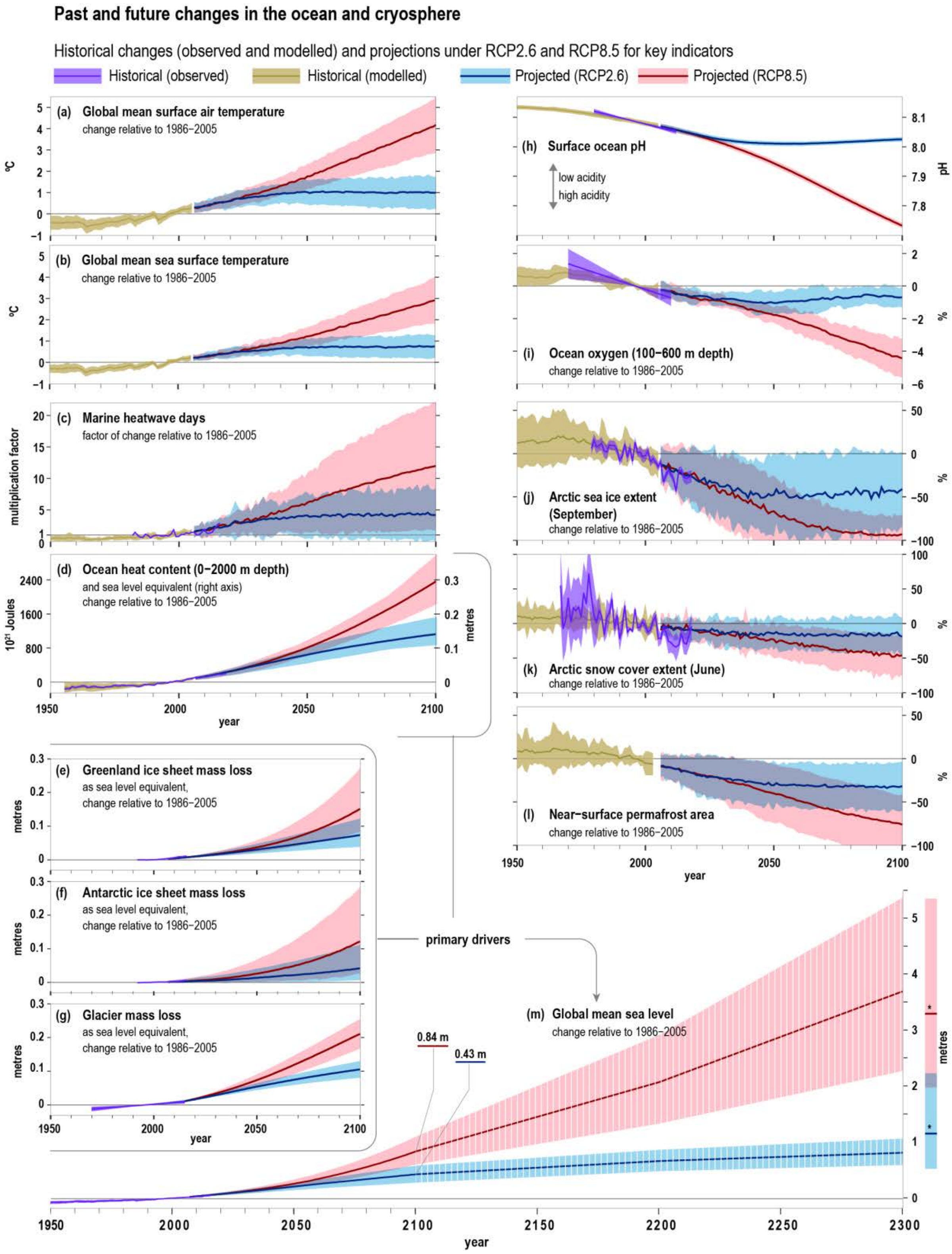

Figure 3.2. Global climate change, historical (since 1950) and projected (to 2100; to 2300 for sea level rise). IPCC (2019).

Intertidal flats and salt marshes of the Wadden Sea will drown if they cannot keep up with the pace of sea level rise. Recent investigations of how the different tidal basins of the Wadden Sea may respond revealed that most basins can keep up with moderate rates of sea level rise (Hofstede et al. 2016, van der Spek 2018). Drowning of the system will occur in the more extreme climate scenarios and will take at least several decades.

More extensive descriptions of potential physical impacts are summarised in the Wadden Sea Quality Status Report (QSR) chapters 'Climate change' (Oost et al. 2017; Table 3.1) and 'Climate ecosystems' (Philippart et al. 2017). The Coastal Atlas website (www.coastalatlas.org) also shows several effects of climate change in the Wadden Sea region.

3.3 Ecological impacts of climate change on the Wadden Sea

In addition to physical impacts on the Wadden Sea environment, there are impacts on the ecological system of the property. Climate influence on the processes that shape the abiotic factors of the Wadden Sea ecosystem will also affect habitats and species, and their communities, thus having the potential to alter ecological networks. Increases in water temperature and frequency of extreme heat events may affect the biological system more severely and may precede effects of increasing sea level. While these climate effects may occur within the World Heritage property, the influence of climate change outside the property can also affect the ecology within the property. For example, barrier islands and hinterland (only some of which are part of the World Heritage property) contain essential habitat for birds and fish. Changes along the migratory routes of these animals, within and beyond the property, may influence their ability to thrive in the Wadden Sea. The QSR includes an overview of known effects of climate on the ecosystem (Philippart et al. 2017).

Workshop discussion on the impacts of climate change on ecological dynamics of the Wadden Sea included four key topics: geographical distributions, timing, shrinkage and teleconnection. Observed shifts in **geographical distribution** (areal shift) of species have included a northward shift due to chronic water temperature increase, and a shift in depth to cooler areas (Philippart et al. 2017; Figure 3.3). Further, climate change has influenced the **timing** of migration and reproduction. The latter may lead to a decoupling of trophic linkages within the coastal food web, resulting in reduced transfer to higher trophic levels (e.g., from plankton to shellfish to birds; Philippart et al. 2003, 2014). While certain species adapt to such changes in timing, others, such as the red knot (*Calidris canutus*) are less flexible and encounter reduced food availability along their migratory route (Tucker et al., 2019). These impacts may also lead to juvenile birds having reduced sizes (**shrinkage**) at the start of their migration route from the Arctic over the Wadden Sea to Mauritania (Van Gils et al., 2016). In the case of birds along their entire flyway, exposure-response relationships in individual locations can have far-reaching **teleconnections**; e.g., from breeding to overwintering sites.

Table 3.1: Overview of climate change projections for 2100 (Oost et al., 2017); full resolution available online. Projections for 2050 also in Oost et al. (2017).

Variable	Indicator (change)	Climate 1981_2010 (KNMI) or 1961_1990 (DMI , 2014)	Scenario climate change end of the century: Dutch 2071_2100, relative to 1981_2010 (KNMI, 2014) G_L_G_H	Dutch W_L_W_H	Danish 2071_2100, relative to 1986 to 2005 (DMI, 2014)	German 2071_2100, relative to 1961_1990 (Wadden Sea Region CLIMATE	Natural variation average 30 yrs
Increase world temperature	Mean (in ^{0}C)				**1.5 _ 3.5**		
Atmospheric temperature	Mean (in ^{0}C)	10.1	+1.3_1.7	+3.3_3.7	+1.2 ± 0,5 _ +3.7 ± 1.0	+2.6 (0.9-4,8)	±0.16
	Days with frost	85 ± 8	-35_-50%	-60_-80%	-66% ± 6%	-25% (-8_-51%)	
	Duration of growing season (successive days above 5 ^{0}C)	230 ± 11			+70 ± 11	+60 (19_96)	
	Longest heat wave (mean Tmax>28^{0}C) days	3.2 ± 0.7			5.6± 1.9		
Sea water temperature	Estimate based on atm. temp. (in ^{0}C)				**1-5**		
Precipitation	Annual mean	851 mm	+5%	+7%	+2±5% _ +7±6%	+9% (-6_31%)	±4.2%
Solar radiation	Solar radiation	354 kJ/cm^2	-+0.5_+1.1%	-0.9_+1.4%			±1.6%
Evaporation	Potential Evaporation	559 mm	+2.5_+5.5%	+6_+10%			±1.9%
Drought	Average highest precipitation deficit during growing season	144 mm	+1_+19%	+14_+50%			±13%
	Mean highest precipitation deficit in summer exceeded once in a 10 years	230 mm	+3.5_+17%	+15_+40%			_
	Longest dry period (increase number of days)					1 (-3_13)	
Wind	Mean speed					0% (-4_+6%)	
	Mean speed in winter	6.9 m/s	-2.0_+0.5%	-2.5_+2.2%			±3.6%
	Highest daily mean in winter	15 m/s	-2.0_-0.9%	-1.8_+2%			±3.9%
	Number of days between south and west	49	-1.6_+6.5%	-6.5_+4.0%			±6.4%
Storms - KNMI (2014)	Storm intensity					0% (-4_4%)	
	Tropical cyclone in North Sea Basin					Might increase?	
	Stormy days (number)					0 (-11_13)	
Storm surges (Weisse et al., 2012)	Heights					Uncertain tendency to increase	
Wave climate (Weisse et al., 2012)	Wave heights					Uncertain tendency to increase	
Sea level	Absolute level (cm) Schleswig Holstein (flood protection)				50_150		
	Absolute level (cm) Schleswig Holstein (general strategies)				50_80		
	Absolute level (cm)	+3 cm DOL	25_60	45_80	34 (10_60) _ 61 (30_90)	105 (Katsman)	±1.4
	SLR velocity (mm/yr)	2	1_7.5	4_10.5			±1.4

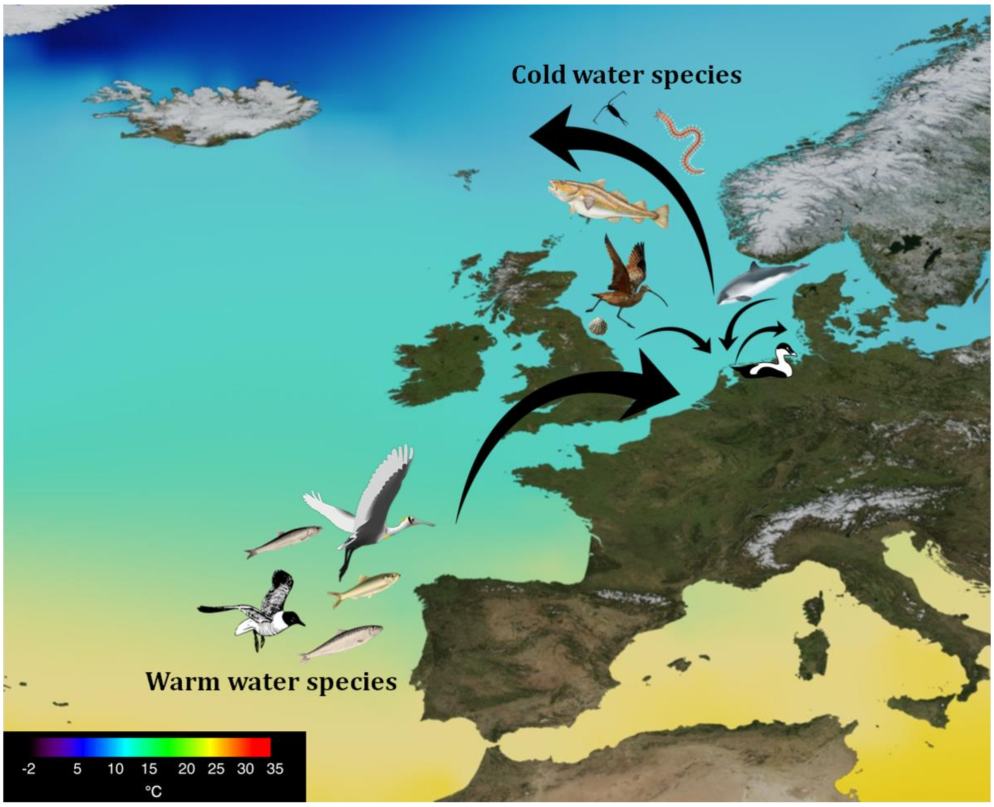

Figure 3.3. Sea surface temperature map shows a selection of warm-water species shifting northwards, whereas cold-water species retreat the Wadden Sea to keep up with the colder waters (Philippart et al. 2017).

When viewed as a whole, the ecological functioning of the ecosystem is complex and consists of many feedback loops and consequences. Estimating the ecological impact of climate change is a challenging task. Drivers include increased temperatures, lowered oxygen levels and reduced food supply. Impacts may be mitigated due to the adaptive capacity of individuals and evolutionary rates of species. Both long-term trends and frequency of extreme events need to be considered (K. Philippart, pers.comm.).

> *"The Wadden Sea, as most coastal marine ecosystems, experiences multiple environmental stressors simultaneously that can differ widely in their pathways and strengths of impact. An understanding of all relevant stressors is critical to prioritise conservation actions, including restoration, protection, and management. Yet, scientific concepts and empirical evidence on the separate and cumulative impacts of all relevant stressors is often insufficient to guide such decisions. Climate change, together with other anthropogenic effects, such as large human-made infrastructures, (reduced) eutrophication, fisheries, pollutants and invasive species, will presumably lead to synergistic and/or cumulative effects."* (Philippart et al. 2017)

3.4 Observed and predicted climate change in the Wadden Sea region

It is very important to realise that global estimates for climate change may not directly apply at the regional scale of the Wadden Sea. Although several stressors may follow the global trend, regional changes may deviate significantly. It is therefore necessary to also look at regional projections. In the descriptions below, RCP 2.6 and 8.5 scenarios (as used in the recent IPCC reports) are considered with focus on the period between 2050 and 2100. For the workshop it was important that participants had a consistent picture of the range of possible changes. The order of magnitude is important to estimate possible impacts on the OUV and its attributes.

Sea level rise and rate of change

For the Wadden Sea geomorphological system, the rate of sea level rise is of special importance. As sea level rises, the Wadden Sea tends to import sediments leading to the growth of intertidal flats; however, there is a limit to the capacity of this natural process – under rapid sea level rise, intertidal flats will start to drown. In the Netherlands predicted rates of sea level rise that result in drowning of intertidal flats were estimated to be between 4 and 10 mm/year, depending on the area analysed (van der Spek 2018). For the German part of the Wadden Sea, morphological projections on two tidal basins indicate a large time lag between sea level rise and decline of intertidal areas. Depending on tidal range, even under a sea level rise of 17 mm/year, it may take decades before intertidal areas substantially reduce in size and (relative) height (Hofstede et al. 2016).

The present global rate of sea level rise (likely range) is 3.1-4.1 mm/year (IPCC 2019). Regional values in Germany in recent decades are consistent with the global rise (Dangendorf et al. 2020); however, observed rates at tidal gauges in the Dutch Wadden Sea are currently lower, ranging 1.3-2.0 mm/year (Vermeersen et al. 2018). It is expected that eventually the rate of regional sea level rise will follow the global trend (Le Bars et al. 2019). The rate of global mean sea level rise under RCP8.5 is projected to reach 15 mm/year (10–20 mm/year, likely range) in 2100, with projected sea level rise of 0.84 m (0.61–1.10 m, likely range) relative to 1986-2005. Under RCP2.6, the rate is projected to reach 4 mm/year (2–6 mm/year, likely range) in 2100, with an associated increase in sea level of 0.43 m (0.29–0.59 m, likely range) relative to 1986-2005. Regionally, projected sea level rise for the Dutch Wadden Sea from 2018 to 2100 ranges from 0.16-0.66m (RCP2.6) up to 0.40-1.12m (RCP8.5) (Vermeersen et al. 2018; Table 3.2).

Table 3.2: Sea level rise scenarios for the Dutch Wadden Sea (Vermeersen et al. 2018).

	RCP2.6	RCP4.5	RCP8.5
2018-2030	0.06 ± 0.07 m	0.07 ± 0.06 m	0.08 ± 0.06 m
2018-2050	0.16 ± 0.12 m	0.19 ± 0.11 m	0.23 ± 0.12 m
2018-2100	0.41 ± 0.25 m	0.52 ± 0.27 m	0.76 ± 0.36 m

Air temperature trend

The global mean air temperature is rising due to increased emissions of CO_2 and other greenhouse gases (IPCC 2019; Table 3.3). Dutch observations indicate a greater increase in mean air temperature in recent decades than the global trend linked to the improvement of air quality since the 1980s (Deltares 2019); however, this effect is expected to dampen out in the future (Deltares 2019). Wadden Sea regional projections of 0.9-4.8°C (2071-2100; www.coastalatlas.org; see also Table 3.1) are consistent with the likely range of global air temperature rise of 0.9-2.4°C (RCP2.6) and 3.2 to 5.4°C (RCP8.5) for the period 2081-2100 (IPCC 2019; Table 3.3).

Water temperature trend

Water temperature in the Wadden Sea is determined by a combination of local heating (including the influence of air temperature change) and tidal interaction with the North Sea. The North Sea had the second fastest increase in water temperature among 63 globally-distributed coastal areas (1982-2006; Belkin 2009). It was among 24 identified marine areas with the globally fastest rates of historical increase in annual water temperatures (1950-99) for which rapid warming is projected to continue (2001-2050; Hobday & Pecl 2014). Mean surface water temperature in the North Sea has increased 1.3°C between 1969 and 2017 (BSH 2019). The increase in water temperature in the North Sea thus directly impacts the Wadden Sea water temperature as - due to the tides – they exchange large volumes of water. According to Dutch observations the water temperature in the Marsdiep inlet has risen approximately 1.5°C since the 1960s (Deltares 2019).

Globally, water temperature is projected to rise 0.73-2.58°C (RCP2.6-RCP8.5) by the end of this century (2081-2100) (IPCC 2019, Table 3.3). Regional projections for the future water temperature in the Wadden Sea were not found. Associated effects of water temperature increase include the decrease of solubility of oxygen and reduced periods of ice coverage during winter.

Table 3.3: Global mean air and sea surface temperature rise (after IPCC 2019).

		Near-term: 2031-2050		End-of-century: 2081-2100	
	Scenario	**Mean**	**5-95% range**	**Mean**	**5-95% range**
Global Mean Surface Air Temperature (°C)	RCP2.6	0.9	0.5-1.4	1.0	0.3-1.7
	RCP4.5	1.1	0.7-1.5	1.8	1.0-2.6
	RCP6.0	1.0	0.5-1.4	2.3	1.4-3.2
	RCP8.5	1.4	0.9-1.8	3.7	2.6-4.8
Global Mean Sea Surface Temperature (°C)	RCP2.6	0.64	0.33-0.96	0.73	0.20-1.27
	RCP8.5	0.95	0.60-1.29	2.58	1.64-3.51

Extreme temperature events

The intensity and duration of periods of extreme air temperature (atmospheric heatwaves) are both expected to increase globally (IPCC 2018). Regional climate model projections indicate a zero to 13-day increase in the number of days for which maximum air temperature is above 30°C (2071-2100; www.coastalatlas.org). Atmospheric heatwaves have a greater effect on shallow coastal waters, like the Wadden Sea, than on deeper waters in both the magnitude and rate of warming. Since 1901, the occurrence and duration of heat waves in the Netherlands have shown clear increases (Figure 3.4).

Marine heatwaves are prolonged periods of anomalously warm seawater temperature – extreme events occurring in any season. Extreme heat waves can have significant effects on the Wadden Sea ecosystem; e.g., during a hot and dry period in 2018, widespread death of cockles resulted from prolonged heat stress (Deltares 2019). Marine heatwaves are globally projected to increase in frequency, duration, spatial extent and intensity under future warming, with the number of marine heatwave days globally increasing by a factor of 5-15 by 2100 (IPCC 2019).

Precipitation – trend and intense events

Annual precipitation is expected to increase slightly, with a relatively larger increase in winter and a reduction in summer (Table 3.1; www.coastalatlas.org). It is expected that the intensity of rainfall will also increase, meaning more rain in less time. The mean increase of precipitation is expected to have limited impact on the Wadden Sea. However, the transient influxes of fresh water from the hinterland will likely increase, which may have effects (e.g., salinity gradients relevant to certain species).

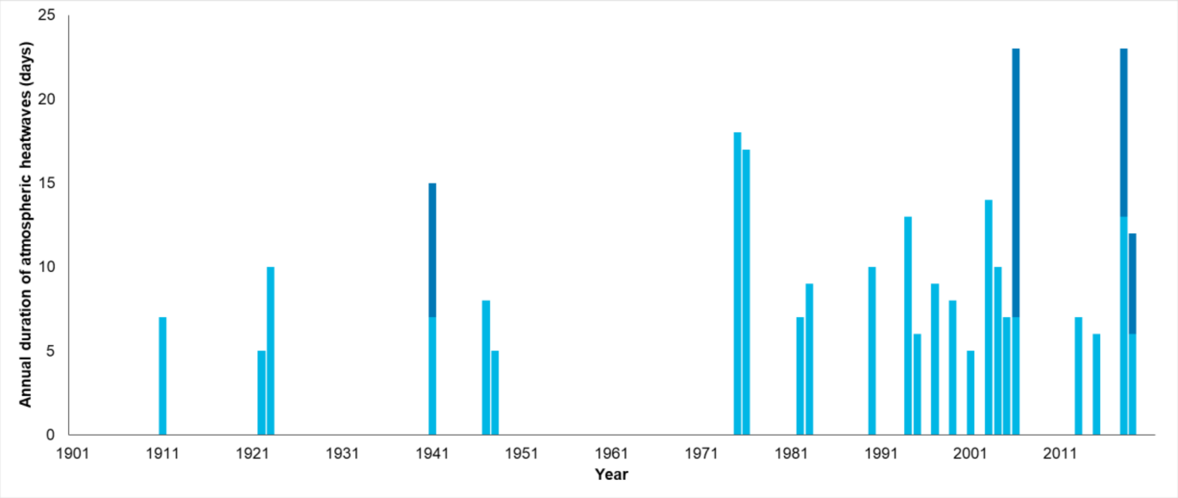

Figure 3.4. Annual occurrence and duration of atmospheric heatwaves in De Bilt (Netherlands) between 1901 and 2019 (data: www.knmi.nl/nederland-nu/klimatologie/lijsten/hittegolven). Stacked columns indicate that separate heatwaves occurred within a single year.

Drought

Intensity and duration of periods with drought (and consequent water shortages) are expected to increase globally. Regionally, the projected change in the longest dry period ranges from -3 to +13 days (www.coastalatlas.org). Precipitation deficit is predicted to increase by 3.5-40% for the period 2071-2100 (Table 3.1; Oost et al. 2017). Drought mainly impacts the dry habitats on the islands and along the coastline, such as salt marshes. Prolonged periods of drought also reduce freshwater flows towards the Wadden Sea and thus influence salinity gradients along the coast, as well as nutrient inputs into the ecosystem.

Changes in (mean) wind, storm intensity and frequency

Observations in the Netherlands to-date do not clearly indicate a changed wind climate in the Wadden Sea region and the Dutch Coast (Deltares 2019). This is projected to remain consistent in the future with limited changes in projected mean wind speed, number of stormy days and storm intensity (e.g., a range of -5% to +5% for mean wind speed and storm intensity; www.coastalatlas.org). The scenarios produced by the Dutch Meteorological office (KNMI) similarly project relatively small changes in both mean and extreme wind speeds for 2070-2100 (KNMI 2014). Model projections for the North Sea also indicate that neither maximum wind speeds nor storminess are expected to change significantly (De Winter et al. 2013).

Storm surge and extreme water levels

Storm surges are the response of the localised sea level to large-scale meteorological conditions. They are caused by storm wind fields pushing the water towards the coast and, to a smaller extent, by the action of the atmospheric pressure on the sea surface (Weisse et al. 2012). The magnitude of a storm surge depends on the size, movement, and intensity of the storm system, the nearshore local bathymetry (water depth) and the shape of the coastline. Storm characteristics may be altered with climate change; however, the expected changes are relatively small (www.coastalatlas.org, Klein et al. 2018; see description above). Consequently, based on current knowledge, large changes in storm surges due to changes in storms are not expected. However, the nearshore bathymetry of the Wadden Sea may change significantly in the future (e.g., Becherer et al. 2018). Under high levels of projected sea level rise, parts of the Wadden Sea may experience a lack of sediment supply, leading to increasing water depths and a related increase in storm surge levels. Human interventions can also influence the (local) morphological development and therefore storm surge characteristics.

Extreme water levels (coastal flooding) and sea state (waves) are also relevant for coastal risk management and protection. Extreme water levels occur due to combined effects of sea level, high tidal excursion and storm surge (Weisse et al. 2012). As mean sea level rises, the likelihood of extreme water levels will correspondingly increase. Tidal ranges may be altered due to morphological changes in the tidal basins. If water depths increase, wave heights along the Wadden Sea coast may also increase, exacerbating coastal impacts. As changes to these parameters, and to their interactions, are uncertain in the long-term, their effect on the coastal zone is difficult to predict. However, the high likelihood of sea level rise suggests an overall increase in both extreme water level events and wave impacts. An increase in the frequency of extreme water levels during spring and summer (summer storms) may lead to decreased breeding success of birdlife.

4. Applying the Climate Vulnerability Index (CVI) to the Wadden Sea World Heritage property

4.1 The CVI process

The Climate Vulnerability Index (CVI) is a rapid assessment tool that was specifically developed for application to World Heritage properties but which is also applicable for other types of protected areas. The CVI framework (Fig. 1.1) builds upon the vulnerability framework described in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007).

Vulnerability of OUV is determined by assessing the exposure, sensitivity and adaptive capacity of the OUV system with respect to identified climate stressors (Fig. 1.2). The OUV Vulnerability becomes the exposure term to assess the vulnerability of the community associated with the property, combining with assessments of economic-social-cultural dependency (the sensitivity term) and adaptive capacity (Fig. 1.1). The process uses a customised spreadsheet-based worksheet to determine outcomes based on user inputs. A detailed outline of the CVI process is presented in Day et al. (2020).

For the Wadden Sea, phase 1 of the CVI process (to assess OUV Vulnerability) was undertaken in February 2020. This involved the following four steps:

1. Conduct a high-level risk assessment (exposure and sensitivity) of OUV from the identified three key climate stressors within an agreed timeframe (e.g. by 2050).
2. Use the spreadsheet-based worksheet to identify the potential impacts of the key climate stressors on the key values.
3. Consider the likely adaptive capacity of OUV in relation to the key climate stressors.
4. Use the worksheet to determine the OUV Vulnerability to the key climate stressors.

While much of the analysis was conducted during the workshop, substantial preparations were undertaken in advance by the workshop Steering Group and invited participants.

4.2 Preparatory steps

Development of attributes from key values

The Statement of OUV (SOUV) for the Wadden Sea is a narrative in broad descriptive terms. An initial list of 10 key values for Wadden Sea was derived from the SOUV by TG-WH and CWSS (Table 2.1). Some of these values were very broad (e.g., high biomass production) or at coarse a scale (e.g., diversity of geomorphological features) for an effective assessment as part of the CVI. Consequently, the workshop planning committee agreed to further break these down into what were termed *'key value elements'* in the framing document that was circulated amongst participants prior to the workshop. These subdivided the 10 key values into finer, more measurable levels that are also closer to the level at which management occurs (e.g. sand dunes, beaches).

Advice from World Heritage experts is that the terminology used for such a breakdown of the SOUV is more appropriately 'attributes' (rather than 'key value elements'). The hierarchy of these and associated terms used in this report are outlined in Figure 4.1.

In essence, attributes express the values in a more quantifiable way but must be derived from excerpts from the SOUV (or refer directly to excerpts from the SOUV). Throughout the remainder of this report, the terms 'key values' and 'attributes' are used.

Pre-workshop tasks

Prior to the workshop, the following pre-workshop tasks were requested of all participants:

- Read the Statement of Outstanding Universal Value (SOUV) and understand how the breakdown of key values and attributes was developed from that Statement.
- Consider which climate stressors are significant and likely to be impacting those attributes; from those select your top three key climate stressors.
- Identify Significant Property Values (SPVs); while these were not included within the stated OUV, they do have local, regional or national significance.

Within the Wadden Sea, certain **values** have been identified because of their significance.

The particular values that have been recognised as globally significant and conferring Outstanding Universal Value (under three of the World Heritage criteria) are its **key values**.

Each of the above key values have **attributes** (at the level at which management would occur); these may be tangible or intangible.

Other values within the property are also important; if they are considered nationally, regionally or locally 'significant', they are referred to as other **Significant Property Values** (SPVs) and are distinct from those values that comprise the OUV.

Figure 4.1. Hierarchy of World Heritage terminology as applied for the Wadden Sea (after Heron et al. 2020).

The responses received (n = 24; ~70%) demonstrated the value of this component, firstly in creating a common level of understanding regarding OUV, the provided list of climate stressors and other values of or related to the property that are not included within OUV. Several participants noted that some climate stressors are inter-related, resulting from combined effects of other listed climate stressors (e.g., Coastal erosion may result from combined effects of Sea level rise and Storm surge). Regarding the climate stressor "coastal erosion", several participants suggested that for Wadden Sea coastal erosion is an inherent process and should not be considered as a stressor. As a result, for the workshop analysis, the decision was taken to not select 'coastal erosion' as a climate stressor but rather direct selection to the underpinning stressor/s that lead to altered erosion (e.g., sea level rise). In addition, it was decided to add ocean acidification to the list as a 'context-specific' climate stressor. Regarding the Significant Property Values (i.e., those not included within OUV), there was some confusion that arose from the terminology initially used – 'Significant Local Values' – specifically in regard to the definition of 'local'. Discussion during the workshop included the importance of locations across the entire East-Atlantic Flyway to the stated key value that, appropriately, were not included within the Statement of OUV but also cannot be considered local. The revision of terminology to Significant Property Values will be valuable for future applications of the CVI process.

4.3 Evaluation of current condition and trend of the key values

Assessment of the current condition and the trend in condition since inscription (2009) was undertaken during the workshop to provide participants, and other stakeholders more broadly, with a baseline from which future climate vulnerability can be considered (Table 4.1). Initially, these were to be evaluated at the level of the identified World Heritage attributes; however, discussions during the workshop determined that it was appropriate to assess many at the key value level. This was either because (i) the identified attributes could not be distinguished or differentiated for the purpose of assessing condition and trend; or (ii) there was no distinction between the assessed condition and trend across the attributes. As such, assessments are reported at the attribute level only when necessary.

There was agreement amongst many participants that the historical context of the Wadden Sea system is over much longer temporal scales than is reflected in the period since inscription (in 2009), which may be considered a somewhat arbitrary benchmark. For example, loss of marshland over the last 1,000 years (up to 50 km inshore from the current coastline) and blocking of fish migration in some areas occurred prior to the designation of protected areas (around the 1980s), which preceded World Heritage inscription. Therefore, many of the elements discussed were assessed as good with some concerns and stable due to this short timeframe, while consideration of a longer timeframe for the system may lead to a different assessment.

Table 4.1. Wadden Sea key values (derived from the Statement of Outstanding Universal Value by the Trilateral Task Group World Heritage) and attributes (developed by the Steering Group), together with the assessed current condition and trend since inscription in 2009. These may not reflect the condition and trend with respect to a longer timeframe; i.e., prior to inscription. Legend (on page 27) adapted from IUCN (2012).

Key value	Attributes *[cross-reference]*	Current Condition and Trend
1. Unbroken tidal flat and barrier system	1a. Extent and distribution of mud flats, sand shoals, and barrier islands	→
2. Geomorphological diversity	2a. Barrier islands (incl ongoing forming or erosion of island/sand banks)	→
	2b. Tidal flats, gullies, channels, ebb-tidal deltas	
	2c. Sub-tidal shoals	
	2d. Sand dunes, beaches	
3. On-going geomorphological processes	3a. Geomorphological processes (e.g. sediment movement by waves, current and wind), accretion/sedimentation patterns, erosion)	→
4. Intact natural intertidal ecosystems	4a. Estuaries, tidally influenced transition zones	↘
	4b. Coastal wetlands (e.g. saltmarshes, beaches and dunes) *[see also 8c]*	→
5. Linked geomorphological and biophysical processes	5a. Numbers and distribution of species typical for Wadden Sea ecosystems (e.g, species adapted to salt marshes or wet dunes, sediment gradient of tidal flats).	→
	5b. Ecological processes (e.g. primary production, predation, particle feeding, recruitment, connectivity)	
	5c. Bio-geomorphological interactions (e.g. eelgrass meadows slow down flow, trap suspended particles, raising the seabed, mussel beds. Seabed reworking by infauna changes the sedimentary composition)	
6. High biomass production	6a. Fish stocks *[see also 7c]*	→
	6b. Birds *[see also 7a & 8d]*	
	6c. Filter feeders (e.g. shellfish, mussels)	
	6d. Suspension feeders (e.g. sandworms/ lugworms - *largest worm population worldwide*)	
	6e. Productivity (high bacterial remineralization, strong import of organic matter, high microphytobenthos production)	
7. Migratory birds and other wildlife	7a. Migratory birds *[see also 9a-9c]*	→
	7b. Marine mammals (e.g. common harbour seal, grey seal, harbour porpoise)	
	7c. Diadromous fish (e.g. flounder, smelt, eel)	

(table continues next page)

Key value	Attributes *[cross-reference]*	Current Condition and Trend
8. High biodiversity (flora and fauna)	8a. Subtidal fauna/flora (e.g. shrimp, fish, sponges, tunicates, harbour porpoise)	→
	8b. Intertidal fauna/flora (e.g. crabs, mussels, oysters, seagrass)	
	8c. Dunal fauna/flora (e.g. saltmarsh, grassland, Kentish Plover, Little Tern, Snow Bunting)	
	8d. Important bird breeding areas (e.g. Eurasian Spoonbill, Avocet, Gull-billed Tern, Sandwich Tern) *[see also 6b, 10a &10b]*	
9. Staging, moulting and wintering area for migratory birds	9a. Staging areas (e.g. important for Bar-tailed Godwit, Grey Plover) *[see also 7a & 10a]*	→
	9b. Moulting areas (e.g. important for Common Shelduck, Common Eider and Common Scoter) *[see also 7a & 10a]*	
	9c. Over-wintering areas (e.g. important for Great Ringed Plover, Dunlin, Herring Gull, Redshank) *[see also 7a & 10a]*	
10. Key migratory stopover (low disturbance, food availability)	10a.Food availability and quality for migratory birds	↘

Current Condition	Criteria
Good	The site's values are in good condition and are likely to be maintained for the foreseeable future, provided that current conservation measures are maintained.
Good with some concern	While some concerns exist, with minor additional conservation measures the site's values are likely to be essentially maintained over the long-term.
Significant concern	The site's values are threatened and/or are showing signs of deterioration. Significant additional conservation measures are needed to maintain and/or restore values over the medium to long-term.
Critical	The site's values are severely threatened and/or deteriorating. Immediate large-scale additional conservation measures are needed to maintain and/or restore the site's values over the short to medium-term or the values may be lost.

Trend			
→ **Stable**	↗ **improving**	↘ **Deteriorating**	? **Unknown**

4.4 OUV Vulnerability

Two short presentations introduced effects of climate change on the Wadden Sea to inform the assessments within the CVI process, including the selection of key climate stressors: 'Climate change and its impact on abiotic values of the Wadden Sea', presented by Albert Oost; and 'Impacts of climate change on the natural dynamics of the Wadden Sea', presented by Katja Philippart. Information from these have been included in this report.

Application of the CVI process typically occurs for a single future timeframe; however, the Wadden Sea workshop produced much discussion about the value of considering both ca. 2050 and ca. 2100, especially as climate-related tipping points are projected for the period between these times. As such, the workshop was quickly pivoted to allow for both timeframes to be assessed. In both cases, the workshop considered a 'business-as-usual' climate scenario informed by model projections under Representative Concentration Pathway (RCP) 8.5. Additionally, it was decided that Ocean acidification should be augmented to the list of 14 climate stressors as a 'context-specific' climate stressor.

The CVI process employs both plenary sessions and breakout groups. Plenary sessions were used for presentations, discussions and to compile information from the breakout groups. For some elements of the process, breakout groups approached tasks in different (but equally effective) ways. In all cases, outcomes from the groups were brought together in plenary to resolve any differences and reach the final conclusions.

Assessment for ca. 2050

From the agreed upon list of climate stressors (Figure 1.2), breakout groups of participants were asked to select up to three climate stressors most likely to impact each described key value for the timeframe under consideration. Combining inputs from the breakout groups, the top three climate stressors for each key value (including equal-third) were used to then select the three key climate stressors for the property (Table 4.2; Figure 4.2). For the ca. 2050 timeframe these were determined to be (i) Temperature trend (air and/or water); (ii) Extreme temperature events; and (iii) Sea level rise, each considered to impact upon the same number of key values. While 'coastal erosion' had been identified by several participants as a climate stressor in the pre-workshop tasks (light grey in Figure 4.2), the decision during the workshop was to select the underpinning stressor/s that led to altered sediment dynamics, as noted previously.

Exposure to climate stressors and the sensitivity of the OUV system to these are used within the CVI process to assess the potential impacts of each key climate stressor. At this point in the CVI process, consideration is given to all key values collectively, rather than individually. The level of **exposure** (i.e., the nature, magnitude and rate of climatic and associated changes) of the OUV system to each of the three key climate stressors was

Table 4.2. Climate stressors identified as likely to have the greatest impact for each of 10 key values of OUV for ca. 2050. Marked cells indicate that the climate stressor was in the top three responses (including equal-third) for each key value.

Key values of OUV	Temperature trend (air and/or water)	Extreme temperature events	Precipitation trend	Intense precipitation events	Flooding (fluvial, pluvial)	Drought (severity, duration, frequency)	Mean wind trend	Storm intensity and frequency	Sea/lake ice change	Snow cover change	Sea level rise (trend)	Coastal flood	Storm surge	Coastal erosion	Ocean acidification
	Climate stressors														
Unbroken tidal flat and barrier system								x			x		x		
Geomorphological diversity								x			x		x		
On-going dynamic geomorphological processes						x		x			x				
Intact natural intertidal ecosystems	x	x									x				
Linked geomorphological and biophysical processes	x	x						x							
High productivity (fish, shellfish, birds)	x	x	x			x									
Migratory birds and other wildlife	x	x						x			x		x		
High biodiversity (flora, fauna)	x	x				x									
Staging, moulting and wintering area for migratory birds	x	x									x				
Key migratory stopover (low disturbance, food availability)	x	x									x				
Total	7	7	1	0	0	3	0	5	0	0	7	0	3	0	0

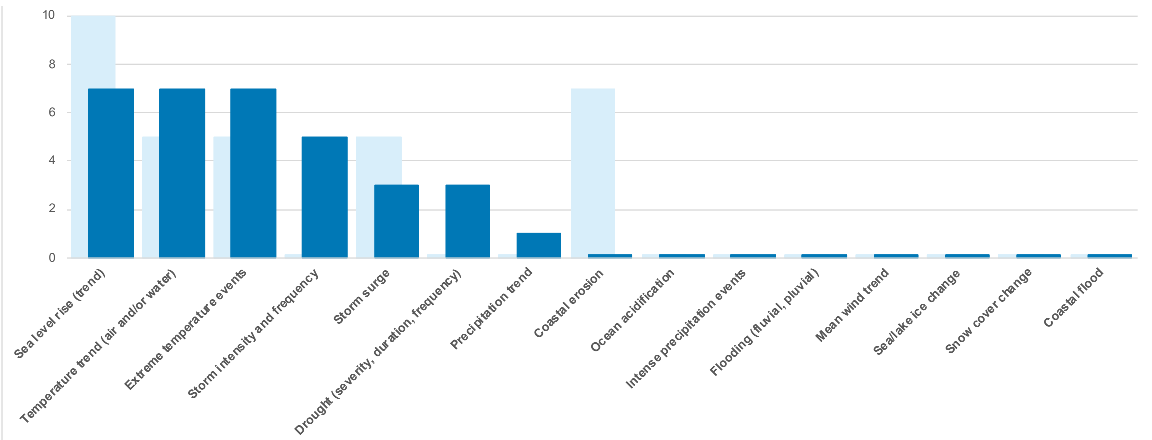

Figure 4.2. Histogram of impacts on 10 key values of OUV from 15 climate stressors whose impacts were assessed for ca. 2050. Pre-workshop responses without specifying a time-period are shown in the lighter blue. Note that 'coastal erosion' was not considered during the workshop.

assessed using a five-point categorical scale (Day et al. 2020). Modifiers assessing temporal scale and trend were also evaluated, potentially amplifying the level of exposure. The measure of the **sensitivity** (i.e., the degree to which the OUV is affected, either adversely or beneficially, by climate variability or change) of the OUV system to each of the three key climate stressors was also assessed using a five-point categorical scale, with modifiers similarly applied to incorporate spatial scale and compounding factors (Day et al. 2020). Compounding factors are non-climate factors that lead to increased impacts upon a property when operating together with climate stressors. For the Wadden Sea, these may include cumulative impacts on the site due to increasing tourism. It was noted during the workshop that while there may not be manageable solutions to reduce effects from climate change, there exists capacity to reduce impacts of compounding stressors.

Combining inputs from the breakout groups, the likelihood of exposure of Wadden Sea to Temperature trend and Sea level rise were assessed as Very likely (>90%). While initially assessed as Likely (67-90%), consideration of modifiers raised the assessment of exposure to Extreme temperature events also to the Very likely category. Evaluation of sensitivity of the OUV system to Temperature trend and Extreme temperature events was initially at the Moderate level for both, with the former assessment elevated to the High level after considering modifiers. Similarly, the sensitivity to Sea level rise was raised to Moderate from the initial assessment of Low. Definitions of each sensitivity level are provided in Day et al. (2020). As a result, the **potential impact** was determined to be Extreme with respect to Temperature trend (the highest category of the four-point scale) and High for each of Extreme temperature events and Sea level rise (Table 4.3).

Table 4.3. Rapid assessment of OUV Vulnerability to identified three key climate stressors for the 2050s. Assessed values of exposure, sensitivity and adaptive capacity contribute to derived outcomes of potential impact and OUV Vulnerability. Colours refer to the elements of the CVI framework (Fig. 1.1)

Key Climate Stressors:	Temperature trend (air and/or water)	Extreme temperature events	Sea level rise (trend)
Exposure	Very likely	Likely	Very likely
Temporal scale	On-going	Frequent	On-going
Trend	Rapid increase	Moderate/Rapid increase	Slow/Moderate increase
Exposure	**Very likely** ○○○○●	**Very likely** ○○○○●	**Very likely** ○○○○●
Sensitivity	Moderate	Moderate	Low
Spatial scale	Widespread	Extensive	Extensive
Compounding factors	Medium/High probability	Medium probability	Medium probability
Sensitivity	**High** ○○○●○	**Moderate** ○○●○○	**Moderate** ○○●○○
Potential impact	**Extreme** ○○○●	**High** ○○●○	**High** ○○●○
Local management response	Low	Low	High
Scientific/technical support	Moderate	Moderate	Moderate/High
Effectiveness	Low	Very low/Low	Moderate/High
Adaptive capacity	**Low** ○●○○	**Very low** ●○○○	**High** ○○○●
OUV Vulnerability	**High** ○○●	**High** ○○●	**Low** ●○○
Combined OUV Vulnerability		**High** ○○●	

Adaptive capacity describes the potential or capability to adjust to climate change, to moderate potential damage, to take advantage of opportunities, or respond to the consequences. In the CVI framework, adaptive capacity of a World Heritage property is considered in terms of:

a. the local management response,

b. the level of scientific and/or technical support, and

c. the effectiveness of these to address the climate stressor being considered.

Each of these components are assessed on a four-point scale, with the **adaptive capacity** also determined on a four-point scale (Day et al. 2020). Together with the assessment of potential impact, the adaptive capacity is used to determine the vulnerability of OUV for each key climate stressor, which are combined to give the OUV Vulnerability for the property.

For both Temperature trend and Extreme temperature events the local management and level of support were assess as Low and Moderate, respectively, combining inputs from breakout groups. However, the measure of effectiveness of actions was evaluated as lower for Extreme temperature events (Low/Very low) than for Temperature trend (Low), which led to a distinction in the overall adaptive capacity (Very low with respect to Extreme temperature events, Low for Temperature trend). In contrast, for Sea level rise, local management was assessed as High, and scientific/technical support and effectiveness were both Moderate/High, resulting in an overall evaluation of adaptive capacity of High. As a result, the vulnerability of OUV (on a three-point scale, low to high) was determined to be High for Extreme temperature events and Temperature trend, and Low with respect to Sea level rise. Combining these, the **OUV Vulnerability** for Wadden Sea was determined as High for the ca. 2050 timeframe (Table 4.3).

This ca. 2050 assessment of OUV Vulnerability can be compared with previous applications of the CVI process using similar timeframes – the natural property Shark Bay, Western Australia (Heron et al. 2020) and the cultural property Heart of Neolithic Orkney (Scotland; Day et al. 2019). In all cases the OUV Vulnerability was in the highest category; however, examining the assessed vulnerability of OUV at the level of the three key climate stressors shows variation between the applications. For Shark Bay, vulnerability was determined as High for all three key climate stressors; for Heart of Neolithic Orkney, two stressors led to High vulnerability with the third evaluated as Moderate. It is important to note that this description is not intended to imply a ranking but rather to indicate that there is a spectrum of outcomes when using the CVI methodology. Most importantly for Wadden Sea is the rapid assessment outcome of High OUV Vulnerability.

Assessment for ca. 2100

As described previously, the Wadden Sea workshop assessed a second timeframe; viz., ca. 2100. As for the ca. 2050 analysis, the first step was to identify the three key climate stressors, which were not assumed to reflect those of the early timeframe. The result was, however, that the same three climate stressors were identified for the ca. 2100 timeframe, but with Sea level rise considered to impact upon the greatest number, and in fact all, of the key values (Table 4.4; Figure 4.3). While Ocean acidification was identified during the breakout groups as having potential impact on several key values, the specifics of and level of certainty regarding those impacts were insufficient at the time to include this as a key climate stressor.

For ca. 2100, the likelihood of exposure of Wadden Sea was assessed as Very likely (>90%) for all three key climate stressors. Sensitivity of the OUV system was initially at the High level for all stressors, and was elevated to High/Very high for Temperature trend and Sea level rise after considering modifiers. The potential impact was determined to be Extreme for all three key climate stressors (Table 4.5).

Table 4.4. Climate stressors identified as likely to have the greatest impact for each of 10 key values of OUV for ca. 2100. Marked cells indicate that the climate stressor was in the top three responses for that key value. Ocean acidification was noted by participants as of potential importance but requiring further research to overcome uncertainty in the level of impact.

	Temperature trend (air and/or water)	Extreme temperature events	Precipitation trend	Intense precipitation events	Flooding (fluvial, pluvial)	Drought (severity, duration, frequency)	Mean wind trend	Storm intensity and frequency	Sea/lake ice change	Snow cover change	Sea level rise (trend)	Coastal flood	Storm surge	Coastal erosion	Ocean acidification
Key values of OUV	**Climate stressors**														
Unbroken tidal flat and barrier system								x			x		x		?
Geomorphological diversity								x			x		x		?
On-going dynamic geomorphological processes						x		x			x				?
Intact natural intertidal ecosystems	x	x						x			x				
Linked geomorphological and biophysical processes	x	x						x			x				
High productivity (fish, shellfish, birds)	x	x									x				?
Migratory birds and other wildlife	x	x									x				
High biodiversity (flora, fauna)	x	x				x					x				?
Staging, moulting and wintering area for migratory birds	x	x									x				?
Key migratory stopover (low disturbance, food availability)	x	x									x		x		
Total	7	7	0	0	0	2	0	5	0	0	10	0	3	0	?6

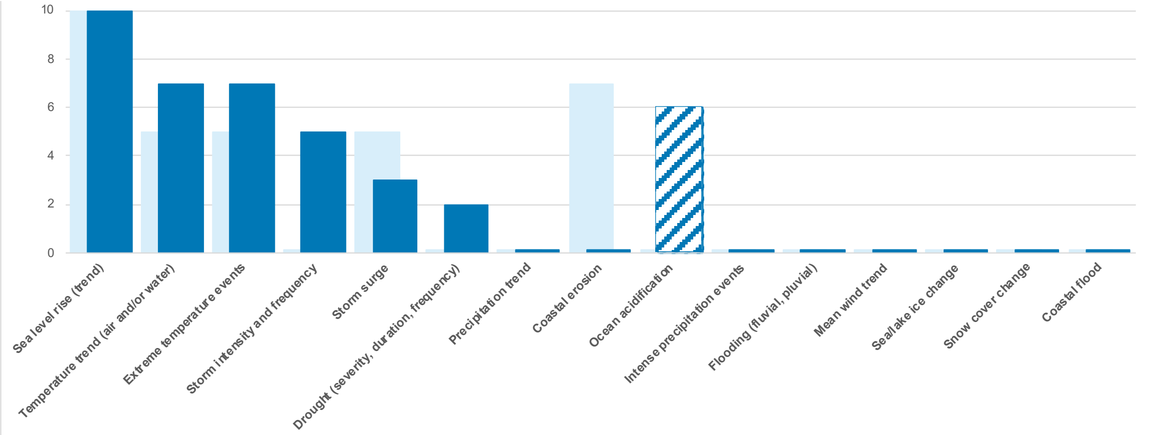

Figure 4.3. Histogram of impacts on 10 key values of OUV from 15 climate stressors whose impacts were assessed for ca. 2100. The hashed column indicates that Ocean acidification was noted by participants as of potential importance but requiring further research to overcome uncertainty in the level of impact. Pre-workshop responses without specifying a time-period are shown in the lighter blue. Note that 'coastal erosion' was not considered during the workshop.

Table 4.5. Rapid assessment of OUV Vulnerability for ca. 2100 (see caption of Table 4.3 for additional detail).

Key Climate Stressors:	Temperature trend (air and/or water)	Extreme temperature events	Sea level rise (trend)
Exposure	Very likely	Very likely	Very likely
Temporal scale	On-going	Frequent	On-going
Trend	Rapid increase	Rapid increase	Moderate/Rapid increase
Exposure	**Very likely** ○○○○●	**Very likely** ○○○○●	**Very likely** ○○○○●
Sensitivity	High	High	High
Spatial scale	Widespread	Extensive/Widespread	Extensive/Widespread
Compounding factors	Medium/High probability	Medium probability	High probability
Sensitivity	**High/Very high** ○○○◑◐	**High** ○○○●○	**High/Very high** ○○○◑◐
Potential impact	**Extreme** ○○○●	**Extreme** ○○○●	**Extreme** ○○○●
Local management response	Low	Low	Low/Moderate
Scientific/technical support	Low/Moderate	Low/Moderate	Moderate/High
Effectiveness	Very low-negligible	Very low-negligible	Low
Adaptive capacity	**Very low** ●○○○	**Very low** ●○○○	**Low** ○●○○
OUV Vulnerability	**High** ○○●	**High** ○○●	**High** ○○●
Combined OUV Vulnerability	**High** ○○●		

While assessments for exposure and sensitivity were elevated, those for components of adaptive capacity were typically reduced. This resulted in evaluations of adaptive capacity as Very low for Temperature trend and Extreme temperature events, and Low for Sea level rise. As a result, the vulnerability of OUV was determined to be High for all three key climate stressors, with the OUV Vulnerability for Wadden Sea for the ca. 2100 timeframe determined as High (Table 4.5).

While the key climate stressors identified act on different timeframes (and therefore had different contributions to the two assessments), the sensitivity and adaptive capacity of the OUV system may not change. The workshop analysis showed that, ultimately, there was minimal difference in the overall assessment of OUV Vulnerability.

4.5 Discussion of outcomes

The outcomes from the CVI process, which were based on expert judgement grounded in the best available scientific information, will enable managers to make informed decisions. The rapid and repeatable nature of the CVI process is a strength that allows managers to re-visit these findings as part of an adaptive management strategy. It was recognised that further research would be beneficial to better inform the process, and to this end identified knowledge gaps are described in Section 5.2. However, it is important to note that management is necessary now and decisions should not await perfect information, especially given the dynamic nature of both the Wadden Sea system and climate change. As revealed during the workshop, there are limits to the adaptive capacity of the system to adjust to either sea level rise or temperature effects without disturbing the natural dynamics. As such, the most effective way to safeguard the OUV of the Wadden Sea is through global actions to reduce greenhouse gas emissions (and atmospheric concentration) and therefore prevent extreme climate changes.

4.6 Management implications

Recognising the critical need for global actions to address the primary cause of climate change (greenhouse gas emissions), management activities will have to be strategic and intentional to support the property and its values through the coming decades of increased frequency and severity of climate-related disturbance.

Among the three identified key climate stressors, the temperature-related stressors (Temperature trend, Extreme temperature events) may have limited options for feasible management responses. Assisted evolution to acquire thermal tolerance may be achievable for some sessile and motile organisms, although the cost of this approach may limit the scale of application.

In contrast, the history of management activity with respect to sea level illustrates the high level of scientific and technical capacity to support adaptation of the Wadden Sea to sea level rise. However, it is also important to note that the workshop determined the high level of adaptive capacity in 2050 would reduce to a low level by 2100 with the projected acceleration of sea level rise towards the end of this century.

Workshop participants recognised the importance of minimising other (localised) stressors on the ecosystem, particularly during periods of acute disturbance. This could involve temporary closures of some sections of the property that are being impacted, for example, by a marine heatwave, to support resistance to and recovery from climate exposure. Should such a closure be considered a viable approach, consultation with communities and industries potentially affected would be vital to the success of the intervention.

4.7 Considerations for assessing Community Vulnerability

The OUV Vulnerability (i.e., the level of vulnerability of the key values that collectively comprise the OUV) is an important outcome of the CVI process. The implications of this for the surrounding community who depend upon the World Heritage property (economically, socially and/or culturally) may also be very significant. Phase 2 of the CVI process is to assess the Community Vulnerability, and is an important aspect that is rarely undertaken in most other assessments of climate impacts. The CVI framework evaluates Community Vulnerability by considering the economic, social and cultural (ESC) dependencies of the community associated with the property (which include local, domestic and international peoples) and the community's adaptive capacity to cope with climate change.

During the workshop to assess OUV Vulnerability, discussion was held regarding the potential to complete the CVI process by assessing Community Vulnerability at a subsequent workshop/s. Topics discussed included:

- dependency of the community has the potential to vary for different regions within the Wadden Sea property, as does the capacity to adapt to climate change;
- that consideration be given to peoples and businesses connected with the World Heritage property;
- that the "cultural history" of the community is deeply connected to the property and the broader Wadden Sea area, including that the historical building of dykes influenced what was inscribed as the Wadden Sea World Heritage property;
- that key community concerns may include demographic changes (loss of identity); health; and, to a lesser extent, sea level rise (which, to some extent, can be managed);
- to what extent should tourists to be considered influential for the World Heritage property;
- only direct economic associations are used (e.g., the ferry company working within the World Heritage property, but not the airline flying the people there);
- harbours represent one relevant economic factor to consider;
- predicted changes in Sea level rise/Temperature trend/Extreme temperature events should be further linked to the potential impacts (e.g., effects on mussel farming, impacts on fishing and tourism);

- stressors other than Sea level rise, Temperature trend and Extreme temperature events may be relevant for community impacts related to Wadden Sea ecology, geomorphology and geology; and
- which timeframe (ca. 2050/2100), emissions scenario (e.g., RCP8.5) and projections reference values or other physical information should be considered:
  - *Sea level rise*: follow the global trends (IPCC 2019);
  - *Temperature trends*: follow the global trends (IPCC 2019);
  - *Extreme temperature events*: use data on the increasing frequency (IPCC 2019).

Past applications of the CVI process have shown that the development of a future scenario within which to consider economic, social and cultural aspects has proven helpful. Recommendations related to the potential for undertaking an assessment of Community Vulnerability for Wadden Sea are provided in Section 5.3.

5. Conclusions

5.1 Workshop outcomes

The Wadden Sea World Heritage property was assessed to have the highest level of OUV Vulnerability (High) for the ca. 2050 and 2100 timeframes with respect to the three key climate stressors identified by the workshop participants: Temperature trend, Extreme temperature events and Sea level rise. Under RCP 8.5, there is the potential for major loss or substantial alteration of the majority of the attributes that convey the OUV of the World Heritage property by 2050. This potential loss is amplified when considering a timeframe to ca. 2100.

In addition to the assessed OUV Vulnerability, outcomes from the workshop included: various learnings from and about the process; knowledge gaps for future investigation; and insights from this workshop towards a future assessment of Community Vulnerability (Phase 2 of the CVI process). These are presented here and, where appropriate, recommendations regarding these are provided. Consideration of future applications of the CVI process for the Wadden Sea (to inform adaptive management of the dynamic system and/or as part of periodic review) and for other associated or similar protected areas are also outlined.

5.2 Knowledge gaps identified

The considerable research conducted in Wadden Sea has produced a wealth of knowledge; however, the following knowledge gaps were identified through the workshop:

- research towards climate change adaptation and if and how projects can involve the land behind the dyke and/or previously reclaimed land;
- a need to quantify carbon sequestration in the Wadden Sea, noting:
    - understanding carbon sequestration in salt marshes is important; and
    - existing research indicates that the water column has sufficient buffering capacities for the next hundreds of years;
- further knowledge development regarding impacts from ocean acidification (highlighted in the assessment for ca. 2100), noting that some buffering may occur due to the high amount of organic material in the Wadden Sea;
- required analysis of water temperature trend and the frequency of marine heatwaves in the Wadden Sea;
- understanding of historical and projected future alteration of the ocean current system;
- additional data needs on sediment state and balance;

- regarding specific species and habitats (possibly some identified as SPVs), prioritisation of important species for closer consideration;
- understanding of the options for adaptation measures in response to the identified key climate stressors, while maintaining the natural dynamics of the system;
- an overview of "no regret" measures (i.e., measures worth implementing regardless of the outcome particularly when consequences are uncertain) that already exist for the Wadden Sea; and
- comparative analysis of systems similar to the Wadden Sea under different climate scenarios and/or present-day climate analogues for Wadden Sea (i.e., locations whose current climate conditions are representative of projected conditions for the Wadden Sea).

5.3 Learnings from the CVI application for Wadden Sea

During the workshop, a number of issues were raised and clarified. Among the issues of ongoing relevance for the CWSS or for the CVI methodology were:

1. The list of **key values** used in workshop (see Table 2.1) was provided by TG-WH and CWSS; however, there was some confusion amongst the workshop participants because some of these key values were not independent. The consideration of measurable attributes within each key value helped some participants to clarify the areas of overlap and was valuable in guiding the assessments undertaken in the CVI process. However, there remained some lack of clarity about the breakdown, especially in assessing Current Condition and Trend.
   - *Resulting recommendation for CWSS*: Consider clarification of key values and attributes; also consider the merit of using attributes given they are identified at the level at which management occurs within the property.
   - *Resulting recommendation for CVI:* Ensure that attributes used for the CVI process are clearly defined and independent.
2. The term **Significant Property Values** (SPVs) was initially named Significant Local Values (SLVs), including in the pre-workshop materials, which caused confusion for some participants regarding the geographic scope permissible for these (see Section 4.1). As the intention was to collate significant values that are of local, regional or national significance and/or are specifically linked to the OUV of the property, including any located outside the property, the terminology was updated.
   - *Resulting recommendation for CVI:* Continue to use the terminology Significant Property Values (SPVs) and seek to clearly define this and provided relevant examples (both within and, where appropriate, beyond the property boundary).
3. Some of the **climate stressors** developed generally for World Heritage properties are inter-related; e.g., Coastal erosion may result from combined effects of Sea level

rise and Storm surge. While some CVI workshops may choose a combined-level stressor, it would be important to ensure that the component stressors are not also selected for the same reasons.

- *Resulting recommendation for CVI*: Determine the inter-relationships among the list of climate stressors and develop protocols to ensure selection of inter-related stressors does not occur.

4. The workshop recognised that climate impacts outside the property can affect key values; i.e., **teleconnections**. For example, climate impacts on migratory birds outside the Wadden Sea can threaten the OUV.
    - *Resulting recommendation for CVI*: Acknowledge that climate impacts outside a property boundary may impact OUV.
5. The **timeframe** for assessing current condition and trend is referenced to the date of inscription, which may not reflect changes to key values over longer timeframes. For the Wadden Sea property (inscribed in 2009), it is appropriate to consider the on-going large-scale development of the sandy barrier coast under rising sea levels over the past 8,000 years. Participants raised the difficulty of determining status and trends for related key values in the relatively short timeframe since inscription.
    - *Resulting recommendation CVI*: Acknowledge that the assessment of current condition and trend prior to inscription may be relevant for some properties.
6. Given the size of, physical variety within and diverse governance structures for the Wadden Sea World Heritage property, the **management arrangements** are complex and undertaken at multiple levels. This resulted in added complexity in categorising the Adaptive Capacity of the OUV system when compared with applying the CVI in smaller more compact World Heritage properties. This is an inevitable tension when applying a rapid assessment process in geographically vast properties.

5.4 Community Vulnerability – the next phase of the CVI

Building upon the results of this workshop, assessment of the next phase of the CVI (i.e., Community Vulnerability) is considered both logical and compelling. A key element of the philosophy of World Heritage is that the preservation of OUV is for humankind, both present-day and future generations. As such, it is important to understand how climate-related impacts on the property can lead to impacts upon the people associated with the property (which may include locals, domestic visitors and international tourists). Assessing how economic, social and cultural characteristics may be affected under future climate change provides communities with opportunity to develop strategies to mitigate impacts and/or to develop alternatives for these.

Community understanding of potential impacts on lifestyle and livelihood will lead to added support for management activities to mitigate climate impacts to the natural system (including through government influence). Strengthening partnerships to build capacity of managers, industries and communities is essential to provide adaptive and future-focused strategies in a changing climate. This will enhance the protection and conservation of heritage for transmission to future generations; and aligns with the Strategic Objectives of World Heritage (the six Cs; expanded from https://whc.unesco.org/en/partnerships/): credibility, conservation, capacity-building, communication, communities and climate change.

Past assessments of Community Vulnerability have demonstrated that it is best undertaken through a workshop of diverse stakeholders (including site managers, researchers, community representatives, dependent business owners, management agency representatives, and other stakeholders). Importantly, these assessments are based on the foundation of the assessment of OUV Vulnerability that was informed by the most-relevant climate projections. There are, however, a number of additional aspects which will need to be considered for application to the Wadden Sea, including:

a. Geographic scope – Should the assessment occur at the property level, country level or for individual management regions?
b. Representation – The Wadden Sea covers a large area, and has a large number and high diversity of potential stakeholders. Should different interests be invited together or would multiple sector-specific workshops be more useful? The former would allow for discussions between sector representatives (potentially drawn from the Wadden Sea Forum stakeholder platform); the latter would permit invitation of more sector-specific experts but would require synthesis of the outcomes (which may be time consuming to reach a compromise).
c. Sectoral climate impacts – Are there associations (e.g., peak bodies) that provide oversight for and broadly represent types of businesses connected with Wadden Sea (e.g., fishing, tourism) who could appropriately represent those sectors? Have economic and social assessments of potential climate impacts been undertaken by or for those broader associations? What does a hotel owner or representative from the tourist sector need to know in order to estimate impact on their business?
d. Timing – The interval between the assessments of OUV Vulnerability and Community Vulnerability should be minimal, noting that overlap in participants between the workshops would be desirable.

Even among these four listed aspects for consideration there is a high level of complexity and inter-relationship; a key strength of the CVI rapid assessment is that it was developed to meet such demands, affirming the value of the process. The choice for an approach for the next step also includes some important practical considerations. Organizing multiple workshops leads to higher costs and more organizational requirements. Also, language issues should be considered; e.g., if a single workshop is chosen, would the plenary descriptions be in a single language, with smaller groups (if country-specific) using their own languages? What are the pros and cons of the whole workshop being conducted in a single language?

Workshop format options for assessing Community Vulnerability for the Wadden Sea include:

- One CVI Community Vulnerability workshop with separate analyses undertaken for each of the five major management regions (three in Germany, one each in Denmark and the Netherlands). Provision of information would be provided in plenary sessions with breakout groups comprised of and focusing on the five regions to enable region-specific aspects to be incorporated. Comparison of outcomes between regions could be undertaken as part of the reporting.
- A variation on the above option would be to conduct separate analyses for each of the three countries; however, this may limit the capacity to include variations between the three German management regions.
- A second variation on the first option would be to undertake analyses at a finer scale of local jurisdictions (i.e., within the major management regions, within each country). This would likely require multiple workshops to ensure logistical feasibility.

While not an exhaustive list, these options are considered to target the desired outcomes of engaging community members, including relevant community/industry sectors and identifying opportunities for strategic development. A helpful preparatory step for the workshop would be to develop fact sheets for each economic sector (e.g., agriculture, conservation activities, tourism, fishing, shipping, ports, island communities).

Initial discussion of potential scenarios to consider when evaluating Community Vulnerability was undertaken during the first workshop. Informed by global projections (IPCC 2019), suggestions for each key climate stressor were identified to provide a scenario within which to consider economic, social and cultural impacts (Table 5.1).

Table 5.1. Scenarios of the three key climate stressors discussed during the workshop to support assessment of Community Vulnerability, phase 2 of the CVI process. Values for each variable (and likely range) from IPCC (2019).

	Ca. 2050	Ca. 2100
Sea level rise	0.32 m (0.23-0.40 m)[1]	0.84 m (0.61-1.10 m)[1]
Sea temperature trend	0.95°C (0.60-1.29°C)[1,2]	2.58°C (1.64-3.51°C)[1,3]
Extreme temperature events (global)	2- to 10-fold increase in frequency	5- to 20-fold increase in frequency

[1]RCP8.5, *relative to 1986–2005* [2]2031-2050 [3]2081-2100

5.5 Future applications of the CVI

For the Wadden Sea

The rapid nature of the CVI process is such that it can be repeated in the future at appropriate intervals which may be incorporated into World Heritage periodic reporting.

In addition, the outcomes here and the list of key values forms the basis of an analysis of the positive or negative impacts on OUV of key industry sectors (e.g., fisheries, shipping, tourism), as part of a Single Integrated Management Plan (SIMP) of the property. Outcomes of a phase 2 of the CVI process (to assess Community Vulnerability) may support the SIMP.

For related locations that share Wadden Sea values

Several key values identified for Wadden Sea are related to the East Atlantic Flyway. As such, the conservation of other related locations is of importance to the protection of Wadden Sea values. Impacts on the flyway elsewhere could have follow-on effects for Wadden Sea. Conversely, any loss of services provided to the flyway by Wadden Sea could have dire consequences on the connectivity, given that Wadden Sea is an important junction of the flyway. These services include food availability and quality in this transitional habitat that is supported by the underpinning geomorphological processes.

Similarly, other co-located areas, including non-World Heritage sites within the broader Wadden Sea region, may have linkages with the biodiversity and geomorphological values that are recognised for Wadden Sea. Impacts on these may also lead to loss of key values for Wadden Sea, including other migratory animals (fish, marine mammals).

The outcomes from this workshop may provide useful information on climate impacts for these areas. The CVI process could be applied to provide specific information on climate vulnerability, which also may benefit from the Wadden Sea application.

For other Danish, Dutch and German World Heritage properties

The application of the CVI methodology and process is of interest and relevance to those managing other heritage sites in Germany, Netherlands and Denmark. Initial scoping of the 46 German World Heritage properties revealed 5 or 6 thematic groupings; for each of these, concurrent application of the CVI process could lead to shared insights for the grouped properties and potential climate impacts. Similar analyses could be undertaken for Dutch and Danish properties, which may fall into thematic groups aligned with those identified for Germany.

For World Heritage properties similar to the Wadden Sea

In addition, other World Heritage properties across Europe and potentially other properties across the globe may find this report particularly useful due to similarities in climate stressors and/or property values. These may include similar natural and cultural landscapes (Frederiksen 2011; CWSS 2012):

- Banc d'Arguin National Park (Mauritania)
- Curonian Spit (Lithuania/Russia)
- Danube Delta (Romania)
- Ferrara, City of the Renaissance, and its Po Delta (Italy)
- Landscape of Grand Pré (Canada)
- Mont-Saint-Michel and its Bay (France)
- The Sundarbans (Bangladesh/India)

Wider applications

The CVI process is flexible and rigorous enough for applications beyond World Heritage, and other groups have expressed interest in its application. The format and process of the CVI in considering key values and climate change challenges can be undertaken by considering the descriptive documents that are equivalent to the SOUV. This includes interest in application of the CVI to land and sea country of Indigenous groups.

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Annex 1: Wadden Sea Statement of Outstanding Universal Value

The following Statement of Outstanding Universal Value (OUV) for the Wadden Sea is a fixed description of the World Heritage property referenced to the time of inscription and has been approved by the World Heritage Committee (see whc.unesco.org/en/list/1314).

Brief synthesis

The Wadden Sea is the largest unbroken system of intertidal sand and mud flats in the world, with natural processes undisturbed throughout most of the area. The 1,143,403 ha World Heritage property encompasses a multitude of transitional zones between land, the sea and freshwater environment, and is rich in species specially adapted to the demanding environmental conditions. It is considered one of the most important areas for migratory birds in the world, and is connected to a network of other key sites for migratory birds. Its importance is not only in the context of the East Atlantic Flyway but also in the critical role it plays in the conservation of African-Eurasian migratory waterbirds. In the Wadden Sea up to 6.1 million birds can be present at the same time, and an average of 10-12 million pass through it each year.

Criterion (viii) to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;

The Wadden Sea is a depositional coastline of unparalleled scale and diversity. It is distinctive in being almost entirely a tidal flat and barrier system with only minor river influences, and an outstanding example of the large-scale development of an intricate and complex temperate-climate sandy barrier coast under conditions of rising sea-level. Highly dynamic natural processes are uninterrupted across the vast majority of the property, creating a variety of different barrier islands, channels, flats, gullies, saltmarshes and other coastal and sedimentary features.

Criterion (ix) to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;

The Wadden Sea includes some of the last remaining natural large-scale intertidal ecosystems where natural processes continue to function largely undisturbed. Its geological and geomorphologic features are closely entwined with biophysical processes and provide an invaluable record of the ongoing dynamic adaptation of coastal environments to global change. There are a multitude of transitional zones between land, sea and freshwater that are the basis for the species richness of the property. The productivity of biomass in the Wadden Sea is one of the highest in the world, most significantly demonstrated in the numbers of fish, shellfish and birds supported by the property. The property is a key site for migratory birds and its ecosystems sustain wildlife populations well beyond its borders.

Criterion (x) to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Coastal wetlands are not always the richest sites in relation to faunal diversity; however this is not the case for the Wadden Sea. The salt marshes host around 2,300 species of flora and fauna, and the marine and brackish areas a further 2,700 species, and 30 species of breeding birds. The clearest indicator of the importance of the property is the support it provides to migratory birds as a staging, moulting and wintering area. Up to 6.1 million birds can be present at the same time, and an average of 10-12 million each year pass through the property. The availability of food and a low level of disturbance are essential factors that contribute to the key role of the property in supporting the survival of migratory species. The property is the essential stopover that enables the functioning of the East Atlantic and African-Eurasian migratory flyways. Biodiversity on a worldwide scale is reliant on the Wadden Sea.

Integrity

The boundaries of the extended property include all of the habitat types, features and processes that exemplify a natural and dynamic Wadden Sea, extending from the Netherlands to Germany to Denmark. This area includes all of the Wadden Sea ecosystems, and is of sufficient size to maintain critical ecological processes and to protect key features and values.

The property is subject to a comprehensive protection, management and monitoring regime which is supported by adequate human and financial resources. Human use and influences are well regulated with clear and agreed targets. Activities that are incompatible with its conservation have either been banned, or are heavily regulated and monitored to ensure they do not impact adversely on the property. As the property is surrounded by a significant population and contains human uses, the continued priority for the protection and conservation of the Wadden Sea is an important feature of the planning and regulation of use, including within land/water-use plans, the provision and regulation of coastal defences, maritime traffic and drainage. Key threats requiring ongoing attention include fisheries activities, developing and maintaining harbours, industrial facilities surrounding the property including oil and gas rigs and wind farms, maritime traffic, residential and tourism development and impacts from climate change.

Protection and management requirements

Maintaining the hydrological and ecological processes of the contiguous tidal flat system of the Wadden Sea is an overarching requirement for the protection and integrity of this property. Therefore conservation of marine, coastal and freshwater ecosystems through the effective management of protected areas, including marine no-take zones, is essential. The effective management of the property also needs to ensure an ecosystem approach that integrates the management of the existing protected areas with other key activities occurring in the property, including fisheries, shipping and tourism.

The Trilateral Wadden Sea Cooperation provides the overall framework and structure for integrated conservation and management of the property as a whole and coordination between all three States Parties. Comprehensive protection measures are in place within each State. Specific expectations for the long-term conservation and management of this property include maintaining and enhancing the level of financial and human resources required for the effective management of the property. Research, monitoring and assessment of the protected areas that make up the property also require adequate resources to be provided. Maintenance of consultation and participatory approaches in planning and management of the property is needed to reinforce the support and commitment from local communities and NGOs to the conservation and management of the property. The State Parties should also maintain their commitment of not allowing oil and gas exploration and exploitation within the boundaries of the property. Any development projects, such as planned wind farms in the North Sea, should be subject of rigorous Environmental Impacts Assessments to avoid any impacts to the values and integrity of the property.

Annex 2: Key values derived from the Statement of Outstanding Universal Value

Key values identified by the Common Wadden Sea Secretariat and the trilateral Task Group-World Heritage in their 27th meeting (May 2019).

Statement of OUV	Key value
Criterion (viii) – to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;	
The Wadden Sea is a depositional coastline of unparalleled scale and diversity. It is distinctive in being almost entirely a tidal flat and barrier system with only minor river influences and an outstanding example of the large-scale development of an intricate and complex temperate-climate sandy barrier coast under conditions of rising sea-level.	1. Scale of the extent of unbroken tidal flat and barrier system with minor river influences. 2. Typical diversity of geomorphological features
Highly dynamic natural processes are uninterrupted across the vast majority of the property, creating a variety of different barrier islands, channels, flats, gullies, saltmarshes and other coastal and sedimentary features.	3. Dynamic on-going natural geomorphological processes, creating typical variety and spatial patterns of natural landforms
Criterion (ix) – to be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;	
The Wadden Sea includes some of the last remaining natural large-scale intertidal ecosystems, where natural processes continue to function largely undisturbed.	4. Naturalness and intactness of intertidal ecosystems
Its geological and geomorphologic features are closely entwined with biophysical processes and provide an invaluable record of the ongoing dynamic adaptation of coastal environments to global change. There are a multitude of transitional zones between land, sea and freshwater that are the basis for the species richness of the property.	5. Dynamic adaptation to linked geological, geomorphologic features with biophysical processes
The productivity of biomass in the Wadden Sea is one of the highest in the world, most significantly demonstrated in the numbers of fish, shellfish and birds supported by the property.	6. High biomass production typical for the Wadden Sea
The property is a key site for migratory birds and its ecosystems sustain wildlife populations well beyond its borders.	7. Key site for migratory birds and other wildlife populations beyond its borders.

Statement of OUV	Key value
Criterion (x) – to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.	
Coastal wetlands are not always the richest sites in relation to faunal diversity, however this is not the case for the Wadden Sea. The salt marshes host around 2,300 species of flora and fauna, and the marine and brackish areas a further 2,700 species, and 30 species of breeding birds.	8. High biodiversity of flora and fauna typical for a natural Wadden Sea.
The clearest indicator of the importance of the property is the support it provides to migratory birds as a staging, moulting and wintering area. Up to 6.1 million birds can be present at the same time, and an average of 10-12 million each year pass through the property.	9. Staging, moulting and wintering area for migratory birds.
The availability of food and a low level of disturbance are essential factors that contribute to the key role of the nominated property in supporting the survival of migratory species. The property is the essential stopover that enables the functioning of the East Atlantic and African-Eurasian migratory flyways. Biodiversity on a worldwide scale is reliant on the Wadden Sea.	10. Essential site for functioning of the East-Atlantic Flyway

Annex 3: List of Significant Property Values (SPVs) for the Wadden Sea World Heritage property

In preparation for the CVI workshop, participants were asked to list Significant Property Values (SPVs) that are not included within the OUV of the Wadden Sea property but are locally, regionally or nationally significant. Suggested values were clustered by the workshop committee and comprise natural and cultural values, human use, and intangible values, with an indication of whether they occur “in”- or “out”-side the property boundary. Of note, these can be outside the property but must be linked to the property.

Summary of Significant Property Values (SPVs) as provided by CVI workshop participants.

Broad groupings	Significant Property Values	In	Out
Archaeological heritage	Archaeological sites such as shipwrecks, dwelling mounds, pre-historic settlements and farmland (also inundated), and other sites.	x	x
Cultural heritage	Villages and historical places, historical buildings, buriel places, archive of historic events, Halligen islands,		x
Nature values	Flora and fauna (including hinterland)	*	x
Land use/Landscape development	History of marsh developement and human settlements, land reclamation, drainige system (ditch, waterway, sluice, pumping stations, dike), use of summerpolder, water management	x	x
Coastal engineering, historical and actual	Safety against sea: History of flood defences (actual and archaeological), such as dykes, dwelling mounds, wells.	x	x
Economy	Tourism and recreational facility, fishing/aquaculture, shipping, gas extraciton,	x	x
Identity	Coastal protection measures, fisheries, living at interface land-sea, stories of the Wadden Sea, historical sites of inundated farmland and settlements, traditional pactices and knowledge	x	x
Intangible values	Darkness, silence, exposure to elements, open seascape, attraction to interfaces (land water) and infinity, aesthetics, scenery	x	x
Climate mitigation	Carbon sequestration areas (Salt Marshes, Dunes, Sea Grass) CO2 mitigation - blue carbon storage.	x	x
Science	Important for understanding boundaries of sustainability. Brings "untouchable" sea floor within reach.	x	x

** in OUV*

Annex 4: Overview and outline of CVI workshop: 10-11 February 2020, Hamburg, Germany

Plenary sessions shown in Blue	**Small Group sessions** shown in Green
Room 022/023	*Rooms 022/023, 022/024, 2nd floor room 253*

10 February 2020

Working lunch will be available for workshop participants from 12:00-12:45, room 022/024

Day 1: 10 February 12:45 – 17:30
1. Overview of workshop aims, introductions, use of plenary and small-group sessions, logistics (toilets, coffee-breaks, etc.)
AIM 1: Understand the Climate Vulnerability Index (CVI) framework and its application in the Wadden Sea
2. Provide overview of CVI concept, followed by discussion - presentation
AIM 2: Understand the significant values that comprise the OUV for the Wadden Sea; and assess condition and trend. Discuss other significant values (i.e., Significant Local Values, SLVs)
3. Ensure all participants are aware of the Statement of OUV for the Wadden Sea and how the table of key values was derived from the Statement of OUV - interactive
4. Undertake high-level assessment of current condition (with context of condition at the date of inscription) and recent trend - interactive
5. Discuss other values that are significant at a local/regional scale (i.e., SLVs) but not part of OUV – interactive
AIM 3: Understand future climate change scenarios facing the Wadden Sea
6. Provide overview of climate change scenarios, differences in projected impacts from scenarios including timescales, and geographically-specific projections - presentation
AIM 4: Assess the climate stressors impacting the values of the Wadden Sea and select key climate stressors
7. Show list of climate stressors – check for (i) understanding? (ii) timescales? Do example together of brainstorming top three climate stressors impacting ONE key value (discussed in #3) - presentation
8. Using the list of climate stressors provided, ask small groups to brainstorm what are the top three climate stressors impacting the key values of OUV - interactive

Day 1: 10 February 18:30
Meet for drinks and invited dinner (dinner at 19:30)

11 February 2020

Day 2 morning 09:00 – 12:30
9. Bring outputs from 8**.** back to plenary and ensure all participants agree on which climate change drivers are impacting the attributes of OUV - interactive
AIM 5: Evaluate vulnerability of OUV to key climate stressors, considering exposure, sensitivity and adaptive capacity for selected climate scenario (e.g., 'Business as Usual', 'Paris Agreement').
10. Revisit process, including detail of thresholds, for exposure and sensitivity. Review the potential impact matrix that combines these. Revisit process for adaptive capacity and review the OUV Vulnerability matrix that combines these - presentation
11. Participants in groups assess the exposure and sensitivity (thus determining potential impact) and adaptive capacity (thus determining OUV vulnerability) for the key CC drivers. Analyse one agreed scenario e.g. 'Business as Usual' - interactive
12. Bring outputs from 11**.** back to plenary and discuss any variation in assessments of exposure, sensitivity and adaptive capacity, and any effect on OUV vulnerability.

Lunch 12:30 – 13:30

Day 2 afternoon 13:30 – latest 16:00
AIM 6: Summary, feedback and next steps - interactive
13. Summarise outcomes from workshop, following final analysis worksheet - interactive
14. Recap on those items that had been 'parked' during the workshop.
15. Introduce Community Vulnerability process for subsequent workshop/s.
16. Short brainstorming community vulnerability
17. Receive feedback on CVI framework and workshop process.
18. Conduct workshop evaluations; other feedback from participants.

Annex 5: List of participants in the CVI workshop Wadden Sea

*Legend: AU – Australia, D – Germany, DK – Denmark, NL – Netherlands; * – Committee*

Name	Institution	Country
Martin Baptist	Wageningen Marine Research	NL
Alexander Bartholomä	Senckenberg Research Institute - Marine Research	D
Maren Bauer	Ministry of Energy, Agriculture, the Environment, Nature and Digitalization Schleswig-Holstein	D
Justus E.E. van Beusekom	Institute of Coastal Research at the Helmholtz-Zentrum Geesthacht	D
Julia Busch*	CWSS	trilateral
Christian Buschbaum	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)	D
Jon Day*	ARC Centre for Coral Reef Studies, JCU	AU
Bruno Ens	Dutch Centre for Field Ornithology (SOVON)	NL
Peter Herman	Deltares	NL
Scott Heron*	James Cook University (JCU)	AU
Piet Hoekstra	Waddenacademie	NL
Claus von Hoerschelmann	Schleswig-Holstein Agency for Coastal Defense, National Park and Marine Conservation National Park Authority /Multimar	D
Jacobus Hofstede	Ministry of Energy, Agriculture, the Environment, Nature and Digitalization	D
Henrik Jørgensen	Ministry of Environment and Food, Environmental Protection Agency (EPA)	DK
Peter Körber	Environmental authority of the free Hanseatic city of Hamburg (BUE), National Park Administration Hamburg	D
Ellen Kuipers	Waddenvereniging	NL
Ester Kuppen	Waddenvereniging	NL
Jantsje van Loon	Wageningen University and Research	NL
Soledad Luna	CWSS (and breakout group facilitator)	trilateral
Harald Marencic*	CWSS	trilateral
Detlev Metzing	Bundesamt für Naturschutz (BfN)	D
Heidi Nielsen	Ministry of Environment and Food, Environmental Protection Agency (EPA)	DK
Albert Oost	Deltares	NL
Katja Philippart	Royal Netherlands Institute for Sea Research (NIOZ)/Waddenacademie	NL
Hans Ulrich Rösner	World Wide Fund for Nature (WWF)	D
Hein Sas	Programma naar een Rijke Waddenzee (PRW)	NL
Gregor Scheiffarth	National Park Authority Lower Saxony	D
Wim Schoorlemmer	Ministry of Agriculture, Nature and Food Quality/Programma naar een Rijke Waddenzee	NL
Anne Sell	Thünen-Institute of Sea Fisheries	D
Carlo Sass Sørensen	Ministry of Environment and Food, Danish Coastal Authority	DK
Manfred Vollmer	Wadden Sea Forum (WSF)	D
Annkatrin Weber	Note-taker - World Wide Fund for Nature (WWF)	D
Karen Wiltshire	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)	D
Christian Winter	Christian-Albrechts-University Kiel	D
Robert Zijlstra*	RWS	trilateral

Annex 6: Acronyms and glossary

AU	Australia
BfN	German Federal Agency for Nature Conservation
CVI	Climate Vulnerability Index
D	Germany
DK	Denmark
EG-C	Expert Group-Climate Change Adaptation
IPCC	Intergovernmental Panel on Climate Change
KNMI	Koninklijk Nederlands Meteorologisch Instituut
MHW	Marine Heat Waves
NL	Netherlands
OUV	Outstanding Universal Value
PKB-Wadden Sea	Dutch Key-planning-decision document Wadden Sea
QSR	Quality Status Report
RPC	Representative Concentration Pathways
RWS	Rijkswaterstaat (Netherlands)
SLR	Sea Level Rise
SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate
TG-WH	Task Group-World Heritage
TWSC	Trilateral Wadden Sea Cooperation
UNESCO	United Nations Educational, Scientific and Cultural Organization
WSB	Wadden Sea Board
WSP	Wadden Sea Plan
WWF	World Wide Fund for Nature