Regional Organization for the Protection of the Marine Environment (ROPME)

ROPME Marine Climate Change Risk Assessment Report

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Regional Organization for the Protection of the Marine Environment (ROPME)

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This Report provides a risk assessment of the anticipated impacts of climate change on marine and coastal ecosystems, coastal communities and industry in the ROPME Sea Area, which encompasses the territorial waters of the eight Member States of ROPME: Kingdom of Bahrain, Islamic Republic of Iran, Republic of Iraq, State of Kuwait, Sultanate of Oman, State of Qatar, Kingdom of Saudi Arabia and the United Arab Emirates.

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Executive Summary

- Climate change is increasingly affecting the ROPME Sea Area (RSA). In order to assist adaptation planning in the Region it is important to identify the priority climate risks. This report presents the outcome of a Risk Assessment exercise involving Regional technical experts to identify, score and prioritise marine climate change risks to the RSA.

- Two risk themes were considered: 'Risks to biodiversity and habitats' and 'Risks to Economy and Society'. The risks were individually scored based on the proximity of the risk (i.e. the time horizon when impacts are anticipated to be felt) and magnitude of the risk from an overall ecological, social and economic perspective. A total of 45 risks were identified, with 23 biodiversity risks and 22 social and economic risks.

- 'Severe' risks included impacts on coral reef associated communities, Harmful Algal Blooms and flooding of coastal areas and infrastructure from storm events and sea-level rise, impacts to maritime operations and workers' safety, and impacts on desalination facilities. The outcome of the Risk Assessment exercise is presented in the table below.

- Out of the 45 risks that were assessed, 13 were considered 'Severe' and therefore are a high priority for future adaptation planning within the Region. Many of the risks identified were transboundary in nature, highlighting the importance of conducting a Risk Assessment at the Regional scale, and the need for holistic approaches to manage their impacts.

- The Risk Assessment was conducted as part of the ROPME Marine Climate Change - Risk Assessment, Adaptation and Mitigation Regional Action Plan. The intention is that this work will support ROPME Member States' in their climate change adaptation planning.

Ranked combined risks for the RSA.

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Changes in coral reef associated communities	4	3	100	Severe	High
Increased incidence of harmful algal blooms (HABs) and nuisance species	4	3	100	Severe	Medium
Impacts on coastal communities	3	3	75	Severe	High
Changes in wild-capture fisheries resources	3	3	75	Severe	High
Flooding impacts on coastal industries and infrastructure	3	3	75	Severe	High
Impacts on desalination plants	3	3	75	Severe	High
Non-flooding related impacts on coastal industries and infrastructure	3	3	75	Severe	Medium
Impacts on operations, safety and movement of goods in the maritime transport sector	3	3	75	Severe	Medium
Changes to phytoplankton primary production	4	2	67	Severe	High
Changes in corals (cover, distribution and health)	4	2	67	Severe	High
Change in jellyfish/gelatinous plankton outbreaks	4	2	67	Severe	Medium
Changes in benthic invertebrates (abundance and distribution)	4	2	67	Severe	Medium
Changes in pelagic fish (abundance and distribution)	4	2	67	Severe	Low
Changes in dugong (abundance and distribution)	3	2	50	Moderate	Medium
Changes in demersal fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in sea turtles (abundance, distribution and nesting sites)	3	2	50	Moderate	High
Changes in seabirds (abundance, distribution and nesting sites)	3	2	50	Moderate	Low
Changes in waterbirds (abundance, distribution, nesting sites, feeding and overwintering sites)	3	2	50	Moderate	Medium
Changes in mangrove forests	3	2	50	Moderate	Low

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Changes to rocky shores	3	2	50	Moderate	Medium
Changes to deep sea habitats (>200m)	3	2	50	Moderate	Medium
Impacts on fishing communities, infrastructure and operations	3	2	50	Moderate	High
Impacts on oil and gas offshore industries infrastructure and operations	2	3	50	Moderate	Low
Impacts on the provision of natural coastal protection	3	2	50	Moderate	Medium
Changes in aquaculture resources, infrastructure and supply chain	2	2	33	Moderate	Low
Impacts on coastal tourism infrastructure, resorts and facilities	2	2	33	Moderate	High
Impacts on pearl oysters	2	2	33	Moderate	Low
Impacts on human health from the marine environment	2	2	33	Moderate	Low
Changes to non-gelatinous zooplankton	4	1	33	Moderate	Low
Changes to microbial communities	4	1	33	Moderate	Low
Changes in saltmarshes, mudflats and Sabkhas	2	2	33	Moderate	Low
Changes to macroalgal beds	2	2	33	Moderate	Low
Changes in seagrass meadows	3	1	25	Moderate	Low
Changes to sandy beaches	3	1	25	Moderate	Low
Impacts on coastal and marine recreational activities	3	1	25	Moderate	High
Impacts on cultural heritage and historic sites	3	1	25	Moderate	Low
Impacts on the provision of natural climate regulation services	3	1	25	Moderate	Low
Changes in cetaceans (abundance and distribution)	2	1	17	Low	Medium
Spread of alien invasive species (AIS)	2	1	17	Low	Medium
Impacts to onshore, nearshore and offshore marine renewable energy (wind, waves, tides)	2	1	17	Low	Low
Impacts on freshwater availability and quality from groundwater sources	2	1	17	Low	Low

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Impacts on aggregate extraction operations	2	1	17	Low	Low
Impacts on the provision of natural waste breakdown and detoxification	2	1	17	Low	Low
Loss of education and research value from the marine environment	1	1	8	Low	Low
Loss of future use value of genetic and biological resources	1	1	8	Low	Low

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1. Introduction

Climate change is increasingly impacting the marine and coastal environment of the ROPME Sea Area (RSA: Box 1), with consequences for biodiversity and society. Physical changes have already been observed, including increasing sea temperatures and salinity within the Inner RSA (I-RSA), and decreasing oxygen levels within the Middle and Outer RSA (M-RSA and O-RSA). These changes in marine climate have led to impacts on biodiversity and ecosystems throughout the Region, such as bleaching events in coral reefs, altered fish abundances and apparent increases in Harmful Algal Blooms. These changes have important consequences for society, including the operation of coastal and maritime industries, food security and direct threats to human health. Future projections show that climate change will continue to affect the seas and coasts of the RSA, including warming sea temperatures, increased salinity and acidification, further declines in oxygen levels, rising sea level and the potential for storm events to become more frequent and severe.

Given the extent of current and future impacts climate change will have within the Region, anticipating the risks climate change presents is critical for informing adaptation planning. This enables negative outcomes to be mitigated, and potential opportunities embraced. Risk assessments apply a coherent and consistent approach to assess how near, and severe, climate change risks to biodiversity, ecosystems, industries and communities could be. Examples of climate change risk assessments exist for many countries around the world, including the United Kingdom (UK) and United Arab Emirates (UAE) (CCC, 2017; MOCCAE, 2019). As well as informing national adaptation programmes, risk assessment outcomes can also be used to support International reporting requirements, such as Nationally Determined Contributions (NDCs) under the United Nations Framework Convention on Climate Change (UNFCCC).

This Marine Climate Change Risk Assessment forms an integral part of the ROPME 'Regional Marine Climate Change Adaptation and Mitigation Strategy' programme that was launched in the RSA in 2019. The Risk Assessment presented is conducted at a Regional level, highlighting the point that common and prioritised risks are likely to be shared by multiple countries. The risks are informed by a comprehensive Marine Climate Change Impacts Evidence Report undertaken as part of this programme (Lincoln et al., 2020), and an expert workshop held in Muscat in November 2019 to identify and prioritise risks. This report summaries the risks from marine climate change identified through this process and focuses on two main themes: 'Risks to Biodiversity and Habitats' and 'Risks to Economy and Society'. It also highlights where actions may be required to support the Region and individual countries in their adaptation planning.

Box 1: The ROPME Sea Area (RSA)

The RSA encompasses the territorial waters of the eight Member States of ROPME: Kingdom of Bahrain, Islamic Republic of Iran, Republic of Iraq, State of Kuwait, Sultanate of Oman, State of Qatar, Kingdom of Saudi Arabia and the United Arab Emirates.

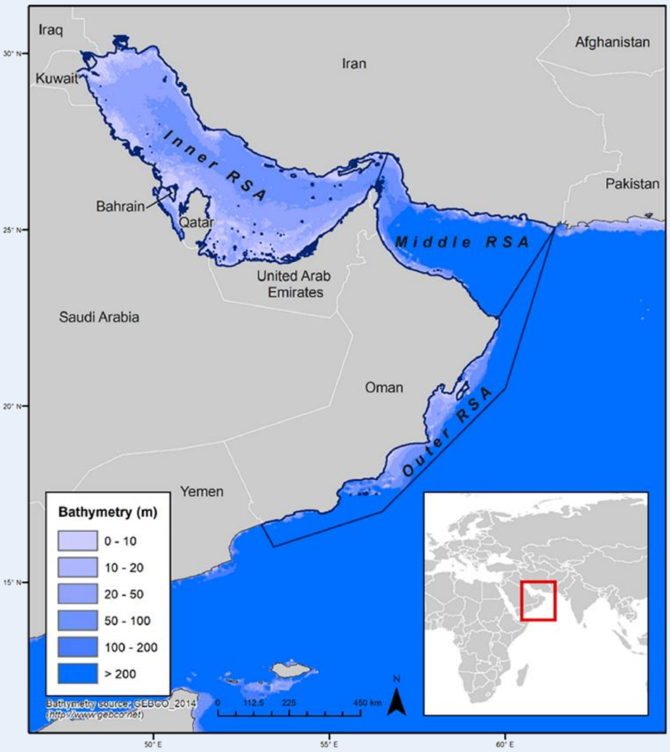

Figure 1: Geographical divisions and coverage of the ROPME Sea Area (RSA). The RSA is comprised of three geographically and environmentally distinct parts: the Inner RSA, Middle RSA and Outer RSA.

The RSA can be divided into three distinct zones (Figure 1), which vary in terms of their physical characteristics and the diminishing influence of the Indian monsoon moving from the Outer to the Inner ROPME Sea Area.

The Inner RSA (I-RSA) is a shallow, semi enclosed sea with an average depth of 38 m. The profile of the seafloor across the I-RSA is asymmetrical, with shallower slopes on the southwest shore and steeper slopes alongside the coast of Iran. Sea surface temperature and salinity vary significantly by location and season. Average sea surface temperatures range from 13 to 35°C and salinity from 36 to 70 psu.

The Middle RSA (M-RSA) is a deep 'arm' that extends for almost 400 km and connects the Indian Ocean with the I-RSA through the shallow and narrow Strait of Hormuz. It is partially affected by the northern Indian Ocean monsoons, but the effect diminishes with increasing distance from the Indian Ocean. Average sea surface temperatures range from 22 to 32°C.

The Outer RSA (O-RSA) is in the northern part of the Indian Ocean and has a monsoonal climate. The summer monsoon (June to September) produces strong seasonal upwelling events along the southeast coast of the Arabian Peninsula. Average sea surface temperatures range from 22 to 26°C. Water depth reaches more than 1000 m on the oceanic fringe of the O-RSA.

2. Methodology

This Risk Assessment focused specifically on the risks associated with climate change impacts on the marine and coastal environment. In some instances, terrestrial drivers were considered but only if they were thought to pose significant challenges and impacts to the marine environment or dependent industries and communities. For example, this included dust storms and shamal winds.

The approach for this Risk Assessment was informed by the Climate Change Risk Assessment methodology used for the United Kingdom, now in its third round of reporting, and a similar exercise in the United Arab Emirates (CCC, 2017; Warren *et al*., 2018; MOCCAE, 2019).

The risk assessment exercise involves identifying, scoring, and prioritising risks associated with climate change. Unlike the national approaches used elsewhere, this Risk Assessment considered risks to the whole RSA. This provides a useful baseline of common risks that occur throughout the Region, recognising the transboundary nature of marine climate change impacts and the need for adaptation strategies to consider this in their planning. This Risk Assessment forms an initial baseline that can be updated and revised at both a Regional and national level to inform future decision-making.

A long-list of risks was initially identified from evidence presented in the Marine Climate Change Impacts Evidence Report (Lincoln et al., 2020) that underpins this assessment. This long-list covered two main themes: 'Risks to Biodiversity and Habitats' and 'Risks to Economy and Society' and formed the basis for discussions at a risk assessment workshop of invited Regional experts held in Muscat, Oman on 12th-14th November 2019. This was hosted by MECA and organised by the ROPME Secretariat, with Cefas providing technical support and workshop facilitation.

2.1 Workshop and Risk Assessment Methodology

Cefas and ROPME identified a range of technical experts from across the RSA to support the risk assessment workshop. Sixteen experts attended the workshop, who had good representation from across the biodiversity and societal themes. The workshop had two key objectives:

1) Review the current long-list of risks, considering whether:
   a. All the specific climate drivers relevant to the Region were identified.
   b. Any risks were missing or whether any existing risks needed to be amended.
   c. Whether all relevant climate drivers affecting each risk had been considered.

2) Score the risk level associated with each risk as a function of its:
   a. Proximity (in time) of occurrence.
   b. Magnitude of the effect.

Initially all participants worked together to discuss the long-list of pre-identified risks and the climate change drivers shown below. Participants were then split into two groups, based on their specific expertise, to refine, score and prioritise risks under the biodiversity and societal themes. Finally, the two groups reviewed all risk scores in plenary.

To mitigate potential issues of subjectivity when scoring, the following actions were taken:

- Identifying other sources of evidence that may not have been captured before the workshop, but which could be used to help inform risk scoring;
- Cross checking with the other group to ensure consistency in scoring across the two risk themes;
- Providing a confidence score for each risk, based on the level of evidence and scientific consensus;
- Critically evaluating the justifications for risk scoring in plenary.

Identifying risks

Initially all participants worked together to discuss the long-list of pre-identified risks that were developed from the evidence report. Additional risks were identified, merged or removed based on expert judgement, evidence available, and using other risk assessment frameworks to guide thinking and discussion (e.g. the UAE Climate Change Risk Assessment).

Identifying risk drivers

After risks were identified, the climate drivers for each risk were discussed and identified. All possible drivers were identified, and principal drivers highlighted. A brief description of these drivers is detailed below, but a full description can be found in the evidence report underpinning this Risk Assessment.

- Sea-level rise

There are few records of Regional sea-level change across the RSA. Based on seven tide gauge stations in the northwest of the I-RSA, an average relative sea-level rise of 2.2 mm per year is estimated for the period 1979–2007. For the M-RSA and O-RSA, estimates of change based on measurements in the wider Northern Indian Ocean are lower at around 1.29 mm. Sea-level rise projections for the RSA are limited, but the most recent estimates published by the IPCC in 2019 suggest a mean sea-level rise of 0.84m by 2100 under a high emission (RCP 8.5) scenario, with a likely range between 0.61 and 1.1 m (Oppenheimer *et al*, 2019).

- Changes in hydrodynamics / ocean circulation

Models project that changes in sea temperatures and rainfall along the coast of Iran will decrease the vertical overturning of the water column, causing an increase in the inflow of less dense waters from the M-RSA (AGEDI, 2015). Currents in the surface layer of the O-RSA are predominantly driven by seasonal changes in temperatures and winds, and as such any alterations caused by climate change to monsoon winds will have repercussions for these currents, in addition to upwelling of nutrient-rich cooler waters (AGEDI, 2015). Exact changes and directionality are difficult to project due to seasonal and interannual variability.

- Air and sea temperature (including humidity)

Sea and air temperatures have increased within the Region, with shallower sea areas warming faster than deeper waters. Estimates show that between 1982–2015 sea surface temperature (SST) in the I-RSA and M-RSA increased by 1°C (Noori *et al.,* 2019). IPCC projections suggest that under RCP8.5 by 2099, SST could increase by 2.8–4.26°C in the I-RSA and 2.5°C in the M and O-RSA relative to a 2005 baseline (Hoegh-Guldberg *et al.,* 2014). Marine heatwaves are also increasing in frequency across the globe (Hobday et al. 2016). Humidity can cause significant issues for biodiversity and humans, and projections suggest mean humidity could increase by 10% by 2060 in the I-RSA (AGEDI, 2015).

- Storms, cyclones, winds, waves and storm surges

Most cyclonic activity in the RSA occurs within the M-RSA and O-RSA, where on average one to two tropical cyclones form over the northern Indian Ocean each year (ROPME, 2013). From 1979 to 2008, a total of 41 cyclonic storms formed in the northern Indian Ocean, of which 23 made landfall. Future projections of tropical cyclones are uncertain but some projections indicate that a shift in locations of storms could lead to a significant increase in the number of tropical cyclones in the O-RSA by the end of this century (Murakami *et al.,* 2013). While the I-RSA is currently not affected by tropical cyclones to the same extent as the O-RSA and M-RSA, the I-RSA is still under the influence of storms and storm surges generated by the Shamal winds, particularly affecting southern shores (El-Sabh and Murty, 1989).

- pH

Few pH measurements exist for the RSA, however monitoring data from the south east of the I-RSA indicate an average annual pH of 8.22. For the M-RSA pH is influenced by seasonal upwelling, with a summer pH of 8.03 (east) and 8.06 (west) (Omer, 2010). In the O-RSA, pH varies strongly, and can range from 7.93 in the summer to 8.05-8.09 in winter. Current trends in pH are unclear, but models suggest that pH in the RSA could decrease by approximately 0.25 units for period of 2050–2099 relative to the average during 1956–2005.

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- Dust storms

In the I-RSA, shamal winds, which can generate storms and surge events and are also important for dust accumulation, appear to have increased since 2000. Dust storms have become more frequent and intense in the Middle East region generally. In the I-RSA, desertification, changes in Shamal winds or ocean circulation patterns could all affect levels of dust deposition in the coastal and marine environment.

- Salinity (including evaporation)

Patterns and drivers of seasonal variability in salinity differ across the Region. The salinity of surface waters in the I-RSA has increased by 0.5–1.0% over the past 60 years. It is generally expected that salinity will increase within the I-RSA, but changes will be less pronounced in the M and O-RSA, with some projections indicating slight declines by 2099.

- Dissolved Oxygen

More than 50% of the area of Oxygen Minimum Zones in the world's oceans occur in the RSA (Helly and Levin, 2004; Stramma *et al.,* 2010). Dissolved oxygen (DO) concentrations are declining in many parts of the RSA, particularly in the I-RSA. Global models (CMIP5) suggest strong declines in DO in the southwestern I-RSA, and in southern areas of the M-RSA and O-RSA, of between -9 to -12 mol m^{-3} in 2050–2099 relative to the average during 1956–2005.

- Changes in freshwater input

Changes in rainfall patterns are expected to occur in the future within the RSA, but will vary depending on subregion and season. Generally, declines in precipitation are expected north of the RSA, and increases expected in the south (Almazroui *et al.,* 2016; Collins *et al.,* 2013). Despite this broad north/south trend, recent downscaled projections for precipitation within the I-RSA suggest a slight increase in the north, and decreases in southern areas in 2080–2099 under RCP8.5 (AGEDI, 2015). Seasonally, IPCC projections for 2081–2100 under RCP8.5 for this Region suggest greatest increases in precipitation in Autumn months, by up to 40–50% across the M and O-RSA, with less change within the I-RSA. Summer months show some increases between 0–20%; winter months little change; and spring seeing possible declines between 0–20% across the Region (Collins *et al.*, 2013).

- Monsoon timing

The timing and strength of monsoons is expected to be impacted by climate change. Some projections for 2100 suggest a weakening in the Indian winter monsoon in the Arabian Sea, which may lead to reduced winter convective overturning in the northern Arabian Sea and affect rainfall patterns (Parvathi *et al.,* 2017). There are also suggestions that the summer monsoon winds may strengthen which can affect upwelling and plankton productivity (Goes *et al.*, 2005).

- Turbidity

Turbidity is not a direct climate change driver, but it is expected that this may be indirectly influenced by climate change into the future and result in impacts in the Region. For example, changes in storm events and hydrodynamics can influence sediment transport and could result in increased turbidity in localised areas and coastal waters. Increases in intense rainfall can increase surface run-off into coastal waters, whilst increased dust deposition in the water from dust storms may also increase turbidity.

- Erosion

While not a direct climate change driver in itself, other climate change drivers may influence erosion rates and therefore amplify ecological and socio-economic impacts. For example, climate driven changes in cyclones, wave patterns and sea-level rise may all result in erosion of beach areas or habitats such as seagrasses.

Risk scoring - Proximity

Risks were scored depending on the time horizon when substantial impacts are anticipated to be felt, and were scored between 1 and 4 (Table 1: Proximity scale used for scoring risks.). A higher score reflects a substantial impact occurring sooner.

Table 1: Proximity scale used for scoring risks.

PROXIMITY (TIME to consequence(s) occurring)	
Score	**Categories**
1	Over 50 years
2	Within next 50 years
3	Within next 20 years
4	Now

Risk scoring - Magnitude

Risks were also scored according to the overall magnitude of impacts occurring. Impacts were not scored individually in terms of environmental, economic, and social components, as was the case of the UK CCRA, but rather the overall magnitude across these themes was evaluated (Table 2 and Table 3).

Table 2: Magnitude scale used for scoring risks.

MAGNITUDE of impact(s)	
Score	**Categories**
1	Low
2	Medium
3	High

Table 3: Guidance for relative magnitude scoring.

Class	Economic	Environmental	Social
High	• Major and recurrent damage to property and infrastructure • Major consequence on Regional and national economies • Major cross-sector consequences • Major disruption or loss of national or International transport links • Major loss/gain of employment opportunities	• Major loss or decline in long-term quality of values species/habitat/ecosystem • Major or long-term decline in status/condition of sites of International/national importance • Widespread failure of ecosystem function or services • Widespread decline in air/water/land quality • Major cross-sector consequences *~ 5000 ha/ 50 km^2 lost/gained* *~ 10000 km^2 seawater quality affected*	• Potential for many fatalities or serious harm • Loss or major disruption to utilities (water/gas/electricity/desalination) • Major consequences on vulnerable groups • Increase in pressure on medical facilities • Large reductions in community services • Major damage or loss of cultural assets/high symbolic vale • Major role for emergency services • Major impacts on personal security, e.g. increased crime *~ million affected* *~ 1000s harmed* *~ 100 fatalities*
Medium	• Widespread damage to property and infrastructure • Influence on the Regional economy • Consequences on operations and service provision initiating contingency • Minor disruption of national transport links • Moderate cross-sector consequences • Moderate loss/gain of employment opportunities	• Important/medium-term consequences on species/habitat/ecosystem • Medium-term or moderate loss of quality/status sites of national importance • Regional decline in land/water/air quality • Medium-term or Regional loss/decline in ecosystem services • Moderate cross-sector consequences *~ 500 ha/ 5 km^2 lost/gained* *~ 1000 km^2 seawater quality affected*	• Significant numbers affected • Minor disruption to utilities (water/gas/electricity/desalination) • Increasing inequality, e.g. through rising costs of service provision • Consequence on health burden • Moderate reduction in community services • Moderate increased role for emergency services • Minor impacts on personal security *~ 100s thousands affected* *~ 100s harmed* *~ 10 fatalities*
Low	• Minor or very local consequences • No consequence on national or Regional economy • Localised disruption of transport	• Short-term/reversible effects on species/habitat/ecosystem services • Localised decline in land/water/air quality • Short-term loss/minor decline in quality/status of designated sites. *~ 50 ha/ 0.5 km^2 damaged/improved* *~ 100 km^2 seawater quality affected*	• Small numbers affected • Small reduction in community services • Within ‘coping range’ *~ 10s thousands affected*

Overall risk score

To generate an overall risk score, the magnitude and proximity scores were combined using the formula:

$$100 \times \left(\frac{Magnitude}{3}\right)\left(\frac{Proximity}{4}\right)$$

This provides a lowest possible score of 8.3 (low magnitude impacts in over 50 years), and a highest possible score of 100 (high magnitude impacts happening now). Scores were categorised as severe, moderate or low (Table 4)

Table 4: Overall risk scores and categories.

Combined overall risk score	Risk Category
100	Severe
75	
67	
50	Moderate
33	
25	
17	Low
8	

Acknowledging that this is a Regional Risk Assessment, there were instances where identified risks were more relevant to particular sub-regions. As such, where the magnitude or timing of a risk could be differentiated at a sub-regional level (I, M and O-RSA), scoring was also provided at this level.

Confidence and uncertainty

In addition to scores of proximity and magnitude, risks were also given a confidence rating to reflect the amount of supporting evidence and level of agreement across this evidence. The confidence levels were based on the model used by the Intergovernmental Panel on Climate Change (IPCC) (Cubasch *et al*., 2013). Figure 2 shows the confidence scale, with an overall score of high, medium or low provided.

Figure 2: IPCC matrix for qualitative confidence scoring.

Risk Prioritisation

The biodiversity and society theme groups scored and then ranked all of their identified risks at a Regional level (Table 5 and Table 6), and where appropriate, a sub-regional level (Appendix). Risks were then combined into one overall list in plenary, with both groups present (see executive summary).

Risk Reporting

This report presents the results of this Risk Assessment exercise, with biodiversity covered first, followed by the societal theme. Under each theme, a one-page summary is provided for each risk, ordered according to the ranking exercise. Each summary includes a short risk description, relevant climate drivers, risk score and confidence level. Climate drivers are shown as icons, with red outlines highlighting the principal driver(s) for each risk. Additional evidence underpinning these risk descriptions is drawn from the ROPME Marine Climate Change Impacts Evidence Report (Lincoln *et al*., 2020).

3. Biodiversity risks

A total of 23 biodiversity risks were identified, covering a range of species and habitats across the Region (Table 5). The highest scoring risks focused on changes in coral reef associated communities (such as reef fish or corals) and occurrence of Harmful Algal Blooms (HABs). A total of 7 risks were categorised as severe and are therefore considered high priority risks. Many of these risks, while having significant implications for marine ecosystems in the Region, will also likely have considerable social and economic impacts for those reliant on these resources and systems. A breakdown of risks for each RSA sub-region can be found in the Appendix (Table A 1, Table A 2 and Table A 3).

Table 5: Ranked Biodiversity Risks for the RSA

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Changes in coral reef associated communities	4	3	100	Severe	High
Increased incidence of harmful algal blooms (HABs) and nuisance species	4	3	100	Severe	Medium
Changes to phytoplankton primary production	4	2	67	Severe	High
Changes in corals (cover, distribution and health)	4	2	67	Severe	High
Change in jellyfish/gelatinous plankton outbreaks	4	2	67	Severe	Medium
Changes in benthic invertebrates (abundance and distribution)	4	2	67	Severe	Medium
Changes in pelagic fish (abundance and distribution)	4	2	67	Severe	Low
Changes in dugong (abundance and distribution)	3	2	50	Moderate	Medium
Changes in demersal fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in sea turtles (abundance, distribution and nesting sites)	3	2	50	Moderate	High
Changes in seabirds (abundance, distribution and nesting sites)	3	2	50	Moderate	Low
Changes in waterbirds (abundance, distribution, nesting sites, feeding and overwintering sites)	3	2	50	Moderate	Medium
Changes in mangrove forests	3	2	50	Moderate	Low
Changes to rocky shores	3	2	50	Moderate	Medium
Changes to deep sea habitats (>200m)	3	2	50	Moderate	Medium
Changes to non-gelatinous zooplankton	4	1	33	Moderate	Low
Changes to microbial communities	4	1	33	Moderate	Low
Changes in saltmarshes, mudflats and Sabkhas	2	2	33	Moderate	Low
Changes to macroalgal beds	2	2	33	Moderate	Low
Changes in seagrass meadows	3	1	25	Moderate	Low
Changes to sandy beaches	3	1	25	Moderate	Low
Changes in cetaceans (abundance and distribution)	2	1	17	Low	Medium
Spread of alien invasive species (AIS)	2	1	17	Low	Medium

SEVERE

Risk: Changes in coral reef associated communities

Climate-driven impacts on the cover, distribution and health of coral reef species (as outlined in Risk: Changes in coral species) have implications for the communities of fish and invertebrates that are associated with reef systems, as well as wider ecosystem services provided by reef systems, such as coastal protection and fisheries. Coral bleaching can result in declines in abundance of fish and invertebrate species, reduced diversity of communities and changes in species compositions. Increases in algal cover over reefs may result from reduced diversity of fish assemblages and a proliferation of herbivorous species. Changes in coral cover and distribution may lead to loss of suitable habitats for species which depend on these areas for food, shelter and breeding. Loss of habitat complexity can also affect predator-prey dynamics within marine foodwebs, with some species becoming more vulnerable to predators. Impacts will vary Regionally depending on current diversity and distribution patterns across the RSA. Other key climate-drivers affecting these communities, in addition to temperature rise, include ocean acidification, declining oxygen levels and increased turbidity. Wider impacts on coral reef communities are discussed further in related biodiversity risks.

Climate change drivers

Risk score

In the I-RSA, evidence shows that there is widespread coral bleaching and mortality linked to climate change. In the M-RSA, there is also evidence of changes and decline of coral reefs, but the link to climate is less clear. In the O-RSA, storm damage has caused substantial and long-lasting structural damage to reefs and therefore the proximity score is high. Many reefs in the O-RSA are unique due to high proportions of endemism of coral and fish species, and because they occur in combination with macroalgae due to the seasonal influence of the monsoon-driven upwelling. Therefore, a high magnitude is also given for this sub-region.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	4	3	4
Magnitude	3	3	2	3
Overall	100	100	50	100

Confidence

High (High agreement/ High evidence)

There is a wealth of robust scientific evidence that shows climate change is a major contributing factor to coral decline in the RSA, and the communities they support.

SEVERE

Risk: Increased incidence of harmful algal blooms (HABs) and nuisance species

Mass algal blooms are commonplace in the RSA and they appear to have become more extensive and persistent under the effect of climate change, although the links are not yet well understood. Algal blooms can cause serious disruption, depending on the species and the scale of the bloom, resulting in hypoxic conditions and in some cases leading to fish and coral mass mortality. Some blooms contain toxins presenting a direct threat to human health if they enter the food chain or the water supply. HABs can also produce nuisance smells, affecting people living or working at the coast.

Research in the RSA indicates that changes in the hydrodynamic conditions, resuspension of nutrients caused by storms and high wind, and warming temperatures create favourable conditions for the onset and spread of HABs. The relative influence of these drivers may differ across the RSA subregions. It is also possible that increasing deposition of airborne dust may stimulate the growth of certain toxic algal species over non-toxic species, but further research is needed to understand this link.

Climate change drivers

Risk score

Higher magnitude scores were given to the I-RSA and M-RSA due to apparent greater frequency, scale and persistence of blooms in these areas compared to the O-RSA.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	4	4	4
Magnitude	3	3	3	1
Overall	100	100	100	33

Confidence

Medium (Medium agreement/ Medium evidence)

Much of the evidence on nuisance and harmful algal blooms in the RSA is based on very localised studies. There is also some uncertainty and disagreement regarding the causes of these blooms, with some studies suggesting that the apparent increase in the incidence of these blooms in recent years may be partly due to improved detection and reporting of these events.

SEVERE

Risk: Changes in phytoplankton primary production

Climate change in the RSA appears to be driving changes in phytoplankton biomass and productivity, although these changes differ across the RSA. Decreases in phytoplankton species diversity and phytoplankton community composition have been observed in recent decades, particularly in the I-RSA. Warming of air and sea temperatures causing increased stratification of the water column and changes to the freshwater input in the I-RSA alter the hydrodynamic and circulation patterns of the RSA. Changes in the onset timing of the large-scale phytoplankton blooms are occurring in the O-RSA that appear to be driven by changes in the timing and intensity of the monsoon winds. These changes have potential major repercussions for marine foodwebs and ecosystems due to the important role of primary production in underpinning these systems. Socio-economic impacts may also arise. For example, reduced primary productivity could lead to declines in recruitment of finfish species and altered spatial distribution of some stocks, resulting in decreases in commercial fishery landings.

Climate change drivers

Risk score

Changes to phytoplankton composition, biomass and productivity are happening already. The magnitude of these changes is relatively higher in the I-RSA due to its enclosed nature, additional influence of thermal and saline stratification and changes in freshwater influx from rivers such as the Shatt al-Arab. The changes in the M-RSA and in the O-RSA are currently less pronounced and the link to the monsoon and how the monsoon system itself is influenced by climate change is also less well understood.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	4	4	3
Magnitude	2	3	2	2
Overall	67	100	67	50

Confidence

High (High agreement/ Medium evidence)

There is high agreement and consensus in terms of climate change driving changes in phytoplankton primary production in the RSA, particularly for changes observed in the I-RSA and the links to changes in the hydrodynamic circulation of this sub-region. More evidence is needed to better understand the influence of climate change in the Indian Ocean monsoon system and the effect on the timing and intensity of the seasonal phytoplankton blooms in the O-RSA.

SEVERE

Risk: Changes in coral species (cover, distribution and health)

Evidence indicates significant and widespread declines in coral cover and health throughout the RSA, driven by climate change and human disturbances such as pollution and coastal developments. Many climate drivers affect the cover, distribution and health of coral species throughout the RSA Increased sea temperatures and marine heatwave events can cause extensive coral bleaching, resulting in mass mortality of corals and loss of cover. Extreme weather events and storm surges can affect corals by damaging structures and causing mortality of species and reduced cover. Flooding from extreme rainfall and storm surges can also result in runoff of silty, nutrient-loaded freshwater resulting in sedimentation and smothering of corals, and increased turbidity. Dust storms can also deposit high loads of particles into surface water, causing prolonged turbidity and reducing the amount of light that reaches the coral. Declines in dissolved oxygen and Harmful Algal Bloom events can affect the productivity and calcification of coral species, leading to impacts on coral health, cover and distributions. Ocean acidification can affect calcification of coral species, leading to declines in coral cover and overall health. Levels of impact vary depending on where corals are located and the extent of additional human pressures. For example, some patches of relatively healthier corals can be found in offshore shoals and fringing reefs in the M-RSA due to lower human impacts in these areas.

Climate change drivers

Risk score

The overall proximity score for the RSA is high, but not all subregions are affected to the same extent and the principal climatic drivers differ. The proximity and magnitude scores are high for the I-RSA. In the M-RSA and O-RSA, magnitude is low as corals appear to have been relatively protected from climate-driven changes.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	4	3	3
Magnitude	2	3	1	1
Overall	67	100	25	25

Confidence

High (High agreement/ High evidence)

There is a wealth of robust scientific evidence that shows climate change is contributing to the decline of the RSA corals, and there is a high level of agreement on the nature of these impacts. However, more studies are needed to better understand the response of corals to ocean acidification, so that this risk can be better evaluated across the RSA.

SEVERE

Risk: Changes in jellyfish/gelatinous plankton outbreaks

Outbreaks of jellyfish, as well as other gelatinous plankton, are being increasingly documented across the RSA. These events can result in large scale accumulations of jelly carcases and detritus over the seafloor, disturbing deep-sea sediments across vast areas of the continental shelf, continental slope and beyond, with implications for organic carbon fluxes. In other cases, jellyfish swarm towards the coast and cause serious disruptions and damage to the water intakes of installations such as desalination and energy plants.

Some evidence suggests jellyfish outbreaks may be linked to climate change. Low oxygen (particularly for the deeper-waters in the M-RSA and O-RSA, and shallow water areas of the I-RSA), increased salinity and increasing temperatures can result in increased outbreaks. Climate change may also have indirect effects on increased jellyfish outbreaks due to changes in top-down trophic control by marine turtles and other predators, due to changes in the abundance or distribution of those groups.

Climate change drivers

Risk score

In the I-RSA, jellyfish outbreaks are becoming increasingly frequent but tend to be relatively localised and differ in scale. In the M-RSA outbreaks are increasing but are less common compared to the I-RSA, and the increases observed so far have been determined from zooplankton counts. In the O-RSA the occurrence of jellyfish outbreaks is more sporadic and therefore the risk lower compared to the I-RSA and M-RSA.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	3	4	3
Magnitude	2	2	2	1
Overall	67	50	67	25

Confidence

Medium (High agreement/ Low evidence)

There is high agreement that jellyfish outbreaks are increasing within the Region, but low evidence currently on the links to climate change.

SEVERE

Risk: Changes in benthic invertebrates (abundance and distribution)

This risk includes benthic invertebrates such as shrimp, abalone, oysters and sea cucumbers, as well as biofouling organisms that colonise submerged man-made surfaces in shallow marine areas, such as barnacles and some molluscs. A wide range of climate drivers will affect species distribution and abundance, depending on the type of species, their distance from the shore and the depths they are found at.

Increased temperatures may affect the cover and composition of biofouling communities, with some observations suggesting increased cover under warmer conditions. Ocean acidification may negatively affect invertebrate abundances, and can also affect shell formation of certain calcifying species. Declining oxygen could also limit reproductive outputs of invertebrates, leading to declining abundances. Those within intertidal ranges will also be affected by sea-level rise and the disturbances caused by strong waves, storms and cyclones, including scouring, sedimentation and turbid water conditions. In some cases, storm events could also lead to mortality events. Certain species like the sea cucumber are closely linked to monsoon seasonality and it is likely their abundance and/or distribution may be affected by changes in the duration and or intensity of the monsoon.

Climate change drivers

Risk score

Impacts on benthic invertebrate communities appear to be more important in the M-RSA and O-RSA sub-regions. However, this could reflect a lack of evidence, and or that baseline conditions have already shifted, so any recent changes in the community composition in the I-RSA has not been noticed.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	3	4	4
Magnitude	2	2	2	2
Overall	67	50	67	67

Confidence

Medium (Medium agreement/ Medium evidence)

Overall confidence is medium, based on current understanding of the links between climate change and benthic communities. There are some monitoring stations within the Region helping to document changes, particularly for shrimp and bivalves such as the pearl oyster.

SEVERE

Risk: Changes in pelagic fish (abundance and distribution)

Changes in the abundance and distribution of pelagic fish species (e.g. tunas in the O-RSA and M-RSA, and mackerel and sardine in the I-RSA) have been observed across the RSA. Modelling studies predict declines in the abundance of some species, particularly within the I-RSA due to its enclosed nature. In some cases, these declines may result in local extinctions. Altered abundance and distributions, particularly of small pelagic species, could have implications for marine mammals such as dolphins.

The drivers behind these changes vary with the subregion. Increasingly extreme conditions (rising temperature and declining oxygen) in the I-RSA and an apparent rise of the thermocline within the water column could lead to mass fish kills and affect the distribution of certain species due to their tendency to shoal in deeper waters as a stress response. Changes in hydrodynamic circulation, salinity and freshwater input may also influence certain species, particularly within the I-RSA, but evidence is limited regarding specific impacts. In the O-RSA and M-RSA, decreasing concentration of dissolved oxygen and changes in the monsoon timing and strength, which alters the Region's hydrodynamic circulation, can also affect abundance and distribution of pelagic fish populations.

Climate change drivers

Risk score

The currently observed changes in pelagic fish species in the RSA, as well as fish kill events suggest climate change impacts are happening now, with moderate effects across the Region.

Scoring	**Whole RSA**	**Inner-RSA**	**Mid-RSA**	**Outer-RSA**
Proximity	4	3	4	4
Magnitude	2	2	2	2
Overall	67	50	67	67

Confidence

Low (Medium agreement/ Low evidence)

There is currently limited evidence, particularly at the sub-regional and local level, regarding how climate change is impacting pelagic fish abundances and distribution, and the magnitude of resulting impacts.

MODERATE

Risk: Changes in dugong (abundance and distribution)

The I-RSA hosts the second largest population of dugong in the world, after Australia, and they are listed as a vulnerable species on the IUCN Red List. Climate change can affect dugongs directly, for example, by causing a higher incidence of parasites and pathogens. However, most effects are likely to be indirect through climate effects on the seagrass meadows where dugongs feed and shelter. Increases in salinity and temperature, changing water circulation and freshwater inputs, and extreme events such as cyclones and heatwaves can affect seagrass growth, distribution and cover. This can have negative indirect impacts on dugong distribution and abundance. In some areas, seagrass growth may be favoured by increasing CO_2 levels (see Risk: Changes in seagrass meadows), which could positively impact dugongs, but this remains uncertain. Dugongs are also known to move in response to changes in the water temperature, for example by aggregating in areas near thermal springs in winter. Dugong health can be affected by parasitic diseases, which could increase in prevalence within the Region under warmer seas, but currently there is limited evidence for how host-parasite relationships will be affected by climate change.

Climate change drivers

Risk score

Changes in dugong populations are already being observed in Bahrain, Qatar and UAE, which may in part be linked to climate change. As part of the compilation of Bahrain's marine atlas, declines have been observed from 1984 onwards linked to declines in food and habitat. Dugong presence outside the I-RSA appears negligible.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	4	N/A	N/A
Magnitude	2	3	N/A	N/A
Overall	50	100	N/A	N/A

Confidence

Medium (Medium agreement/ Medium evidence)

There are some studies from elsewhere documenting climate impacts on dugongs (i.e. Australia) but more evidence is needed for populations within the RSA to determine climate impacts on these species. Modelling studies for the Region have projected changes in habitat suitability but there is only medium agreement among them regarding whether habitat suitability will decline or remain stable into the future.

MODERATE

Risk: Changes in demersal fish (abundance and distribution)

Demersal fish species live on or near the sea-floor and tend to have lower dispersion and spatial ranges compared to pelagic species. This makes them more vulnerable to climate change effects. Currently there is difficulty in determining climate-driven changes in abundance and distributions of these species compared to other drivers such as overexploitation, particularly in the M-RSA and O-RSA where there are a range of compounding effects. Increased water temperatures and reduced oxygen levels are expected to negatively affect demersal species, leading to possible declines in abundance and effects on growth. Some species may shift distribution, but may be limited in their ability to adapt due to their reliance on specific habitats. Due to their high commercial importance, further declines could impact fisheries through reduced habitat extent and productivity. Other climate drivers that may directly or indirectly influence species include ocean acidification, storms and cyclones, changes to monsoon timing and overall changes in hydrodynamic circulation across the Region. However, understanding of these climatic influences is currently lacking.

Climate change drivers

Risk score

Changes have already been observed in demersal stocks, although it is not clear the extent to which these are climate-driven. Magnitude is expected to increase considerably within the next 20 years.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	3	3
Magnitude	2	2	2	2
Overall	50	50	50	50

Confidence

Low (Medium agreement/ Low evidence)

There is currently limited evidence regarding the effects of climate change on demersal species when placed in the context of other pressures such as commercial exploitation.

MODERATE

Risk: Changes in sea turtles (abundance, distribution and nesting sites)

There are a range of turtle species present in the RSA, most of which are highlighted in the 2019 IUCN Red List of Threatened Species. Climate change poses risks to turtles in multiple ways. Green and Hawksbill turtles may experience severe loss in habitat suitability, particularly within the I-RSA due to increases in sea temperatures and salinity. The migratory nature of species may increase their resilience in the short term, but continued temperature increases may force longer term migrations to the deeper, cooler waters of the M-RSA. Climate impacts on seagrasses, which are an important food source for some turtles, may indirectly affect turtle abundance or distribution. Sea-level rise and beach erosion pose significant threats to nesting site access and integrity, causing short term damage, and the potential for permanent inundation at some sites. In the I-RSA in particular, increasing air temperatures will have a significant negative effect on the sex ratio of turtle embryos, leading to population level effects. Climate impacts must also be considered alongside wider human pressures such as coastal squeeze and habitat loss, which may act synergistically to affect turtles.

Climate change drivers

Risk score

Proximity scores took account of the threatened status of turtle species in the RSA, and some observations that suggest climate change is impacting negatively on turtles and their nesting sites. Magnitude was ranked as high in the O-RSA due to the high risk of coastal erosion and beach instability on some existing populations of green and hawksbill turtles.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	3	3
Magnitude	2	2	2	3
Overall	50	50	50	75

Confidence

High (High agreement/ Medium evidence)

Local studies are still lacking, limiting understanding of how climate change will affect turtles within the Region. However, studies outside of the RSA broadly agree on the mechanisms of climate change impacts on marine turtles, and therefore overall confidence is high.

MODERATE

Risk: Changes in seabirds (abundance, distribution and nesting sites)

The RSA is recognised as being of International important for migrant and breeding seabirds. These seabird populations depend on freshwater and salt marshes, mangroves, coral islands and intertidal mudflats. Offshore coral islands also provide nesting grounds for numerous colonies of seabirds, such as terns, and the Socotra Cormorant, which are listed as vulnerable on the IUCN red list. Storms and cyclones as well as coastal erosion can have significant, immediate impacts on coastal nesting sites, damaging nests and wider nesting grounds. Sea-level rise can cause inundation of key habitats such as saltmarshes and mudflats, affecting seabirds' access to food supplies and nesting areas. Additionally, erosion can further limit availability of coastal habitats available to birds, with potential negative impacts on species abundance. Changes to hydrodynamics and increased sea temperatures can all have an indirect but significant effect on seabird populations through impacts on prey species. Altered turbidity can affect the foraging behaviour of some species, meaning seabirds have to shift foraging sites. These climate impacts are expected to result in declines of some seabird species within the area, as has been documented in seabird populations around the world. Additional pressures such as coastal squeeze through coastal developments may further impact these populations.

Climate change drivers

Risk score

The I-RSA provides widespread habitat for seabirds, with many populations foraging and breeding there. The presence of Socotra cormorant in the O-RSA, and its threatened status, was taken into account when scoring magnitude. Within the M-RSA most seabird nesting sites are located on offshore coral islands, which may be less prone to future inundation, so a lower magnitude score was given here.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	3	3
Magnitude	2	2	1	2
Overall	50	50	25	50

Confidence

Low (Medium agreement/ Low evidence)

Evidence from elsewhere suggests that climate change can be one of the main causes of seabird decline worldwide, but there are large knowledge gaps with regard to impacts in the RSA.

MODERATE

Risk: Changes in waterbirds – waders and wildfowl (abundance, distribution, nesting sites, feeding and overwintering sites)

Intertidal coastal areas in the RSA support several million overwintering waders and wildfowl. These waterbirds depend on many habitats that provide feeding, nesting and overwintering grounds including freshwater and salt marshes, mangroves, coral islands and intertidal mudflats. Many of these habitats are highly vulnerable to coastal erosion and coastal flooding due to sea-level rise and extreme weather events. These impacts may reduce foraging opportunities, and make sites less suitable for nesting and overwintering, with negative consequences for species abundance and distribution. Extreme weather can also affect migrating birds by driving them off-course and dust storms can force waterbirds to move away from their usual feeding and resting grounds. These events can also cause mortality of birds during flight or when feeding/nesting/resting. In addition, warming temperatures and changes to the monsoon season may have an indirect effect through changes in coastal wetlands.

Climate change drivers

Risk score

In the I-RSA, extensive inundation of coastal areas due to sea-level rise has not yet been documented. However, given the importance of this Region for waders, a proximity of next 20 years, and a medium magnitude score was given. The same score was given to the M-RSA, due to potential adverse effects from extreme weather events. In the O-RSA, some reports indicate an increase in bird numbers, therefore the magnitude is lower than in the other two sub-regions.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	3	3
Magnitude	2	2	2	1
Overall	50	50	50	25

Confidence

Medium (Medium agreement/ Medium evidence)

Some recent studies report waterbird counts and population changes in the Region, and it is generally accepted that climate change is a driver affecting waterbird populations worldwide.

MODERATE

Risk: Changes in mangrove forests

Mangroves are important ecosystems, supporting marine biodiversity, sequestering carbon and helping to protect shorelines from sea-level rise and flooding. Sea-level rise could result in mortality and inundation of these habitats, which would be unable to retreat landward due to coastal squeeze. Increases in cyclones, storms, storm surges and wider hydrodynamics can affect mangrove productivity, recruitment (e.g. through impacts on seed dispersal) and accretion rates due to effects on spatial cover, erosion and excess sedimentation. Changes in rainfall can affect photosynthetic rates and productivity, accretion rates (important for maintaining surface elevation to prevent inundation from the sea) and supply of ground water to these systems. Extremes in salinity and temperature (>50°C) can cause mortality of species in some cases, and continued increases in air temperatures may also constrain growth. Ocean acidification may be an issue as some studies suggest seedlings do not grow well in acidic soil conditions.

Climate change drivers

Risk score

In the I-RSA and M-RSA, whilst the risk of sea-level rise is not immediate, the magnitude of the risk is medium given that coastal squeeze will restrict landward migration of mangrove forests. Most mangrove forests are found in the O-RSA, and are located in areas that are vulnerable to the impact of storms and cyclones and therefore the proximity is lower, and magnitude is medium.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	2	2	3
Magnitude	2	2	2	2
Overall	50	33	33	50

Confidence

Low (Medium agreement/ Low evidence)

Although there is general agreement on the main drivers of climate change impacts on mangroves (sea-level rise, temperature and salinity and freshwater input), more research is needed in the RSA.

MODERATE

Risk: Changes in rocky shores

Rocky shores in the RSA could be impacted by high air and water temperatures, which can cause excess evaporation, leading to extreme hot and saline conditions in rock pool habitats during low tide. Ocean acidification could create even more extreme conditions in these rock pools in the future.

Storms and cyclones can have devastating effects on the rocky shores of the RSA as the combination of intense waves and sand scouring can destroy rock pool areas and impact upon or remove species within these areas. The extreme conditions experienced in rocky shore environments could become more severe, enhancing weathering and erosion.

Climate change drivers

Risk score

Rocky coasts are ecosystems that already experience a degree of stress in the RSA and it is expected future climate impacts will be substantial. In the I-RSA, extreme temperatures are the main driver already impacting rocky shore habitats, while in the M-RSA and O-RSA the main impacts are from extreme storms and cyclones.

Scoring	**Whole RSA**	**Inner-RSA**	**Mid-RSA**	**Outer-RSA**
Proximity	3	3	3	3
Magnitude	2	2	2	2
Overall	50	50	50	50

Confidence

Medium (High agreement/ Low evidence)

While there is a lack of research in the rocky shores of the RSA, there is good agreement on likely impacts from climate change.

MODERATE

Risk: Changes in deep sea habitats (>200m)

Deep sea habitats are those below 200 m depth and are only present within the M-RSA and O-RSA. In certain areas, these habitats currently receive a deep current (300 m depth) of oxygenated water which originates in the I-RSA, which helps to support a large population of myctophid (bioluminescent) lanternfish. Decreasing oxygen is a key driver of change for these deep sea habitats, which will affect growth, reproduction and survival of species at these depths. Changes in abundances and distributions of species due to declining oxygen, increasing temperatures and declining pH may also result. Changes in hydrodynamic circulation could also affect these systems such as changing influxes of deep oxygenated currents.

Climate change drivers

Risk score

There is some evidence that conditions in RSA deep sea environments have changed in the last 50 years. However, impacts on the communities they support are unclear. In the M-RSA, the potential magnitude of changes to deep sea habitats is scored as medium as they cover a substantial but limited area within this subregion. In the O-RSA deep sea areas are more extensive, and the incidence of oxygen depletion zones stretches across much of this area, so therefore the potential magnitude of changes to these unique environments is high.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	3	3
Magnitude	2	N/A	2	3
Overall	50	N/A	50	75

Confidence

Medium (Medium agreement/ Medium evidence)

There is some consensus that these environments have changed, and how climate drivers are contributing to these changes. More evidence is needed however to understand how those changes affect deep sea communities in the RSA.

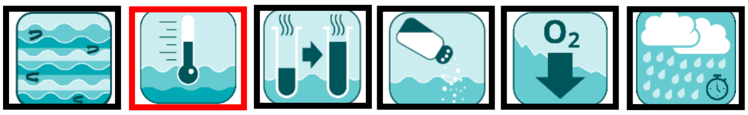
MODERATE

Risk: Changes to non-gelatinous zooplankton

Changes in species composition, biomass and distribution of phytoplankton appear to be affecting zooplankton. An increase in chaetognaths and copepods has been observed while other species are declining. Climate change may affect the species composition, biomass and distribution of zooplankton, although currently there is a lack of long term monitoring to identify long term trends. Within the O-RSA there have been observed declines in zooplankton biomass due to changes in the timing of upwelling and seasonal phytoplankton blooms. Within the I-RSA some changes have been observed, but these are less substantial due to limited upwelling in this area.

Within the RSA it is expected that the main climate drivers affecting zooplankton are increased sea temperatures and changing synchronicity (or lack of) of monsoon-driven upwelling in the O-RSA with the life cycles of zooplankton assemblages.

Climate change drivers



Risk score

Some changes in zooplankton have already been observed within the O-RSA. In the I-RSA changes are expected to occur later due to the reduced role of upwelling on zooplankton species in this area.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	3	4	4
Magnitude	1	1	1	1
Overall	33	25	33	33

Confidence

Low (Low agreement/ Low evidence)

There is limited evidence for long-term changes in zooplankton and the impacts that this is having throughout the Region, with most current evidence drawn from localised studies. Generally, further research is needed to improve understanding of potential changes to zooplankton, its implications for marine food webs and the climatic drivers behind such changes.

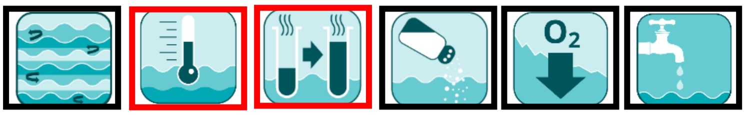
MODERATE

Risk: Changes to microbial communities

Changes in the water column can affect microbial communities both within the wider marine environment, and those associated with particular habitats such as coral reefs and seagrass beds. These changes can have implications for specific microbial traits, such as biodegradation (e.g. in the event of oil spills), with potentially significant consequences for entire ecosystems. Some coral diseases, borne from microbial communities affecting reef systems, may increase under future warming conditions favouring the proliferation of microbes, but evidence is limited on this within the Region.

Key climate drivers affecting microbial communities appear to be increased temperature in the water column and change in pH and freshwater input.

Climate change drivers



Risk score

A low magnitude is provided because changes in microbial communities will likely only have significant ecosystem impacts if their functional roles fundamentally change. It is possible some microbes, such as certain pathogens or diseases may be less favoured by the changed conditions (i.e. climate change may be beneficial).

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	4	4	4	4
Magnitude	1	1	1	1
Overall	33	33	33	33

Confidence

Low (Low agreement/ Medium evidence)

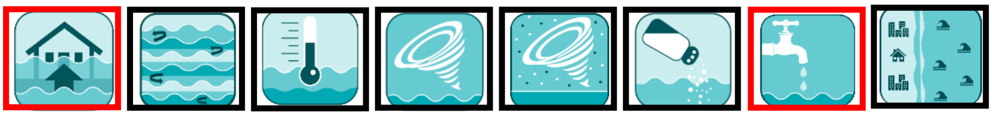
Some evidence from outside of the RSA indicate climate driven changes in microbial communities are already happening. Within the RSA, there is limited evidence and a lack of understanding of how the microbial community would affect ecosystem-scale functions, and how this is affected by climate change.

MODERATE

Risk: Changes in saltmarshes, mudflats and Sabkhas

Saltmarshes, estuaries, mudflats, sabkhas and coastal lagoons in the RSA are under increasing pressure from the combined effects of rising sea level, changes in precipitation patterns and freshwater input, and coastal erosion. They are also vulnerable to high salinity conditions due to increasing evaporation rates under arid and hot conditions, changes in hydrodynamic circulation and dust deposition. Saltwater intrusion in certain habitats from storm surges, sea-level rise and storms and cyclones is also likely to increase under climate change. These climate impacts are likely to affect the dynamics, structure and functioning of these systems, such as marsh vegetation. Biogeochemical cycles could be disrupted, while species reliant on these systems such as waterbirds could also be affected. Wider ecosystem services will be impacted such as carbon sequestration and coastal protection. The relative influence of climate drivers will need to be considered against other human pressures which also degrade these habitats, including overexploitation, coastal development and extensive drainage.

Climate change drivers



Risk score

The main driver of climate risks to these habitats will be sea-level rise, which is expected to show substantial impacts on these systems within the next 50 years. Magnitude scores differ across the Region; higher scores are given to the I-RSA and O-RSA due to the extent and types of important habitats found here. The magnitude of the impact to the M-RSA is lower due to lower extents of these habitats in this area.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	2	2
Magnitude	2	2	1	2
Overall	33	33	17	33

Confidence

Low (Medium agreement/ Low evidence)

Whilst the potential range of impacts is understood, there is little evidence available to understand the nature and scale of impacts in the RSA.

MODERATE

Risk: Changes to macroalgal beds

Extensive macroalgal beds have been reported along the East coast of Oman in the O-RSA, with some small patchy areas also present in other parts of the I-RSA and M-RSA. These form important habitats for many marine species. Future changes in hydrodynamics within the subregion will likely affect macroalgal beds through erosion and changing sediment and nutrient inputs to these systems, with implications for growth and productivity. Storms and cyclones can cause great damage by breaking up and detaching the fronds from substrates, and eroding surfaces for macroalgae to attach to. Sea-level rise will likely cause inundation at a range of sites and reduce light availability, potentially resulting in shoreward migration of these ecosystems if coastal areas are not well developed. Altered turbidity from storm or flooding events and changes in monsoon timing can also reduce light availability to these systems, with impacts on growth. Changes in monsoon timing would also affect nutrient upwelling and availability to these systems. Increases in sea temperature may influence the species composition and distributions of macroalgal communities as those favouring or more tolerant to warmer conditions may dominate.

Climate change drivers

Risk score

Macroalgal beds are extensive in the O-RSA and create a unique and Internationally important habitat. Climate impacts are expected to become more apparent within the next two decades, mainly through changes in the Region's hydrodynamic circulation and intensification of cyclones. The size of these kelp forests decreases towards the I-RSA and therefore the magnitude of any potential changes also decreases from the O-RSA towards the I-RSA.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	2	2
Magnitude	2	1	2	3
Overall	33	17	33	50

Confidence

Low (Medium agreement/ Low evidence)

Whilst the potential range of impacts is understood, there is little evidence available to understand the nature and scale of impacts in the RSA.

MODERATE

Risk: Changes in seagrass meadows

Seagrass meadows are common in shallow subtidal areas of the south and southwestern I-RSA typically associated with sandy and muddy substrates. They support biodiversity, providing nursery and feeding grounds, protect against coastal erosion, and are an effective carbon sink. Sea-level rise, increased turbidity and extreme temperature conditions are the major climate drivers affecting these systems. Temperatures above summer ambient maxima cause thermal stress and can induce 'wasting disease' and extensive mortality, with conditions above 40°C for an extended time considered lethal to seagrass. Sea-level rise will potentially reduce the amount of light available for growth in deep seagrass beds. Changes in water turbidity from storm events, freshwater run-off and sea-level rise can affect growth rates and productivity. Extreme storms cause scouring and leaf loss, persistent turbidity and poor water quality, limiting the growth of the seagrass for long periods after storm events. Changes in hydrodynamics and erosion rates can also affect water quality and integrity of these systems. There may be some resilience within these ecosystems to climate change. Rhizome structures can stabilise sediment reducing their vulnerability to storm events, some *halophilia* species are tolerant to extremes in temperature and salinity, and higher levels of atmospheric CO_2 may actually stimulate growth and productivity in some areas. It is important to note in the I-RSA that seagrasses are under major pressure due to coastal development and dredging activities.

Climate change drivers

Risk score

In the I-RSA, the negative effect of marine heatwaves and wasting disease is already being observed. Due to their importance as dugong feeding grounds and fish nursery habitat, the magnitude to these impacts is scored as medium. In the M-RSA, the extent of the seagrass meadows is more limited and the risk of substantial climate change impacts, particularly from heatwave events in the near future is less acute. In the O-RSA there is one particular large seagrass area that is a known turtle feeding site, but similarly to the M-RSA, risks from climate change impacts are less immediate and likely magnitude is low.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	2	2
Magnitude	1	2	1	1
Overall	25	50	17	17

Confidence

Low (Medium agreement/ Low evidence)

Greater research is needed to understand and project future impacts of climate change on these systems.

MODERATE

Risk: Changes in sandy beaches

Sea-level rise and changes in currents, storms and waves can affect erosion and/or accretion rates at sandy beaches, altering sediment transport and topography of the nearshore zone. Sandy beaches also support many species which may be affected through changes at these sites. For example, erosion may damage or lead to the loss of turtle rookeries and seabird nesting areas, while rising temperatures can affect embryo development of turtles. Consideration of other human pressures affecting sandy beaches, such as coastal development, is also needed when examining the impacts of climate change.

Climate change drivers

Risk score

Whilst climate change impacts are likely to be felt in the next 20 years, there is a relatively low risk to biodiversity in this environment.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	3	3
Magnitude	1	1	1	1
Overall	25	25	25	25

Confidence

Low (Medium agreement/ Low evidence)

Despite general agreement regarding the impact of climate drivers on sandy beaches, the confidence is low as there is relatively limited evidence from the RSA specifically.

LOW

Risk: Changes in cetaceans (abundance and distribution)

Cetaceans in the RSA include over twenty species of toothed whales, dolphins, and porpoises as well as baleen whales. The status of some is currently marked as Vulnerable or Endangered in the IUCN Red List. Within the I-RSA, habitat suitability for a number of species such as the Indo-Pacific Bottlenose Dolphin and Indo-Pacific Humpback Dolphin is projected to decline substantially with warming and increased salinity, particularly in the southwest of the Region. Some species may shift away from the I-RSA in search of cooler conditions in the M-RSA and beyond. The highly migratory nature of many cetaceans means that identifying major climate drivers is difficult. Increased temperatures may indirectly affect distributions and abundance through shifting prey availability (e.g. small pelagic fish). Storms and cyclones, monsoon timing and changes in hydrodynamic circulation may also affect certain species, but currently there is limited evidence on the likely nature and scale of impacts. Severe storms and cyclones may cause disorientation and be linked to stranding and changes in distribution. Any change in monsoon timing or hydrodynamics could impact on productivity, potentially affecting food supply via limiting resources or causing mismatches between the times when food is abundant versus the times when it is required.

Climate change drivers

Risk score

Higher magnitude scores were given for the I-RSA due to the higher temperatures cetaceans will be exposed to, and for the O-RSA due to likely impacts of storms and cyclones on populations. A lower magnitude for the M-RSA was given due to this area expected to have lower temperatures (compared to the I-RSA) and lower impacts from storms and cyclones (compared to the O-RSA). Overall, the risk is scored as low as it is expected these species can move to other areas to find further food or for refuge.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	2	2
Magnitude	1	2	1	2
Overall	17	33	17	33

Confidence

Medium (High agreement/ Low evidence)

There is currently limited information on the impact of climate change on these animals within the RSA, but some modelling studies have been undertaken regarding changes in habitat suitability and indicate similar future patterns. Some species are data deficient, resulting in knowledge gaps regarding their current and future abundance and distribution, and the impact of climate change. The irregularities in the reporting of by-catch, strandings, and other sources of mortality in the Region makes it particularly difficult to assess current or future impacts of climate change.

LOW

Risk: Spread of alien invasive species (AIS)

Non-native or alien invasive species (AIS) are those introduced into an ecosystem where they do not occur naturally, and have the potential to spread and perturb ecosystems and their functioning. One study identified 56 AIS species that are already present, and a further 80 identified as likely to arrive in the RSA, including fish, tunicates, invertebrates, plants and protists (Clarke et al., 2019). Introductions occur largely through shipping traffic, cruise ships, ballast water and fouling. There are examples of changing spread and persistence of AIS species, but greater understanding is needed as to whether they are truly non-native. For example, there is growing evidence regarding the increasing frequency, persistence and scale of mass plankton blooms in the RSA, such as the red tides caused by the dinoflagellate *Cochlodinium polykrikoides*. There are reports of several non-native species including cyst forms from plankton assemblages in Kuwait waters, but this needs to be substantiated with long-term records to examine if these species are considered native or not. Climate change could affect the spread and rate of introductions of these species in the Region, with warming sea temperatures potentially favouring planktonic species of certain bacteria and dinoflagellates. Changes in the species composition of diatom communities in the M-RSA and I-RSA along the Iranian coast can occur following cyclones and storms, suggesting the transfer of new species into the I-RSA via debris following an extreme event. However, the increasingly extreme conditions expected in the RSA, particularly the I-RSA, under future climate change may affect the survival and persistence of many AIS species, limiting their spread.

Climate change drivers

Risk score

There is some evidence for an increase in the establishment and spread of AIS within the I-RSA, but uncertainty regarding the influence of climate change. One factor that could increase risk from AIS is the growth of the aquaculture industry (for example through the release of new species for stock enhancement and transgenic species, the movement of stocks and the discard of materials).

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	1	1
Magnitude	1	1	1	1
Overall	17	17	8	8

Confidence

Medium (High agreement/ Low evidence)

More evidence is needed to clearly identify what constitutes an AIS in the RSA, and to understand how climate change affects AIS spread, persistence and survival.

4. Risks to economy and society

A total of 23 climate change risks were identified across a range of sectors, industries and communities (Table 6). Six of the risks were categorised as severe, requiring adaptation measures soon. A breakdown of risks for each individual Region can be found in the Appendix (Table A 4). The highest scoring risks included impacts on coastal communities and infrastructure, fisheries resources, operations and safety of maritime industries, and changes in freshwater supply and quality.

Table 6: Ranked Social and Economic Risks for the RSA

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Impacts on coastal communities	3	3	75	Severe	High
Changes in wild-capture fisheries resources	3	3	75	Severe	High
Flooding impacts on coastal industries and infrastructure	3	3	75	Severe	High
Impacts on desalination plants	3	3	75	Severe	High
Non-flooding related impacts on coastal industries and infrastructure	3	3	75	Severe	Medium
Impacts on operations, safety and movement of goods in the maritime transport sector	3	3	75	Severe	Medium
Impacts on fishing communities, infrastructure and operations	3	2	50	Moderate	High
Impacts on oil and gas offshore industries infrastructure and operations	2	3	50	Moderate	Low
Impacts on the provision of natural coastal protection	3	2	50	Moderate	Medium
Changes in aquaculture resources, infrastructure and supply chain	2	2	33	Moderate	Low
Impacts on coastal tourism infrastructure, resorts and facilities	2	2	33	Moderate	High
Impacts on pearl oysters	2	2	33	Moderate	Low
Impacts on human health from the marine environment	2	2	33	Moderate	Low
Impacts on coastal and marine recreational activities	3	1	25	Moderate	High
Impacts on cultural heritage and historic sites	3	1	25	Moderate	Low
Impacts on the provision of natural climate regulation services	3	1	25	Moderate	Low
Impacts on onshore, nearshore and offshore marine renewable energy (wind, waves, tides)	2	1	17	Low	Low
Impacts on freshwater availability and quality from groundwater sources	2	1	17	Low	Low
Impacts on aggregate extraction operations	2	1	17	Low	Low
Impacts on the provision of natural waste breakdown and detoxification	2	1	17	Low	Low
Loss of education and research value from the marine environment	1	1	8	Low	Low
Loss of future use value of genetic and biological resources	1	1	8	Low	Low

SEVERE

Risk: Impacts on coastal communities

This risk focusses on both impacts to the built environment, and to the health and safety of people living and working at the coast (e.g. flood and storm risk or heat, humidity and dust storms). The increasing risk of flooding and erosion from sea-level rise will lead to damage, or loss, of belongings, housing, and amenities (including business), compounded by effects from short term extreme weather events. These extreme events include high temperatures (heatwaves) and excessive humidity. The most notable risks from extreme events are related to storms, cyclones and associated surges in the M and O-RSA. Flash flooding from extreme rainfall events could increase, and potentially compound flooding from the sea. In the longer term, shoreline retreat could lead to inland migration of communities to avoid further flooding impacts.

Climate change drivers

Risk score

Given the high population densities found around the RSA, and therefore their potential vulnerability to climate change impacts, risks were considered high across all areas. The risks from cyclones were higher in the M and O-RSA, whilst the inner, low lying areas are more vulnerable to flooding. Substantial risks to all areas might be observed in the next 20 years.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	3	N/A	N/A	N/A
Overall	75	N/A	N/A	N/A

Confidence

High (High agreement/ High evidence)

There is substantial Regional evidence for this risk, and coastal communities globally are known to be highly vulnerable to climate change impacts, as summarised in the IPCC assessment reports through IPCC WG2 (Impacts, Adaptation and Vulnerability).

SEVERE

Risk: Changes in wild-capture fisheries resources

Climate change within the RSA is expected to have a substantial effect on commercial and artisanal fisheries (catching fish and shellfish for human consumption, as well as for fishmeal and bait). Key impacts include changing habitat suitability, shifts in species abundance and distribution, effects on prey availability, and incidence of diseases and HABs affecting fish and shellfish health or quality. These impacts are expected to result in both losses and gains depending on species. Fisheries catches in the M-RSA and O-RSA predominantly consist of pelagics such as skipjack, yellowfin and longtail tuna while in the I-RSA coastal fishes including grouper species and seabreams make up a large proportion of the catch. As such fisheries within these Regions will be affected differently. Projections for the I-RSA suggest local extinctions will outweigh any increased presence of invading new species and therefore consequent declines in fisheries catch potential is likely in this sub-region. In the O-RSA potential declines in chlorophyll concentrations may affect fisheries yields. However, some cephalopod species such as squid may respond positively to warming, providing beneficial effects for fisheries throughout the Region. Overall, declines of commercially exploited species are likely to result in the loss of catch potential for most ROPME Member States. In some cases, distributions shifts may bring new opportunities for commercial exploitation. For example, some M-RSA and O-RSA have reported increases in catches of pelagic species, although this could reflect the development of new fisheries targeting species that were previously present but unexploited (e.g. horse mackerel in Oman).

Regional differences in climate drivers are expected to affect fisheries resources differently. Within the I-RSA increasing temperatures will be a key driver affecting fish and shellfish stocks. In the M-RSA and O-RSA changes in hydrodynamics (particularly possible changes in currents) and declining oxygen availability (with deep water oxygen minima shallowing), through their influence on primary production, may be more critical. Pollution and overexploitation also have strong effects on fisheries resources in addition to these climate drivers.

Climate change drivers

Risk score

While differences across the Region are likely, a single overall score was determined due to a lack of sufficient evidence for the M-RSA and O-RSA to inform reliable sub-regional scoring.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	3	N/A	N/A	N/A
Overall	75	N/A	N/A	N/A

Confidence

High (High agreement/ Medium evidence)

SEVERE

Overall, confidence was high due to a strong scientific evidence base from both International and RSA research communities. However, at a sub-regional level there is less confidence due to uncertainty over how particular climate drivers will subsequently affect fish and shellfish stocks, particularly with regards to the O-RSA where changes in hydrodynamics, upwelling and primary production are highly uncertain.

SEVERE

Risk: Flooding impacts on coastal industries and associated infrastructure

This risk applies to major industry operations and infrastructure at the coast including: ports and marinas used for the maritime transport and/or water sport sector; coastal power plants; bunkering sites and shipping terminals; coastal transportation infrastructure including roads, railways, bridges and causeways; sewage treatment plants; and nearshore oil and gas refineries and terminals.

Coastal infrastructure will be impacted by sea-level rise through flooding and long-term inundation. This can result in damage to and loss of sites or facilities, with repercussions for operating efficiency and disruption to industries at these sites. Land subsidence in some areas may also heighten sea-level risk at certain sites. Indirectly, other industries away from the coast, which rely on coastal roads, bridges and maritime transport for distribution of goods could be affected.

Climate change drivers

Risk score

Proximity scores for the M-RSA and O-RSA are lower due to their steeper coastlines being less vulnerable that coastal plains in the I-RSA. Given the high value and strategic importance of these industries, the magnitude is high everywhere.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	3	2	2
Magnitude	3	3	3	3
Overall	75	75	50	50

Confidence

High (High agreement/ High evidence)

There is substantial Regional evidence for this risk, and coastal infrastructure globally is known to be highly vulnerable to climate change impacts, as summarised in IPCC assessment reports through IPCC WG2 (Impacts, Adaptation and Vulnerability).

SEVERE

Risk: Impacts on desalination plants

Freshwater supply for human consumption and irrigation may be affected through changes in both water availability and quality. Increased storm and cyclone activity may impair and damage infrastructure at desalination sites and may result in some sites being temporarily shut down with consequent effects on water supplies. Sea-level rise will increase the risk of inundation at coastal sites and damage to infrastructure, with a potential need to re-locate sites. HABs can also affect water quality, risking human health if affected water enters the drinking water supply network. Increased turbidity, algal blooms and jellyfish outbreaks may lead to clogging of intake filters, affecting operating efficiency. Increases in temperature may lead to increased cooling demands at plant sites, while increasing salinity will affect the quality of water that can be used for turning into drinking water, and thus potentially increase operating demands. Although there is some resilience built into the industry to cope with current environmental risks to water supply and quality, future climate change could challenge the industry beyond its current resilience planning.

Climate change drivers

Risk score

No sub-regional scores were given. Whilst the principal drivers experienced are different across the RSA, overall impacts were thought to 'balance out'. For example, the O-RSA may be more exposed to storms and cyclones, while the I-RSA and M-RSA are potentially more affected by HABS. The effects of these were both deemed to have similar overall scores for proximity and magnitude. Given the fundamental importance of water security in the Region, this risk is rated as high magnitude. Whilst major climate driven impacts are not being experienced now, they could be an issue for desalination plants within the next 20 years.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	3	N/A	N/A	N/A
Overall	75	N/A	N/A	N/A

Confidence

High (High agreement/ High evidence)

There is clear evidence that the industry is sensitive to temperature, salinity and sea level change, and that vulnerability of desalination plant operations will likely increase in the future. Indirect effects such as through HABs or clogging could also become more acute in the future.

SEVERE

Risk: Non-flooding related impacts on coastal industries and associated infrastructure

This risk applies to industry operations and infrastructure at the coast including: ports and marinas used for the maritime transport and/or water sport sector; coastal power plants; bunkering sites and shipping terminals; coastal transportation infrastructure including roads, railways, bridges and causeways; sewage treatment plants; and nearshore oil and gas refineries and terminals.

Any potential increase in storm and cyclone activity would increase the risk of physical damage to infrastructure and disrupt operations, affecting all industries to various extents. Underwater cables and pipes for power plants and nearshore oil and gas refineries may be scoured, damaged and/or displaced in rougher sea conditions. Pollution risks may be amplified from sewage treatment plants, oil and gas facilities and ports or terminals if these sites are damaged by extreme events.

Damage at ports and marinas, and to coastal transport infrastructure, could have large implications for the delivery and transportation of goods. Increases in air and sea temperatures will affect the efficiency of cooling systems and could increase cooling demands, for example at power plants and oil/gas facilities. Increased jellyfish outbreaks may also cause problems for operating efficiency through blocking cooling intake structures. Dust storms may also damage infrastructure for some industries, and in some cases could cause power failures.

Climate change drivers

Risk score

A lack of information exists regarding how these drivers would affect the full range and scale of industries and sectors across different areas, and this has impeded sub-regional scoring.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	3	N/A	N/A	N/A
Overall	75	N/A	N/A	N/A

Confidence

Medium (High agreement/ Medium evidence)

Given the varied nature of the threats described, it is likely that negative impacts will be experienced across all sectors. A more detailed analysis of these risks in the RSA in needed.

SEVERE

Risk: Impacts on operations, safety and movement of goods in the maritime transport sector

This risk focusses on safety at sea, navigation and disruption of shipping in the RSA. Changes in storm intensity and the frequency of high winds could disrupt maritime traffic and may also pose risks to seagoers' safety and wellbeing. Damage to boats and pollution incidents may also increase as a result of boats operating in rough conditions, as the likelihood of cargo being lost or ships floundering may increase. The Strait of Hormuz is an area of high concern as a recognised strategic maritime chokepoint. Any increase in dust storms in the Region could lead to further disruption, and temperature increases could affect the comfort of operating staff.

Impacts on port and marina infrastructure and operations are included in the coastal infrastructure risks.

Climate change drivers

Risk score

Given how crucial the maritime transport sector is to the Region, the magnitude of impacts is potentially high across the RSA. If the frequency and intensity of storms increases, there could be major impacts on the sector in the coming decades.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	3	N/A	N/A	N/A
Overall	75	N/A	N/A	N/A

Confidence

Medium (Medium agreement/ Medium evidence)

Anecdotally there are reports of disruption to the maritime transport sector, and the potential vulnerability of the sector to changing conditions is widely acknowledged.

MODERATE

Risk: Impacts on fishing communities, infrastructure and operations

As described for the risk on ‘changes in wild capture fisheries resources’, commercial and artisanal fisheries are being impacted by climate change. In addition to fishery resources, supporting infrastructure, operations, and dependant communities will be affected by climate change. Levels of vulnerability depend on what climate impacts they are exposed to and the type of fishery. Changing sea and storm conditions may disrupt fishing operations, including limiting opportunities to get to sea, affecting use of certain types of gears in rougher conditions, and even loss of gears (e.g. pots and traps). This could be a particular issue for the M-RSA and O-RSA with any change in storminess, and rougher conditions could also risk fishers’ safety and wellbeing at sea. Changes in dust storms may affect visibility and navigation for fishers when at sea. Declines in fisheries catch potential could result in declines in revenues for some fisheries, with likely repercussions for the wider fisheries supply chain and community. Boats, gears, ports and harbour infrastructure may be damaged or lost due to changing storm activity and sea-level rise may also increase the risk of inundation of landing sites or ports, affecting use of and access to sites, especially during storm surge events. Landing sites and/or ports with less protection may be more vulnerable to these impacts compared to those with more resilient structures. For example, fishers simply using beaches for landing sites are exposed to beach erosion resulting from sea-level rise.

Climate change drivers

Risk score

Proximity scores for the M-RSA and O-RSA were increased due to the threat from increased cyclone activity in these areas.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	2	3	3
Magnitude	2	2	2	2
Overall	50	33	50	50

Confidence

High (High agreement/ Medium evidence)

Overall confidence of risks to the fishing sector is high. There is higher confidence about changes in cyclone activity affecting the M-RSA and O-RSA, but less confidence regarding the extent to which the I-RSA will be impacted.

MODERATE

Risk: Impacts on oil and gas offshore industries infrastructure and operations

Rigs and associated infrastructure and facilities at offshore oil and gas sites are vulnerable to damage from storm and wave activity. Not only can this disrupt or even cease operations for extracting these materials, but damage to underwater cables and pipes may also lead to issues regarding onward supply. Pollution risks from spillages and leaks, if the integrity of structures is impaired or damaged, may also affect the wider marine environment. Workers safety could also be compromised if they have to operate in rougher conditions with high winds and waves, and transportation of workers to these sites could also incur greater risks (e.g. helicopter flights may be disrupted in high winds).

Climate change drivers

Risk score

The magnitude of the risk is lower in the M-RSA and O-RSA due to the industry being more limited in this area compared to the I-RSA. Given the inbuilt resilience of structures to extreme weather and waves, the proximity of this risk is regarded as being more distant.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	2	2
Magnitude	3	3	2	2
Overall	50	50	33	33

Confidence

Low (Medium agreement/ Low evidence)

There is currently limited evidence regarding the specific climate impacts the industry will face within the Region.

MODERATE

Risk: Impacts on the provision of natural coastal protection

This risk describes the protective physical role the natural environment provides for human settlements and infrastructure, including reefs (corals and biogenic), mangroves, seagrass, saltmarsh and sand dunes. These habitats provide important barriers that help to control flooding as well as helping to prevent coastal erosion. As both coastal and marine habitats are included, a wide range of drivers are expected to impact these systems. These may include direct physical (storms, flooding) and biological (temperature, pH, oxygen stress) impacts. Changes in the aerial extent and integrity of these habitats will compromise their effectiveness as natural barriers. The role of other human pressures, through coastal and nearshore developments, need to be considered alongside climate impacts.

Climate change drivers

Risk score

The proximity score reflects the near term risks to coastal habitats. Local studies show that these habitats, such as mangroves in the U.A.E. and Kuwait, are providing an important coastal protection role. However, for many areas, the extent of these habitats and the value of their role in coastal protection is less well known, so magnitude is rated as moderate across the Region.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	2	N/A	N/A	N/A
Overall	50	N/A	N/A	N/A

Confidence

Medium (Medium agreement/ Medium evidence)

It is well known that these habitats play an important coastal protection role and are vulnerable to climate change. Greater understanding is needed regarding the full extent of these habitats in the RSA, and their role in protecting the Region (including what is being protected by these habitats, to determine the social and economic risks).

MODERATE

Risk: Changes in aquaculture resources, infrastructure and supply chain

This risk includes fish and shellfish maintained in coastal ponds and/or offshore sites. The aquaculture industry is currently limited within the Region to a few areas, but most countries have strategies to grow and expand the industry. Changing habitat suitability may affect the suitability of aquaculture sites for growing and housing particular fish or shellfish species. Increasing temperatures may exceed the thermal tolerance of certain species, and declines in oxygen may also limit growth and affect other physiological processes. Aquaculture resources may also be at risk from increased incidences of HABs, which can lead to mass mortality events. Warmer conditions may result in increases in outbreaks of marine diseases and pathogens which can affect fish and shellfish health, as well as the quality of these products.

Site infrastructure is at risk from several climate drivers. If storm and cyclone activity increase, this may damage coastal processing and storage facilities, and disrupt operations. Netted pens and cages in coastal waters or in offshore areas may be increasingly vulnerable to storm damage, leading to economic losses and potential for stock to escape into the wider sea area. Flooding from storm events and storm surges may result in increased nutrient and sediment run off into some ponds and sites. Sea-level rise can result in saltwater intrusion and flooding of coastal aquaculture ponds. Finally, climate-driven jellyfish blooms can result in clogging of net cages and could result in fish deaths within these structures.

Climate change drivers

Risk score

As the industry is currently restricted to a few sites, major risks are unlikely in the near term. However, the industry is likely to expand and consequently a medium magnitude score was assigned to reflect this growth.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	N/A	N/A	N/A
Magnitude	2	N/A	N/A	N/A
Overall	33	N/A	N/A	N/A

Confidence

Low (Medium agreement/ Low evidence)

There is currently little evidence regarding climate change impacts on this risk, due in part to the industry being limited in size and uncertainty about the nature and scale of future developments in the industry.

MODERATE

Risk: Impacts on coastal tourism infrastructure, resorts and facilities

This risk focuses on the infrastructure and facilities that support mass tourism in the Region. This includes resorts and hotels, marinas and cruise ship facilities, as well as changes in the climatic conditions that might affect tourists' comfort and their preferences (e.g. temperature, humidity, dust storms). Related issues include the effects of coastal change on erosion, which may reduce the appeal of coastal resorts and recreation spots. For example, many resorts built on man-made 'islands' may be at risk from erosion and inundation from sea-level rise. Storm events can also damage hotels and resort infrastructure and disrupt activities. Future changes in the incidence of dust pollution and sandstorms could negatively affect the seaside experience for visitors and locals alike, and for those who visit the coast, there will be a higher risk of heat-related illnesses due to the prolonged high temperature exposure outdoors.

The main climate change drivers identified are storms, winds, waves, sea-level rise, storm surge and erosion. Short term effects from extreme heat, humidity and dust storms, as well as localised high rainfall and associated flooding are also important.

Climate change drivers

Risk score

Impacts are focussed on locations where resorts, hotels, marinas, and cruise ship operations are most developed. Proximity and magnitude of major impacts are considered to be higher in the I-RSA, where most activity is concentrated, and risks from sea-level rise are higher in low lying coastal areas and islands.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	3	2	2
Magnitude	2	3	2	2
Overall	33	75	33	33

Confidence

Medium (Medium agreement/ Medium evidence)

Whilst risks to coastal infrastructure and human wellbeing are being explored, specific impact studies on the mass tourism sector are needed to determine the extent of impacts on tourism infrastructure and to understand the geographical distribution of major impacts.

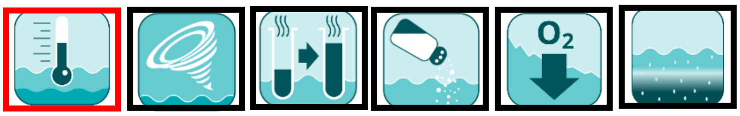
MODERATE

Risk: Impacts on pearl oysters

This risk includes climate change impacts on the resource itself, including changes in habitat suitability, as well as any short-term effects that result in poor conditions for harvesting oysters (e.g. storms, turbidity). This risk applies to the I-RSA only. Principal climate change drivers are the effects of changing temperature and salinity on pearl oysters and the nursery grounds of oyster larvae. Changing pH, oxygen and turbidity could also have negative effects on pearl oysters.

The overall effects of climate change are unclear, and some studies suggest that warming sea temperatures could stimulate calcification in pearl oysters by enhancing certain physiological processes, therefore counteracting the impact of ocean acidification. The risks from climate change also need to be placed in the context of impacts from other human pressures, such as fishing and habitat degradation (e.g. seagrass meadows), that may affect pearl oysters.

Climate change drivers



Risk score

Historically this practice has held a very important symbolic value for some countries (e.g. Kuwait, UAE) and growth is expected in some countries. The cultural significance of pearl oysters is reflected in the magnitude score. Impacts on species (and their supporting habitats) may be occurring now, but major impacts on this activity from climate change are yet to be reported.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	N/A	N/A	N/A
Magnitude	2	N/A	N/A	N/A
Overall	33	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

Impacts on the resource are similar to those reported for other ecosystem components, but there is very little specific research on climate change impacts on pearl oysters and their harvesting.

Risk: Impacts on human health from the marine environment

This risk specifically relates to human health impacts from the marine environment. Climate-driven changes in the emergence, spread and distribution of marine viruses, pathogens and toxic blooms can cause illness, disease and poisoning in humans that come in contact with contaminated water or seafood (e.g. through consumption or swimming). Physical threats to life or injury may result from coastal flooding such as storm surges, or flash flooding. Storms and cyclones can also lead to serious injuries and loss of life.

Occupational health for those working in maritime industries may also be at risk from increased heat stress due to rising air temperatures or having to work in stormier conditions. Changing humidity can also affect people's health for those working at or visiting the marine and coastal environment. These risks are likely to be higher for more vulnerable parts of society, such as the elderly or those with existing health conditions.

Given the varied nature of the physical and biological risks described, a wide range of climate change drivers are identified. Impacts of temperature change on the prevalence of marine pathogens and the physical threat from storms and flooding are considered the principal drivers.

Climate change drivers

Risk score

Overall, this is currently scored as a low risk for the RSA, and there are warning systems in place for some physical (storm surge) and biological risks (e.g. fish poisoning data). There is some anecdotal site-specific evidence of impacts, but not enough evidence to assign a close proximity for this risk. The M and O-RSA are more exposed to cyclones, so there is a greater potential for mortality in the coming decades if cyclone activity increases.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	2	3	3
Magnitude	2	2	2	2
Overall	33	33	50	50

Confidence

Low (Low agreement/ Low evidence)

Research on the impacts of climate change on human health is limited, and for biological threats, transmission pathways through the environment and food-chain are complicated.

MODERATE

Risk: Impacts on coastal and marine recreational activities

The focus of this risk is on important 'experiential' recreational activities. These include swimming and water sports, which may be affected by changes in water quality and harmful blooms; recreational fisheries, where sportfish species abundance and distribution may change; and wildlife watching, which might be affected by changes in wetland species, charismatic marine species, and the quality of diving sites. For immersion activities, HABs may prevent swimming, and if turbidity is bad, diving is affected. Changes in air and sea temperature, either through direct impacts on comfort, as well as their indirect effects on the quality, distribution and abundance of habitats and species, are identified as the principal drivers. Given the wide and varied nature of these activities, in coastal, nearshore and offshore locations, all drivers could impact on the quality of these experiences. Impacts on related infrastructure are included in the coastal industries risk.

Climate change drivers

Risk score

Magnitude is low as the comparative value of these activities, versus other economic activities in the area, is marginal. Mass tourism within the Region doesn't tend to be driven by recreation and viewing, and instead is centred on relaxing on beaches and activities on land. However, the tourism sector is growing, so these risks may increase in the future. Currently significant impacts from climate change are not readily apparent. No differentiation is made between areas, although activities may be more prevalent in more populated parts of the I-RSA, with high visitor numbers.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	25	N/A	N/A	N/A

Confidence

High (High agreement/ Medium evidence)

A high confidence is given as there is good evidence that climate drivers affect recreational activities (e.g. dust storms cancelling trips), and for some impacts (e.g. on species and habitats) there is a considerable evidence that climate change is having an impact.

MODERATE

Risk: Impacts on cultural heritage and historic sites

This risk focuses on ancient forts, seaports and historic settlements containing archaeological finds as well as culturally important locations including traditional freshwater wells and springs. These are scattered along the coastlines of the RSA countries, and some are recognised sites of outstanding universal value. They vary in size and scale from Trilifs (3 small balanced rocks) to UNESCO world heritage sites. Coastal wells may be affected by water recharge from changing rainfall patterns, as well as impacts from saline intrusion with sea-level rise. Flooding from heavy rainfall and/or storm surges may affect integrity of sites. Tourists' comfort at sites may also be affected by temperature and humidity.

The principal climate change drivers of concern are the long term effects of sea-level rise on flooding and erosion, as well as the short terms effects of storms, winds and waves on sites.

Climate change drivers

Risk score

As well as the income they provide, archaeological sites have important non-monetary values (e.g. sense of cultural heritage, identity, sense of place) that require consideration. Impacts may be seen in the next 20 years, but the magnitude is scored low due to a lack of research and the challenge of quantifying the non-monetary value of these sites. Given this low understanding, scores are not differentiated by sea area.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	25	N/A	N/A	N/A

Confidence

Low (Medium agreement/ Low evidence)

There is a lack of research on the impacts of climate change on cultural sites, but effects are likely to be similar to other coastal infrastructure.

MODERATE

Risk: Impacts on the provision of natural climate regulation services

This risk describes the role of coastal and nearshore habitats (e.g. mangroves, seagrasses, marshes and sedimentary habitats) in helping regulate climate through carbon storage and sequestration, as well as marine biogeochemical processes that store and exchange greenhouse gases with the atmosphere. Most climate change drivers have a role to play in affecting these habitats. Principal drivers are identified as sea-level rise, temperature change and storms/cyclones, which will impact habitat integrity, productivity and function and therefore the level of climate regulation they can provide. Damaged ecosystems as a result of climate-driven changes are unlikely to be able to sequester and store carbon as successfully. Changes in freshwater input, turbidity and hydrodynamics will also influence ecosystems such as seagrasses and mangroves, influencing their ability to store and sequester carbon. For some habitats, notably seagrass, it should be noted that there may be some benefits to growth from higher temperatures and carbon dioxide levels. These climate change impacts need to be placed in the context of other human activities that are also degrading the coastal habitats described.

Climate change drivers

Risk score

Higher concentrations of coastal and nearshore habitats are found in the I-RSA, but the O-RSA has more upwelling and effects from the biological pump in the marine environment, which broadly balances out the scores.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	3	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	25	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

Currently there is limited evidence on the magnitude of these impacts and how functionality of these systems with regards to this carbon sequestration service will be affected by climate change. Most evidence is country, habitat and site specific, often related to specific habitat restoration projects.

LOW

Risk: Impacts on onshore, nearshore and offshore marine renewable energy (wind, waves, tides)

Currently the marine renewable energy sector within the RSA is small, although there are plans in most countries to expand in coming decades. Increases in wind and wave action would likely be beneficial for the sector although structures used to generate energy (e.g. turbines) could be damaged if storms and cyclones become more extreme. Tidal energy outputs could benefit from possible increases in surge events from changing storm conditions. Offshore sites could be at risk, or benefit, due to their increased exposure to these conditions. Rougher sea conditions and cyclone activity may pose increased safety risks to workers at offshore sites, as well as disrupt wider operations and access. Workers in exposed offshore areas may be at risk from heat stress due to increasing temperatures and humidity. Infrastructure, particularly at the coast, may be subjected to damage and inundation due to increased flooding risk from storm surges and longer-term sea-level rise.

Climate change drivers

Risk score

Proximity and magnitude of this risk is low due to the sector being relatively small scale, and the likely impacts of climate change being unknown.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	17	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

A low confidence score was given, largely reflecting the fact that this industry is small within the Region and so little is known about the impacts of these climate drivers.

LOW

Risk: Impacts on freshwater availability and quality from groundwater sources

The availability and quality of water may be affected at coastal freshwater wells, lenses and in traditional wells and springs due to reduced water levels from decreases in average rainfall. Sea-level rise is expected to increase inundation at coastal sites, leading to saltwater intrusion affecting the suitability and quality of water for human consumption. Infrastructure at these sites, such as wells, pipes, pumps and other structures could be damaged by increases in storm and cyclone activity. Groundwater recharge is also important and could be affected by changes in precipitation patterns and monsoon timing.

Climate change drivers

Risk score

A lower score was given to the O-RSA due to the steeper coastline and therefore reduced risk from sea-level rise compared to the I-RSA and M-RSA, which are typified by large coastal plains and are therefore more susceptible to inundation. It was considered unlikely that this risk would become a major risk in the near future, and the overall magnitude is low.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	N/A	N/A	1
Magnitude	1	N/A	N/A	1
Overall	17	N/A	N/A	8

Confidence

Low (Medium agreement/ Low evidence)

Limited evidence is available regarding the future impacts of climate change on water availability and quality of these sites.

LOW

Risk: Impacts on aggregate extraction operations

Currently large quantities of sand and gravel are extracted from the seabed for use in construction, beach replenishment and land reclamation. Nearshore and offshore activities may be disrupted by increased storm and cyclone activity. Workers' safety may be put at risk from working in rougher conditions. There could be potential for increased demand for aggregates to protect the coast and reclaim land from sea-level rise and coastal flooding.

Climate change drivers

Risk score

There could be increased risk for the I-RSA due to a larger industry here, but insufficient evidence prevented reliable sub-regional scoring. Overall magnitude of climate driven risks to the industry was considered low, with relatively minor disruptions to operations.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	2	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	17	N/A	N/A	N/A

Confidence

Low (Medium agreement/ Low evidence)

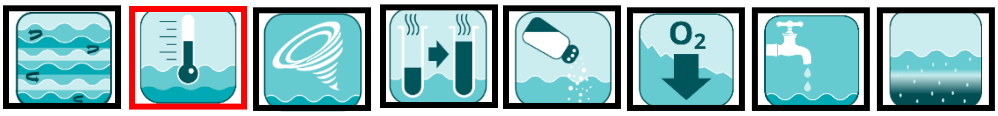
Limited evidence is available regarding the future impacts of climate change on the aggregate industry.

LOW

Risk: Impacts on the provision of natural waste breakdown and de-toxification

This risk relates to the capacity of the natural environment to breakdown and de-toxify pollutants (e.g. from sewage, ballast water and oily wastes) and how this might be compromised by climate change. This includes the potential to diminish the role of natural habitats (e.g. mangroves) in ‘cleaning’ air and water, changes in the dispersion of waste by seawater, and how microbes break down waste materials under different temperature regimes. A wide range of drivers can affect the broad environmental conditions experienced in coastal and marine environments, which together may act to degrade the environment and thus affect the provisioning of this service. Erosion and sedimentation of certain habitats may also affect this cleaning function. Inundation of sewage systems and landfills due to increased coastal flooding may increase the risk of water supplies being contaminated.

Climate change drivers



Risk score

Potential magnitude may vary by sub-region depending on the different countries’ policies regarding waste. Some resilience may already be in place but conditions in the future are unlikely to be like those experienced in the past.

Scoring	**Whole RSA**	**Inner-RSA**	**Mid-RSA**	**Outer-RSA**
Proximity	2	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	17	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

Currently there is very little research on this issue and disentangling the impacts of climate change from other human drivers is difficult.

LOW

Risk: Loss of education and research value from the marine environment

This risk describes the loss of opportunities for experiential learning, and the acquisition of future knowledge from the marine environment due to climate change and human activities. For example, the degradation of habitats or localised species extinctions may mean there are fewer opportunities to learn about these ecosystems, but their degrading state may also necessitate increased research in order to build knowledge to help protect them. Conversely, research will also be stimulated by the need to build resilience and adapt to climate change. Given the all-encompassing nature of this risk, all drivers are considered relevant, but no principal driver is identified.

Climate change drivers

Risk score

The scoring is conservative as there is little knowledge in this area. However, further consideration of this risk should recognise how the need to mitigate and adapt to climate change favours new social learning and knowledge generation.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	1	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	8	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

There is currently very limited information on this topic.

LOW

Risk: Loss of future use value of genetic and biological resources

This risk describes the potential future loss of genetic and biological resources through climate impacts on marine biodiversity and habitats. For example, a loss of a species may inadvertently lead to loss of genetic material that is useful for future medicine or biotechnology purposes or inhibit long-term adaptation potential. There may be hotspots in the Region that provide some of these resources, but currently these are unknown.

Given the all-encompassing nature of this risk, all drivers are considered relevant, but no principal driver is identified.

Climate change drivers

Risk score

The potential magnitude could be large e.g. if the opportunity to develop significant lifesaving medicines is compromised, but this may be difficult to attribute to climate change and the likelihood of such impacts is unknown.

Scoring	Whole RSA	Inner-RSA	Mid-RSA	Outer-RSA
Proximity	1	N/A	N/A	N/A
Magnitude	1	N/A	N/A	N/A
Overall	8	N/A	N/A	N/A

Confidence

Low (Low agreement/ Low evidence)

Currently there is low evidence and agreement on this issue.

5. Discussion

This Risk Assessment identified a total of 45 risks to the RSA, covering impacts on biodiversity, society and economies. Of this, 13 are considered 'severe', with impacts occurring now, or within the next 20 years, and with a magnitude of 'medium' to 'high'. Many of these risks will likely have large scale impacts, but due to the differences in climate drivers and patterns in biodiversity and dependent sectors/industries throughout the Region, these impacts will be felt differently depending on the subregion. For risks categorised as severe and therefore 'high priority' we expect that some of these will be taken forward to inform future adaptation work within the area and be a focus of the ROPME Climate Change Strategy in the forthcoming years.

Many of these risks are transboundary in nature, requiring a holistic approach that considers the interlinkages between sub-regions and their effect. While developing adaptation strategies at the national level is important, consideration of wider spatial and temporal scales of risks will be critical to determine how best to manage these risks overall and ameliorate their effects. Additionally, many risks are intertwined, such that changes in one risk can affect the impacts and levels of risk for another. This is particularly true for species and habitats within the Region that provide vital ecosystem services, such as supporting fisheries and coastal protection.

When undertaking the Risk Assessment, it was clear that many of the risks are heightened by non-climate factors. The RSA is a heavily utilised area with ever increasing demand on its coastal and marine environment and natural resources. Increasing human pressures such as overexploitation, pollution and coastal development have additional and significant consequences for many of the risks identified, particularly those within the biodiversity theme. For example, overexploitation can reduce the resilience of fished populations to warming temperatures, while increasing coastal developments mean that many habitats are already being lost and climate change will therefore add further pressure to these systems. Any future adaptation strategies will need to consider these wider factors and their interactions when planning to build resilience to climate change. This could include management actions aiming to reduce or limit other pressures within an area.

For many risks there is limited evidence for how certain climate drivers will continue to impact the Region, and how these trends may differ at the sub-region level. This is particularly true for drivers such as storms, and changes in hydrodynamics, where there is considerable uncertainty about future changes. Greater research effort would help build knowledge on the likely range and scale of future climate change impacts.

Marine ecosystems offer a huge wealth of social, cultural and economic services and benefits to the RSA. As this Risk Assessment indicates, climate change is expected to affect many of these services, if it hasn't already. Some of the biggest risks are expected for coastal communities through coastal flooding and long-term inundation from sea-level rise, as well as impacts on water quality and availability. While Internationally focused literature can help provide insights into some of the impacts that are occurring or are expected within the Region, there are very limited Regional studies. This can impede further understanding into how exactly impacts may be felt by individuals and communities, who or what is most vulnerable, as well as broader scale economic implications. Increasing the knowledge base within this area for social and economic risks would be extremely informative for the development of long-term adaptation strategies.

For some countries within the RSA, individual risks may be considered more or less important depending on local contexts and priorities. As such, we expect that this Risk Assessment could be adapted at the national level. Additionally, as new evidence becomes available it is likely that some risks may change ranking or confidence and therefore this Risk Assessment should be viewed as an initial step. Future risk assessments may wish to modify risks, or add ones as they emerge or develop. Further work could also consider how to better incorporate other sources and forms of knowledge. This could include greater stakeholder participation from different sectors to help identify risks and discuss their impact, or through wider public consultation processes.

6. Concluding remarks and next steps

The Risk Assessment presented here provides the first climate change risk assessment for the RSA Region, and highlights a number of severe, high priority risks that the area is already experiencing. This assessment will assist in the development of best practice guidance for selected risks to support marine climate change adaptation and mitigation in the Region.

The outputs from the ROPME work programme are supporting ROPME Member States to develop national climate change responses and provide them with an opportunity to highlight climate risks, and priority action areas, on the International stage.

7. Acknowledgements

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9. Appendix

Table A 1: Ranked Biodiversity Risks for the I-RSA.

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Changes in coral reef associated communities	4	3	100	Severe	High
Increased incidence of harmful algal blooms (HABs) and nuisance species	4	3	100	Severe	Med
Changes to phytoplankton primary production	4	3	100	Severe	High
Changes in corals (cover, distribution and health)	4	3	100	Severe	High
Changes in dugong (abundance and distribution)	3	3	75	Severe	Medium
Change in jellyfish/gelatinous plankton outbreaks	3	2	50	Moderate	Medium
Changes in benthic invertebrates (abundance and distribution)	3	2	50	Moderate	Medium
Changes in pelagic fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in demersal fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in sea turtles (abundance, distribution and nesting sites)	3	2	50	Moderate	High
Changes in seabirds (abundance, distribution and nesting sites)	3	2	50	Moderate	Low
Changes in waterbirds (abundance, distribution, nesting sites, feeding and overwintering sites)	3	2	50	Moderate	Medium
Changes to rocky shores	3	2	50	Moderate	Medium
Changes in seagrass meadows	3	2	50	Moderate	Low
Changes in mangrove forests	2	2	33	Moderate	Low
Changes to microbial communities	4	1	33	Moderate	Low
Changes in saltmarshes, mudflats and Sabkhas	2	2	33	Moderate	Low
Changes in cetaceans (abundance and distribution)	2	2	33	Moderate	Medium
Change to non-gelatinous zooplankton	3	1	25	Moderate	Low
Changes to sandy beaches	3	1	25	Moderate	Low
Changes to macroalgal beds	2	1	17	Low	Low
Spread of alien invasive species (AIS)	2	1	17	Low	Medium
Changes to deep sea habitats (>200m)					

Table A 2: Ranked Biodiversity Risks for the M-RSA.

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Increased incidence of harmful algal blooms (HABs) and nuisance species	4	3	100	Severe	Medium
Changes to phytoplankton primary production	4	2	67	Severe	High
Change in jellyfish/gelatinous plankton outbreaks	4	2	67	Severe	Medium
Changes in benthic invertebrates (abundance and distribution)	4	2	67	Severe	Medium
Changes in pelagic fish (abundance and distribution)	4	2	67	Severe	Low
Changes in coral reef associated communities	3	2	50	Moderate	High
Changes in demersal fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in sea turtles (abundance, distribution and nesting sites)	3	2	50	Moderate	High
Changes in waterbirds (abundance, distribution, nesting sites, feeding and overwintering sites)	3	2	50	Moderate	Medium
Changes to rocky shores	3	2	50	Moderate	Medium
Changes to deep sea habitats (>200m)	3	2	50	Moderate	Medium
Changes in mangrove forests	2	2	33	Moderate	Low
Changes to non-gelatinous zooplankton	4	1	33	Moderate	Low
Changes to microbial communities	4	1	33	Moderate	Low
Changes to macroalgal beds	2	2	33	Moderate	Low
Changes in corals (cover, distribution and health)	3	1	25	Moderate	High
Changes in seabirds (abundance, distribution and nesting sites)	3	1	25	Moderate	Low
Changes to sandy beaches	3	1	25	Moderate	Low
Changes in saltmarshes, mudflats and Sabkhas	2	1	17	Low	Low
Changes in seagrass meadows	2	1	17	Low	Low
Changes in cetaceans (abundance and distribution)	2	1	17	Low	Medium
Spread of alien invasive species (AIS)	1	1	8	Low	Medium
Changes in dugong (abundance and distribution)					

Table A 3: Ranked Biodiversity Risks for the O-RSA.

Risk	Proximity	Magnitude	Risk score	Risk category	Confidence level
Changes in coral reef associated communities	4	3	100	Severe	High
Changes in sea turtles (distribution, abundance, nesting sites)	3	3	75	Severe	High
Changes to deep sea habitats (>200m)	3	3	75	Severe	Medium
Changes in benthic invertebrates (abundance and distribution)	4	2	67	Severe	Medium
Changes in pelagic fish (abundance and distribution)	4	2	67	Severe	Low
Changes to phytoplankton primary production	3	2	50	Moderate	High
Changes in demersal fish (abundance and distribution)	3	2	50	Moderate	Low
Changes in seabirds (abundance, distribution and nesting sites)	3	2	50	Moderate	Low
Changes in mangrove forests	3	2	50	Moderate	Low
Changes to rocky shores	3	2	50	Moderate	Medium
Changes to macroalgal beds	2	3	50	Moderate	Low
Increased incidence of harmful algal blooms (HABs) and nuisance species	4	1	33	Moderate	Med
Changes to non-gelatinous zooplankton	4	1	33	Moderate	Low
Changes to microbial communities	4	1	33	Moderate	Low
Changes in saltmarshes, mudflats and Sabkhas	2	2	33	Moderate	Low
Changes in corals (cover, distribution and health)	3	1	25	Moderate	High
Change in jellyfish/gelatinous plankton outbreaks	3	1	25	Moderate	Medium
Changes in waterbirds (abundance, distribution, nesting sites, feeding and overwintering sites)	3	1	25	Moderate	Medium
Changes to sandy beaches	3	1	25	Moderate	Low
Changes in seagrass meadows	2	1	17	Low	Low
Changes in cetaceans (abundance and distribution)	2	1	17	Low	Medium
Spread of alien invasive species (AIS)	1	1	8	Low	Medium
Changes in dugong (abundance and distribution)					

Table A 4: Ranked Social and Economic Risks for RSA with sub-regional scoring. Risks are ranked according to the overall score across the whole RSA. Sub-regional overall scores are coloured according to the risk category, and blank cells represent cases where sub-regional scores were not given.

Risk	Whole Region Proximity	Whole Region Magnitud	Whole Region Risk score	Whole Region Risk category	I-RSA Proximity	I-RSA Magnitud	I-RSA Risk score	M-RSA Proximity	M-RSA Magnitud	M-RSA Risk score	O-RSA Proximity	O-RSA Magnitud	O-RSA Risk Score	Confidence level
Impacts on coastal communities	3	3	75	**Severe**										High
Changes in wild-capture fisheries resources	3	3	75	Severe										High
Flooding impacts on coastal industries and infrastructure	3	3	75	Severe	3	3	75	2	3	50	2	3	50	High
Impacts on desalination plants	3	3	75	Severe										High
Non-flooding related impacts on coastal industries and infrastructure	3	3	75	Severe										Medium
Impacts on operations, safety and movement of goods in the maritime transport sector	3	3	75	Severe										Medium
Impacts on fishing communities, infrastructure and operations	3	2	50	Moderate	2	2	33	3	2	50	3	2	50	High
Impacts to oil and gas offshore industries infrastructure and operations	2	3	50	Moderate	2	3	50	2	2	33	2	2	33	Low
Impacts on the provision of natural coastal protection	3	2	50	Moderate										Medium
Changes in aquaculture resources, infrastructure and supply chain	2	2	33	Moderate										Low
Impacts on coastal tourism infrastructure, resorts and facilities	2	2	33	Moderate	3	3	75	2	2	33	2	2	33	High
Impacts on pearl oysters	2	2	33	Moderate	2	2	33							Low
Impacts on human health from the marine environment	2	2	33	Moderate	2	2	33	3	2	50	3	2	50	Low
Impacts on coastal and marine recreational activities	3	1	25	Moderate										High
Impacts on cultural heritage and historic sites	3	1	25	Moderate										Low
Impacts on the provision of natural climate regulation services	3	1	25	Moderate										Low
Impacts to marine renewable energy (wind, waves, tides)	2	1	17	Low										Low
Impacts on freshwater availability and quality from groundwater sources	2	1	17	Low							1	1	8	Low
Impacts on aggregate extraction operations	2	1	17	Low										Low
Impacts on the provision of natural waste breakdown and detoxification	2	1	17	Low										Low
Loss of education and research value from the marine environment	1	1	8	Low										Low
Loss of future use value of genetic and biological resources	1	1	8	Low										Low

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