Earth Systems and Climate Change Hub

National Environmental Science Programme

SHARK BAY world heritage

WORKSHOP REPORT

Climate change and the Shark Bay World Heritage Area

Foundations for a climate change adaptation strategy and action plan

November 2018

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Workshop acknowledgements

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Cover photo credit: Karen Pearce

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Executive summary

Shark Bay was listed as a World Heritage property in December 1991 on the basis of its outstanding universal value; that is, it has:

- outstanding examples representing the major stages of the Earth's evolutionary history (including the stromatolites and microbial mats of Hamelin Pool)
- outstanding examples representing significant ongoing geological process, biological evolution and man's interaction with his natural environment (including steep salinity gradients, three biotic zones, Wooramel seagrass bank, seagrass meadows, *Fragum erugatum* shell deposits)
- superlative natural phenomena, formations or features (including Faure Sill, Hamelin Pool, Zuytdorp Cliffs, Dirk Hartog Island, inundated birridas and lagoons)
- the most important and significant natural habitats where threatened species of animals or plants of outstanding universal value still survive (including five endangered mammal species, 12 threatened reptile species, marine megafauna including dugongs)

Climate changes such as changes in air temperature and in the intensity and frequency of storms and extreme marine heat events are expected to threaten the resilience of areas in Shark Bay and the outstanding universal value of the area that led to its World Heritage listing.

Workshop

In September 2018, the Shark Bay World Heritage Advisory Committee convened a workshop to lay the foundations for the development of a climate change adaptation strategy and action plan for the Shark Bay World Heritage Property using a rapid assessment tool (Climate-change Vulnerability Index).

Climate change

Climate change refers to long-term changes in the average pattern of weather that occur over decades, centuries or longer. Climate variability, for example due to the El Niño Southern Oscillation, occurs at shorter timescales of years to decades, while weather occurs on the timescale of hours to days.

Climate change projections are not predictions, but they tell us about the response of the climate system to possible future scenarios. Climate projections for Shark Bay include:

- Increased average air temperatures in all seasons (*very high confidence*)
- More hot days and warm spells with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells (*very high confidence*).
- Decreasing winter and spring rainfall (*high confidence*). Rainfall changes in summer and autumn are not as clear.
- More intense extreme short-duration rainfall (*high confidence*) and the wettest day of the year will get wetter.
- Fewer but more intense tropical cyclones (*medium confidence*)

- A small winter decrease in wind later in the century; a small increase in spring wind speeds (*low confidence*)
- Increased fire weather risk (*low confidence*)
- Increased potential evapotranspiration in all seasons (high confidence
- Decreased humidity in winter and spring (*high confidence*) and in summer and autumn (*medium confidence*) later in the century.
- Increased winter radiation (*medium confidence*) later in the century
- Rising mean sea level and increased height of extreme sea-level events (*very high confidence*).

Detailed climate change projections for Australia are available at www.climatechangeinaustralia.gov.au – Shark Bay is the Rangelands (South) sub-cluster. Sea-level rise projections for coastal councils are also available at coastadapt.com.au.

Climate-change Vulnerability Index

The Climate-change Vulnerability Index (CVI) is being developed to provide method for systematically assessing climate change impact across all World Heritage properties.

In determining the CVI for the Shark Bay World Heritage Area, storm intensity and frequency, extreme marine heat events and air temperature change were identified as the potential climate stressors with the greatest potential impact on Shark Bay's outstanding universal value (OUV). The vulnerability of Shark Bay's OUV to each of these drivers was HIGH (on a three-point scale: low, moderate, high), resulting in an overall assessment of HIGH vulnerability to climate change.

Next steps

The Shark Bay World Heritage Advisory Committee will develop a climate change adaptation strategy and action plan, identifying knowledge gaps along the way. The Western Australian Marine Science Institution will facilitate implementation of the plan and develop an appropriate science plan to support the ongoing management of Shark Bay in a changing climate.

1. Introduction

1.1 Background

Shark Bay has a unique combination of a large, sheltered, shallow body of water that provides exceptional marine environments and a series of promontories and islands that provide isolated terrestrial habitat – set in an area that contains elements of both temperate and tropical climate. The biology of the bay reflects this unique setting, providing opportunities for stromatolites and marine and terrestrial flora to survive, as well as supporting a very productive biological environment that sustains significant fisheries; an extensive and spectacular landscape; local communities and tourism activities. These are the reasons that Shark Bay was listed as one of Australia's first World Heritage properties.

In a changing climate, changes in air temperature and in the intensity and frequency of storms and extreme marine heat events are expected to threaten the resilience of areas in Shark Bay and the outstanding universal value (OUV) of the area that led to its World Heritage listing.

In September 2018, the Shark Bay World Heritage Advisory Committee (SBWHAC) convened a workshop in Denham to identify possible impacts of climate change on Shark Bay in order to lay the foundations for the development of a climate change adaptation strategy and action plan. The workshop featured presentations from subject matter experts before working through a rapid risk assessment tool (Climate-change Vulnerability Index, CVI) that is being developed for World Heritage properties.

1.2 Workshop context

For decades, the succession of advisory committees with responsibility for the Shark Bay World Heritage Area have been advocating an assessment of climate change impacts on Shark Bay's OUV. However, it wasn't until 900 km^2 of large, temperate, meadow-forming seagrass species[1] was lost (and other OUV attributes impacted) in the 2010/11 marine heatwave that this became an area of focus.

In 2012, a workshop was convened to pull together historical and current data to start to understand climate impacts on Shark Bay. The findings of this workshop were in a special issue of *Marine and Freshwater Research*.[2]

Additional publications followed up on the effects of the heatwaves. These were synthesised in Fisheries WA workshop volumes.[3] In addition to the loss of seagrass habitat, other impacts included: a drop in birth rates in dolphins; negative effects on crab, oyster and other fisheries; and tourism visitation that fell well short of projections.

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[1] Arias-Ortiz et al. 2018. A marine heatwave drives massive losses from the world's largest seagrass carbon stocks. *Nature Climate Change*, 8, 338–344

[2] Kendrick et al. 2012. Science behind management of Shark Bay and Florida Bay, two P-limited subtropical systems with different climatology and human pressures. *Marine and Freshwater Research*, 63, 941–951

[3] http://www.fish.wa.gov.au/Documents/sofar/status_reports_of_the_fisheries_and_aquatic_resources_2016-17_gascoyne_bioregion.pdf

In 2012, the World Heritage Scientific Advisory Committee recommended a coordinated multi-institutional and multi-discipline approach to research. However, five years on there was little evidence of such a coordinated approach to research.

Recognising the impending risks to Shark Bay's OUV, the Western Australian Marine Sciences Institution (WAMSI) organised a workshop in June 2018[4] to identify priority knowledge gaps and whether something could be done to address them. The importance of each gap was evaluated by comparing the consequences of 'taking action' versus 'doing nothing'. Outcomes from the gap analysis included:

- a shared vision for a cross-sectoral focused program to address the integrated management of Shark Bay under climate change for the values as outlined in the World Heritage site documentation and for sustainable tourism, commercial and recreational fishing and industry
- the need for a policy response to maintain resilience in both natural environment and human activities that rely on Shark Bay. The policy response should incorporate adaptive responses in the local industries to predictions of the effect of climate change to the Shark Bay ecosystem. There is enough prior research to make reasonable assessments of risk but this research needs to be captured
- the importance of continued focused research that advances predicting climate change in Shark Bay and that supports management responses and interventions is also a priority. Waiting and monitoring and doing nothing is not an alternative.

The outputs from the workshop have subsequently been turned into summaries and will be presented as a white paper for government action. Subsequently the SBWHAC encouraged the National Environmental Science Program Earth Systems and Climate Change Hub to become involved with Shark Bay.

The SBWHAC provided the drive for the September workshop, recognising that there was a need to:

- develop the CVI rapid assessment tool as a consistent methodology for other World Heritage areas
- use the CVI methodology to determine the vulnerability of the World Heritage area OUV to climate change
- use the methodology to focus on the key climate change stressors likely to impact on key OUV attributes for Shark Bay
- progress toward a climate change adaptation strategy and adaptation plan for the Shark Bay World Heritage property.

1.3 Workshop aims

Overall aim: To lay the foundations for the development of a climate change adaptation strategy and action plan for the Shark Bay World Heritage Property using a rapid assessment tool (Climate-change Vulnerability Index, CVI).

[4] https://www.wamsi.org.au/shark-bay-workshop

Series of steps/aims to achieve this:

1. Understand the significant values that comprise the outstanding universal value (OUV) plus the other significant (but non-OUV) values of Shark Bay.
2. Agree on consistent terms to describe climate change stressors. Discuss the list of climate change stressors and their potential to impact the values of Shark Bay.
3. Discuss possible future climate change scenarios facing Shark Bay and agree to consider two scenarios for the future of Shark Bay (e.g. 'Business as Usual' and 'Paris Agreement').
4. To provide focus, conduct a high-level risk assessment (likelihood and consequence) of all climate change stressors impacting the values (prioritising the OUV) of Shark Bay – identifying the stressors representing the highest risks to OUV and then prioritise those risks.
5. Develop diagrams of key climate change stressors impacting the highest risk values of Shark Bay and then determine the related physical, ecological, economic and social impacts.
6. Understand the proposal for CVI and test its applicability using Shark Bay as a case study.
7. Discuss and agree on possible adaptation strategies to address the priority impacts.

1.4 This report

This report provides a summary of the information presented at the workshop and a high-level overview of the CVI process as applied to Shark Bay and the outcomes of that process. It is intended to provide a reference that will inform ongoing management of the Shark Bay World Heritage Area in a changing climate.

The workshop program and participant list are included in the appendices of this report.

1.5 Acknowledgements

The SBWHAC would like to acknowledge the time, money and effort put into preparing for and running this workshop. Representative agencies, organisations and individuals have been generous with their precious time and knowledge and they are all gratefully received. The workshop was organised by Cheryl Cowell and Phil Scott, both representing the SBWHAC.

This report was prepared by the National Environmental Science Program Earth Systems and Climate Change Hub. Thanks to all participants and in particular to the following people who presented at the workshop and made their notes and presentations available to assist with the preparation of the report:

- Simon Allen (dolphins)
- Arani Chandrapavan (fisheries, sea surface temperature)
- Cheryl Cowell (Shark Bay World Heritage Area and OUV)
- Vanessa Hernaman (climate change)
- Scott Heron (coral, CVI)

- Phil Scott (next steps)
- Luke Twomey (WAMSI's role)
- Di Walker (seagrass)
- Therese Morris (microbial communities)

Erica Suosaari did not attend the workshop but provided useful advice on climate impacts on stromatolites and the carbonate dominated marine environment.

Scott Heron facilitated the workshop and provided the CVI framework and tool. Scott was fully supported, and this report was partially supported, by NOAA grant NA14NES4320003 (Cooperative Institute for Climate and Satellites – CICS) at the University of Maryland/ESSIC.

Letter from Hamelin Pool

Hey

I got here before you
And you would not be, without me
I've learnt a trick or two over 3.8 billion years
But I've got nothing up my sleeve to fix my latest fears.

But my ear is to the ground
I heard a group was in town
A group that might help to see me through
The next decade or two.

You see, I've got these good friends that live out in the Bay
And some of them, well, they're struggling day to day
And we all depend on them in the bay
And I don't know what I'll do if they don't stay.

Anyway, you lot seem to be smart enough
To find a way to fix this stuff
Or at least, put up a fight.
Thanks, your friendly stromatolite.

(Thanks to Phil Scott for conveying this message from the stromatolites to the workshop participants.)

2. The Shark Bay World Heritage Area

The Shark Bay World Heritage Area (WHA) is located at the most westerly point of the Australian continent (Figure 1). Covering 2.2 million hectares and with more than 1500 km of coastline, Shark Bay (which is, in fact, two bays) is a biodiverse region of ecological, geological and hydrological significance as well as a region of exceptional beauty. Most of the WHA (70%) is marine waters.

Shark Bay has a semi-arid to arid climate, with hot dry summers and mild winters. Evaporation exceeds rainfall by a factor of 10: mean annual precipitation ranges from 200 mm in the east to 400 mm in the far south-west, while mean annual evaporation ranges from 2000 mm in the west to 3000 mm in the east.[5]

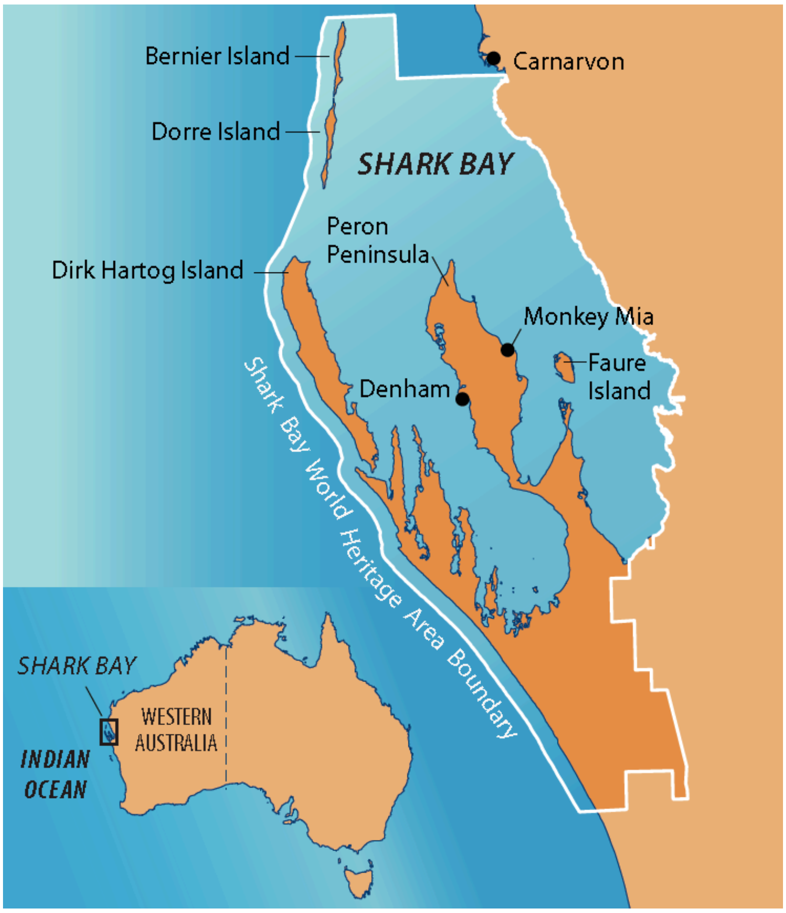

Figure 1. Shark Bay World Heritage Area (source: https://www.sharkbay.org/publications/brochures-maps/)

5 https://www.wamsi.org.au/sites/wamsi.org.au/files/files/2_%20Shark%20Bay%20W'shop_Em%20Prof%20Di%20Walker_SBWH%20Values%20and%20risks.pdf

2.1 World Heritage listing – what this means

Shark Bay was listed as a World Heritage area in December 1991. It was the first World Heritage site in Western Australia.

World Heritage properties are sites of global natural or cultural significance that have been recognised through the World Heritage Convention. The Convention, adopted in 1972 through UNESCO, came into force in 1975. It recognises the need to preserve a balance between World Heritage values and how people interact with nature.

All States Parties signed up to the World Heritage Convention – currently 167 countries (including Australia) – agree to adhere to the Convention and to nominate properties for inclusion on the World Heritage List. They commit to protecting World Heritage values, which includes having management plans in place to protect these values and report on their condition.

There are currently 1092 properties on the World Heritage List – 845 recognised for their cultural value, 209 for their natural value and 38 for both cultural and natural value.

World Heritage properties are to be preserved for the future on the basis of their outstanding universal value (OUV). Each property has a statement of OUV which is:

- the principal reference for all plans and legislation relating to future protection and management of the property
- a point of reference for all monitoring, state conservation reporting and a mandate to maintain the values as per at Listing.

The fundamental concept is passing on the property to future generations with the values/attributes as they are recorded in the OUV.

There are 10 criteria for OUV – four natural and six cultural.[6] Shark Bay is one of only 21 sites (out of the 1092 listed worldwide) that meets all four natural criteria:

> vii. contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.
>
> viii. be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.
>
> ix. be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.

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[6] http://whc.unesco.org/en/criteria/

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

(Others meeting all four natural criteria include the Wet Tropics and Great Barrier Reef in Australia, Yellowstone National Park in the US, and the Galapagos Islands.)

World Heritage properties must also meet the conditions of integrity (natural sites) or authenticity (cultural sites) – that is, they must have sufficient protection/management in place to ensure the World Heritage values at Listing are maintained and safeguarded into the future. The IUCN defines the integrity of a World Heritage property as:

> "… a measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes. Examining the conditions of integrity, therefore requires assessing the extent to which the property:
>
> a) includes all elements necessary to express its outstanding universal value;
> b) is of adequate size to ensure the complete representation of the features and processes which convey the property's significance;
> c) suffers from adverse effects of development and/or neglect."[7]

Shark Bay's integrity as a World Heritage property is considered to be vulnerable to the impacts of climate change. This has been a significant motivation for commencing a systematic evaluation of future climate scenarios and planning for the future.

2.2 Management of Shark Bay World Heritage Area

The Australian Government has primary responsibility for the development and implementation of national policy on World Heritage matters.

Implementation of policy and day-to-day management is the responsibility of the Western Australian Government. Most of the on-ground responsibility is with the Parks and Wildlife Service within the Department of Biodiversity, Conservation and Attractions; however, other agencies (e.g. Department of Primary Industries and Regional Development) have significant responsibilities for managing fisheries and pastoral leases within the World Heritage area. Most of the World Heritage area is also state-listed marine and terrestrial conservation estate, which provides for conservation management separate to the World Heritage listing.

Local government also plays a role. 60% of the WHA is within the Shire of Shark Bay, 40% is in Carnarvon Shire. These shires work with state agencies to maintain the World Heritage values of the area.

The Shark Bay World Heritage Advisory Committee provides advice to State/Commonwealth Ministers, agencies, researchers, developers, etc. on:

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[7] https://whc.unesco.org/document/115532

- Protection, conservation, presentation and management of the WHA
- Threats and risks to the site's OUV and integrity
- Research and monitoring priorities
- Development proposals, EPBC Act referrals
- Dirk Hartog Island Ecological Restoration Project.

Shark Bay Statement of OUV[8]

Brief synthesis

On the Indian Ocean coast at the most westerly point of Australia, Shark Bay's waters, islands and peninsulas covering a large area of some 2.2 million hectares (of which about 70% are marine waters) have a number of exceptional natural features, including one of the largest and most diverse seagrass beds in the world. However it is for its stromatolites (colonies of microbial mats that form hard, dome-shaped deposits which are said to be the oldest life forms on earth), that the property is most renowned. The property is also famous for its rich marine life including a large population of dugongs, and provides a refuge for a number of other globally threatened species.

Criterion (vii): One of the superlative natural phenomena present in this property is its stromatolites, which represent the oldest form of life on Earth and are comparable to living fossils. Shark Bay is also one of the few marine areas in the world dominated by carbonates not associated with reef-building corals. This has led to the development of the Wooramel Seagrass Bank within Shark Bay, one of the largest seagrass meadows in the world with the most seagrass species recorded from one area. These values are supplemented by marine fauna such as dugong, dolphins, sharks, rays, turtles and fish, which occur in great numbers.

The hydrologic structure of Shark Bay, altered by the formation of the Faure Sill and a high evaporation, has produced a basin where marine waters are hypersaline (almost twice that of seawater) and contributed to extensive beaches consisting entirely of shells. The profusion of peninsulas, islands and bays create a diversity of landscapes and exceptional coastal scenery.

Criterion (viii): Shark Bay contains, in the hypersaline Hamelin Pool, the most diverse and abundant examples of stromatolites (hard, dome-shaped structures formed by microbial mats) in the world. Analogous structures dominated marine ecosystems on Earth for more than 3,000 million years.

The stromatolites of Hamelin Pool were the first modern, living examples to be recognised that have a morphological diversity and abundance comparable to those that inhabited Proterozoic seas. As such, they are one of the world's best examples of a living analogue for the study of the nature and evolution of the earth's biosphere up until the early Cambrian.

The Wooramel Seagrass Bank is also of great geological interest due to the extensive deposit of limestone sands associated with the bank, formed by the precipitation of calcium carbonate from hypersaline waters.

Criterion (ix): Shark Bay provides outstanding examples of processes of biological and geomorphic evolution taking place in a largely unmodified environment. These include the evolution of the Bay's hydrological system, the hypersaline environment of Hamelin Pool and the biological processes of ongoing speciation, succession and the creation of refugia.

One of the exceptional features of Shark Bay is the steep gradient in salinities, creating three biotic zones that have a marked effect on the distribution and abundance of marine organisms. Hypersaline conditions in Hamelin

[8] https://whc.unesco.org/en/list/578

Pool have led to the development of a number of significant geological and biological features including the ‘living fossil’ stromatolites.

The unusual features of Shark Bay have also created the Wooramel Seagrass Bank. Covering 103,000 ha, it is the largest structure of its type in the world. Seagrasses are aquatic flowering plants that form meadows in near-shore brackish or marine waters in temperate and tropical regions, producing one of the world’s most productive aquatic ecosystems. Australia has one of the highest diversity of seagrasses globally, with 12 species occurring in the Bay.

Criterion (x): Shark Bay is a refuge for many globally threatened species of plants and animals. The property is located at the transition zone between two of Western Australia’s main botanical provinces, the arid Eremaean, dominated by *Acacia* species and the temperate South West, dominated by *Eucalyptus* species, and thus contains a mixture of two biotas, many at the limit of their southern or northern range. The property contains either the only or major populations of five globally threatened mammals, including the Burrowing Bettong (now classified as Near Threatened), Rufous Hare Wallaby, Banded Hare Wallaby, the Shark Bay Mouse and the Western Barred Bandicoot. A number of globally threatened plant and reptile species also occur in the terrestrial part of the property.

Shark Bay’s sheltered coves and lush seagrass beds are a haven for marine species, including Green Turtle and Loggerhead Turtle (both Endangered, and the property provides one of Australia’s most important nesting areas for this second species). Shark Bay is one of the world’s most significant and secure strongholds for the protection of Dugong, with a population of around 11,000. Increasing numbers of Humpback Whales and Southern Right Whales use Shark Bay as a migratory staging post, and a famous population of Bottlenose Dolphin lives in the Bay. Large numbers of sharks and rays are readily observed, including the Manta Ray which is now considered globally threatened.

Integrity

At time of inscription in 1991 it was noted that human impacts, while not as pronounced as in other World Heritage properties due to the property’s relative remoteness, have had some effects including impacts from pastoralism and feral animals. The small, local centre of Denham, along with industrial activities such as salt and gypsum mining in the region, could comprise threats if not properly managed. Tourism and recreational boating also needs to be carefully managed. The marine environment has undergone some modification through historically intensive pearl shell, fishing, trawling and whaling activities. However, the ecosystems in Shark Bay appear relatively unaltered by human impact, although this could change if terrestrial mining of mineral sands were to take place. Other potential threats could be from improved technology in producing drinking water which would lead to increased tourism and residential density, the upgrading of road access, agricultural developments to the east (dependent on water supply), expansion of gypsum mining, and the introduction of intensive aquacultural or fishing technologies. Climate change could also impact on the complex marine ecosystem. While the property meets the required conditions of integrity and contains the components required to demonstrate all aspects of the natural processes, it is important that the property’s management arrangements provide the framework in which these integrity issues can be monitored and addressed.

Protection and management requirements

The Shark Bay World Heritage property encompasses a number of different land tenures and thus a variety of statutory and management arrangements protect its values. At the time of nomination of the property, existing conservation reserves totalled approximately 200,000 hectares and mainly consisted of small island nature reserves, Bernier and Dorre Islands and the Hamelin Pool Nature Reserve. Specific suggestions to increase the conservation tenure boundaries included expanding the northern boundary of the Hamelin Pool Class A Marine Nature Reserve; extending the southern boundary of the terrestrial park on the northern end of the Peron Peninsula; the inclusion of the Gladstone Embayment in the Hamelin Pool Marine Nature Reserve; the extension of the northern boundary line of the Marine Park in the Denham Sound area; securing reserve status for Dirk Hartog Island and the incorporation of the southern part of Nanga pastoral station into the reserve system.

Since inscription, Francois Peron National Park (52,586 hectares), Shell Beach Conservation Park (517 hectares), Monkey Mia Reserve (446 hectares), Monkey Mia Conservation Park (5 hectares), Zuytdorp

Nature Reserve (additional 58,850 hectares), Nanga pastoral lease (176,407 hectares), part Tamala pastoral lease (56,343 hectares), South Peron (53,408 hectares), part Carrarang pastoral lease (18,772 hectares), Bernier, Dorre and Koks Islands Nature Reserves (9,722 hectares) and Dirk Hartog Island National Park (61,243 hectares) have been added to the conservation estate. With the designation of the Shark Bay Marine Park (748,725 hectares) in 1990, incorporating the Hamelin Pool Marine Nature Reserve, the total formal conservation area of the World Heritage property is approximately 1.24 million hectares. In addition, the coastal portion of the Yaringa pastoral lease (19,396 hectares), part of Nerren Nerren pastoral lease (104,351 hectares) and part of Murchison House pastoral lease (37,578 hectares) have been added as a buffer. The Yaringa portion adjoins the Hamelin Pool Nature Reserve and in addition to having very high conservation value, is of strategic significance in bordering the World Heritage property.

A management agreement between the Australian Government and the State of Western Australia provides for management of the property to be carried out by the Western Australian Government in accordance with Australia's obligations under the World Heritage Convention. In addition, a comprehensive programme of management and administrative structures and planning processes has been implemented. Under the terms of the Agreement, a ministerial council and two advisory committees (scientific advisory and community consultative) were formed. The Shark Bay World Heritage Advisory Committee replaced the two previous Scientific Advisory and Community Consultative committees with a new committee consisting of community, scientific and Indigenous representatives. Owing to the diversity of land tenures and managing agencies and individual interests within the property, the *Shark Bay World Heritage Property Strategic Plan 2008-2020* was prepared to develop a partnership between governments and the community.

From July 2000, any proposed activity which may have a significant impact on the property became subject to the provisions of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*(EPBC Act), which regulates actions that will, or are likely to, have a significant impact on World Heritage values. In 2007, Shark Bay was added to the National Heritage List, in recognition of its national heritage significance under the Act.

Management issues raised at the time of inscription included the control of human use through both zoning and designation of conservation areas, restrictions on public access to certain areas, the management of the trawl fishery to protect values, the purchase of land for conservation use, and increased staffing. Since then, climate change has emerged as an additional potential threat to the World Heritage values. Fire also represents a threat to species that are highly restricted in their distribution, particularly populations which only survive on islands which could be severely affected by a single large fire. Australia has introduced a range of measures at both the national, and property-specific, level to address these potential threats.

2.3 Seagrasses, salinity, stromatolites and species

Shark Bay's four most significant attributes, recognised in the Statement of OUV, are its extensive seagrass beds, salinity gradient, stromatolites and species assemblages, including some species that are found nowhere else in the wild. More information about Shark Bay's significance is available at www.sharkbay.org. This workshop explored the exposure to climate change of these four key attributes.

2.3.1 Seagrasses

Shark Bay has extensive seagrass beds. They cover more than 4000 km^2 and produce 8 million tonnes of leaves annually. They are comprised of 12 species of seagrass, the most seagrass diversity in any one place on the planet. The most abundant species is *Amphibolis antarctica* (southern wireweed), which covers approximately 3700 km^2 of the bay.[9]

The seagrass meadows are the foundation of the marine ecosystem in Shark Bay. They provide food, shelter and nursery areas for many marine animals, including dugongs.

The seagrass beds have also modified Shark Bay's geology and chemistry. Faure Sill is a massive seagrass bank that restricts tidal flow to Hamelin Pool, contributing to its hypersalinity.

Following the 2010/11 marine heatwave, around 36% of the bay's seagrass meadows died off. Two years after the event, leaf biomass showed some recovery, but below ground mass decreased. (Information presented by Diana Walker at the workshop.)

While the impacts do not appear to have affected dugong populations, the seagrass loss had an impact on the abundance and distribution of blue swimmer crabs and brown tiger prawns, with consequences for both fisheries.

2.3.2 Salinity

Shark Bay has a strong salinity gradient from marine to metahaline to hypersaline (Figure 2). This is caused by a combination of the seagrass banks, high evaporation rates, shallow water and climate. Water in L'haridon Bight and Hamelin Pool is almost twice as salty as the open ocean. The high salinity conditions mean that the waters are relatively free of predators and competitors. This allows salt-tolerant species, like the cockleshell *Fragum erugatum* to flourish, leading to unusual phenomena such as Shell Beach. The hypersaline Hamelin Pool Marine Nature Reserve is the only marine nature reserve in Western Australia.

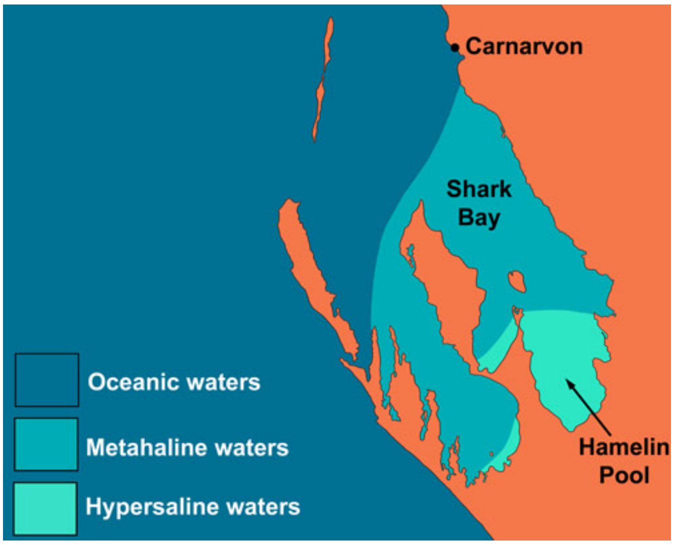

Figure 2. Shark Bay's salinity gradient (source: https://www.sharkbay.org/nature/geology/salinity/)

[9] *Shark Bay: twin bays on the edge*, p 55

Flooding of Faure Sill due to sea-level rise would lead to a decrease in salinity which will impact *stromatolite value* (overgrowth of eukaryotes) and *hypersalinity value* (increased species diversity with increased grazing/scraping fish, gastropods, etc. and changes in biotic zonation). (Information provided by Erica Suosaari.)

2.3.3 Stromatolites

The hypersaline environment of Hamelin Pool (and consequent absence of predators) has allowed salt-tolerant micro-organisms to thrive and form microbial mats, which are diverse and complex ecosystems. When these mats trap particles and create stone they become microbialites. Tall, layered microbialites are called stromatolites. The micro-organisms that built the stromatolites are similar to those found in fossil evidence of the first life on earth, around 3.7 billion years ago. The Shark Bay stromatolites are the world's most extensive and diverse system of living stromatolites.

Climate impacts on stromatolites

- Suppression of groundwater. Evidence suggests that having a seasonal influx of fresh water is important for stromatolites. The water gets less saline with groundwater input during the time of the year that the sea level is lower, suggesting that sea-level rise will increase hydrostatic pressure, inhibiting groundwater infiltration.
- Increased storms/increased precipitation/storm surge would topple stromatolites and increase turbidity, impacting on the *stromatolite and seagrass value*. Erosion and runoff of fine terrigenous sediments could smother the stromatolite building microbial mats.
- Changing wind patterns could affect how the water piles up on different sides of the basin, impacting the seasonal function of water levels experienced by microbial surface communities, so impacting on *stromatolite value*. Changing winds may also lead to changing morphology of stromatolites, which reflects wind/current patterns for the last thousand+ years.
- Increased temperatures and extreme heat events will impact on *seagrass value, hypersaline value* and possibly *stromatolite value*. Increased temperature will have an unknown effect on stromatolites (Brendan Burns has shown that the microbes can experience stress under high temperatures). Stromatolites generally thrive in extreme environments, so the effect of increased heat events on them is unclear. Extreme heat events will likely result in a die-off of the seagrass, which could cause a destabilisation of the Faure Sill and associated flooding with open marine water (decreased salinity).
- Reduction in carbonate precipitation will impact on *stromatolite value* and *carbonate dominated marine environment value*. Cementation of stromatolites and precipitation of grains will be reduced with increased ocean acidification. Preservation potential will be reduced. Stromatolite community may cease to build structures.

(Information provided by Erica Suosaari.)

2.3.4 Species

Shark Bay is a transition zone between temperate, sub-tropical and desert zones, contributing to its significant biodiversity. The region has 145 known plant species at their northern limit and 39 known plant species at their southern limit, and 230 species of birds.

There are 98 species of reptiles and amphibians, a number of which are at the northern end of their range.

There is a rich and diverse range of marine megafauna and marine life, including around 10% of the world's dugong population as well as dolphins, sharks, rays, fish and turtles – including Australia's largest nesting colony of loggerhead turtles.

Shark Bay's bottlenose dolphins have been studied since 1982 at Monkey Mia (eastern Shark Bay) and since 2007 at Useless Loop (western Shark Bay). Shark Bay's dolphins have incredibly complex social behaviour, with multi-level alliance formation, tool use (sponges and shells) and cooperation.

Following the 2011 marine heatwave, researchers identified more 'shelling' activity (where the dolphins use large shells to catch fish then tip them into their mouths), fewer calves born and a decline in survival (less so for 'sponging' dolphins, that is, those that use sponges as beak guards while foraging for fish).

(This information was presented by Simon Allen at the workshop. More information about Shark Bay's dolphins is available at www.sharkbaydolphins.org.)

The islands of Shark Bay also provide refuges for wild populations of endangered and threatened animals. There are over 120 isolated islands in Shark Bay. Bernier and Dorre Islands are nature reserves and are home to some species now found nowhere else in wild populations – banded hare wallaby, rufous hare wallaby (Mala), western barred bandicoot and Shark Bay mouse. The islands are relatively free of feral cats, foxes and rabbits. Dirk Hartog Island, a national park, was recently declared feral herbivore free and cat free in the southern section, allowing for the introduction of banded and rufous hare-wallabies. Salutation Island is home to a thriving population of re-introduced stick nest rats (which became extinct on the mainland in the 1930s, although they were once found throughout south and western arid Australia).[10]

The 2010/11 marine heatwave and above-average summer temperatures in the following two summers had a significant impact on key fisheries in Shark Bay.[11]

The 2011 commercial scallop catch in Shark Bay that started just after the heatwave event was well below the prediction based on a fishery-independent survey in November 2010. This was attributed at the time to poor growth and mortality of scallops with fishers also reporting poor meat quality. The October and November 2011 scallop survey in Shark Bay showed very low recruitment and poor survival of 1+ scallops that had been left behind after fishing ceased in the middle of that year. This low abundance resulted in closure of the fishery between 2012 and 2015. Recruitment in Denham Sound has since returned to historic levels but northern Shark Bay continues to fluctuate at relatively low abundance.

[10] Greater stick-nest rat fact sheet. https://www.sharkbay.org/wp-content/uploads/2017/04/Greater-Stick-nest-rat.pdf

[11] Caputi et al. 2015 doi:10.13140/rg.2.1.2240.7200 and Caputi et al. 2016. doi:10.1002/ece3.2137

The Shark Bay crab fishery produced reasonable catches immediately after the marine heatwave but the abundance dropped rapidly by the middle of the year with a very low recruitment to the fishery in 2011/12. While the warm temperatures during the juvenile phase in the summer showed a negative effect on recruitment, warm temperatures during the autumn/winter spawning appears to be beneficial to recruitment. The cause of the low recruitment to the fishery in 2011/12 was considered to be a combination of a very cool winter in 2010 followed by the 2011 heatwave event. The stock abundance has returned to historic levels.

There were above-average catches of brown tiger and western king prawns after the 2011 heatwave event; however, there was an apparent shift in the distribution of the brown tiger prawns in the eastern part of the bay (this is regarded as the key tiger prawn spawning area). A very low spawning stock abundance was recorded for 2012 in this area. The higher summer sea surface temperature in 2010/11 that affected the seagrass may have influenced recruitment and distribution in subsequent years.

While crabs, scallops and prawns have relatively short life cycles (two to three years), demersal scalefish such as pink snapper can live for 30 years, reaching maturity after four to six years. Very low numbers of three- to four-year-old fish were found in commercial catches in oceanic waters outside Shark Bay during 2015. This suggested poor recruitment in 2011, 2012 and possibly 2013 spawning seasons within Shark Bay, when the very high temperatures associated with the marine heatwave event and related environmental conditions may have negatively impacted spawning and subsequent recruitment.

3. Climate change

3.1 Weather, climate, climate variability and climate change

Weather is how we experience climate, but weather and climate are not the same thing. Weather refers to atmospheric conditions and events that occur over short periods of time, typically hours to days. Climate is the average pattern of weather over an extended period of time, typically around 30 years.

Climate is what you expect, weather is what you get.[12]

The climate is not uniform, but varies over months, years and decades (Figure 3). These variations are due to natural processes. On a timescale of months, climate varies due to seasonal cycles. On a timescale of years, the El Niño–Southern Oscillation[13] causes variations in climate, while climate variability at a decadal timescale is influenced by processes such as the Pacific Decadal Oscillation.[14]

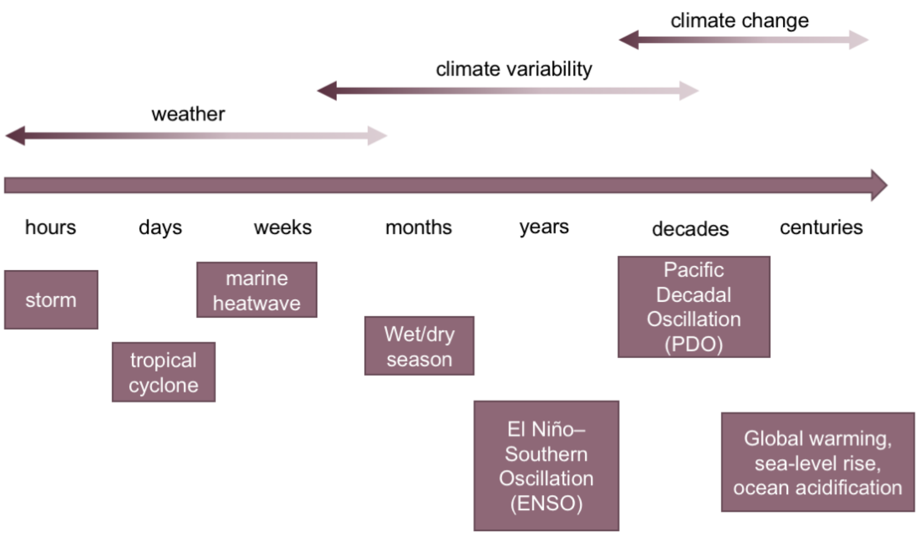

Figure 3. Climate and weather time scales

Climate change refers to long-term changes in the average pattern of weather that occur over decades, centuries or longer. It is the result of natural and man-made processes. Since industrialisation, rapidly increasing concentrations of greenhouse gases in the atmosphere have resulted in global warming. As the climate becomes warmer, other climate processes also change.

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[12] Often attributed to Mark Twain, this quote is from Robert A. Heinlein's 1973 science-fiction novel, *Time Enough for Love*.

[13] http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml?bookmark=enso

[14] https://www.metoffice.gov.uk/videos/5580792782001

3.2 What influences Western Australia's climate?

As global temperatures increase, the hydrological cycle intensifies and atmospheric circulation patterns change, the tropical belt widens and winter storm tracks and subtropical dry zones move towards the poles. In Western Australia, the subtropical ridge, Indian Ocean Dipole, El Niño–Southern Oscillation and Madden-Julian Oscillation help shape the climate (Figure 4).

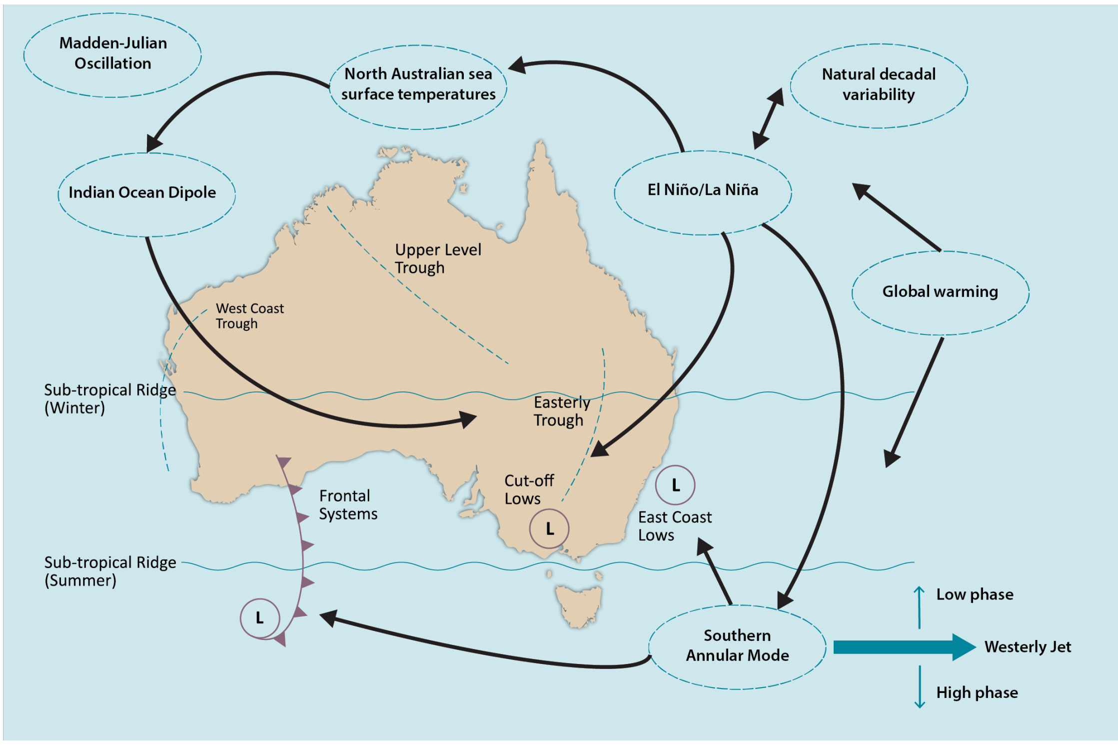

Figure 4. Climate influences on Western Australia (Source: ESCC Hub)

The **subtropical ridge** runs across a belt of high-pressure systems. In summer it sits to the south of the continent but moves northwards over central Australia in winter. The movement of the subtropical ridge is related to the monsoon trough that brings cloud and rain to northern Australia. As the subtropical ridge moves south, the monsoon moves over the northern part of Australia. As the subtropical ridge moves north, the monsoon moves northwards. The subtropical ridge can block rain-bearing fronts from the west.

The **Indian Ocean Dipole** (IOD) is the difference in sea surface temperature (SST) between the eastern and western tropical Indian Ocean. In its positive phase, when SST in the west is warmer than normal and SST in the east (near Australia) is cooler than normal, rainfall can be reduced. In its negative phase, when SST near Australia is higher than average, rainfall can be enhanced.

The **El Niño–Southern Oscillation** (ENSO) is a natural cycle driven by SST and winds in the central and eastern tropical Pacific. An El Niño develops when trade winds weaken and SST in this region is warmer than usual. A La Niña is when the opposite occurs: winds are stronger and SST is cooler than usual. In a La Niña, the Leeuwin Current is stronger than usual, carrying warmer water further south along the Western Australian coast. The 2010/11 marine heatwave off the Western Australian coast occurred during a La Niña event. In an El Niño, the current weakens and ocean temperatures cool.[15]

The **Madden-Julian Oscillation** (MJO) is a ~60-day pulse of cloudiness/rain that moves eastwards around the topics. It can have an effect on the timing and intensity of the monsoon, leading to enhanced rainfall.

3.3 Observed climate trends

3.3.1 Temperature

In the Shark Bay region, annual mean surface air temperature has increased by around 1.0°C (~0.1°C /decade) since 1910 (Figure 5).

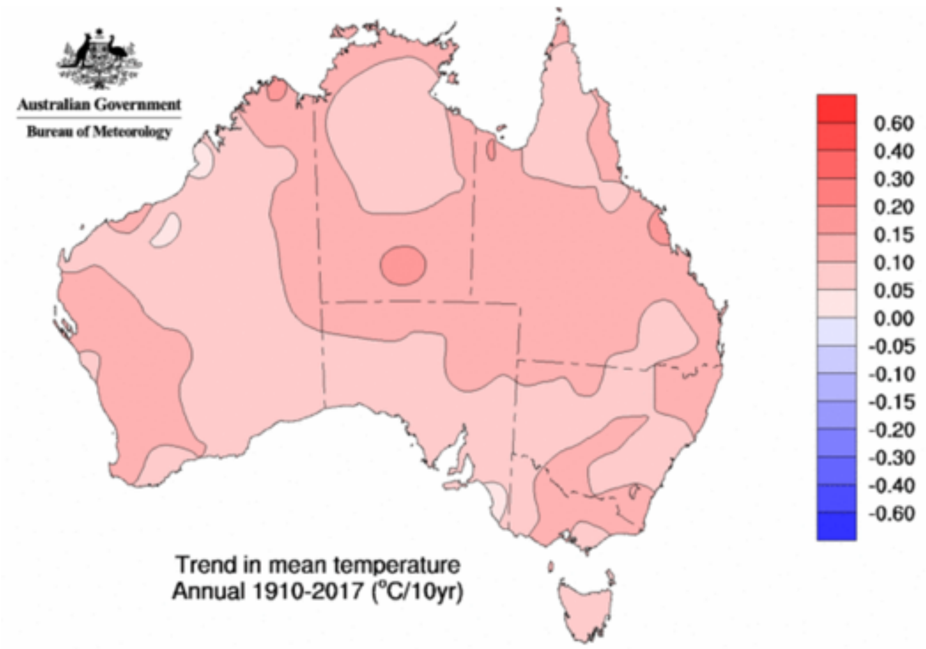

Figure 5. Trend in mean annual temperature for 1910–2017 in °C per decade. (source: Bureau of Meteorology)

3.3.2 Rainfall

Annual mean rainfall has decreased by 10 to 20 mm per decade since 1970 around Shark Bay (Figure 6).

[15] https://blogs.csiro.au/ecos/the-good-news-el-nino-story-for-western-australias-oceans/

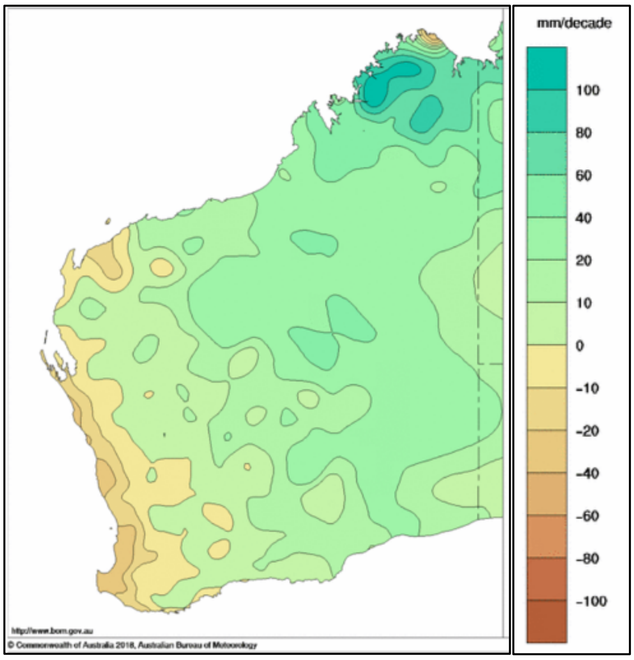

Figure 6. Mean annual trend in rainfall for 1970–2017 in mm per decade. (source: Bureau of Meteorology)

3.3.3 Sea surface temperature

Shark Bay sits adjacent to the south-west Australia marine ‘hot spot’ – a region warming faster than the global average. Sea surface temperature off the Western Australian coast has warmed around 1.2°C since 1960. The warming varies seasonally, with the maximum rate of increase occurring in summer (Figure 7). Local hydrodynamics within Shark Bay have a strong influence in modifying seawater coming into the bay from offshore. In summer, sea surface temperature within Shark Bay increases landward with intruding upwelled water cooling the bay. In winter, water from the Leeuwin Current warms the bay. This effect is greatest near the entrances.[16]

The Leeuwin Current is a warm, ocean boundary current that flows south from Indonesia along the west and south coasts of Australia. It is driven by the sea level in the Indonesian archipelago, which builds up in La Niña years (pushing more warm water south) and drops off in El Niño years. The Leeuwin Current is stronger in winter than in summer, and its year-to-year variability has profound impacts on marine ecosystems off the west and south coasts of Australia.

[16] www.wamsi.org.au/sites/wamsi.org.au/files/files/3_Workshop_Pattiaratchi_oceanography_s.pdf

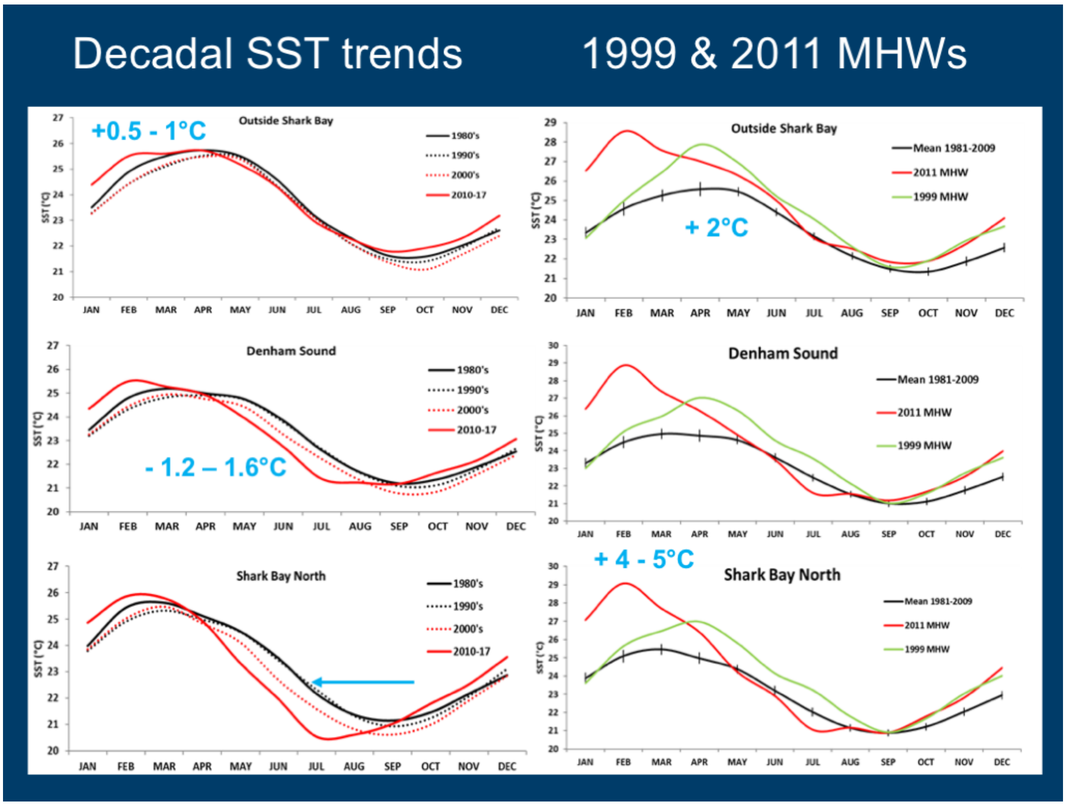

Figure 7. Decadal sea surface trends (left) and marine heatwave water temperature (right) presented by Arani Chandrapavan (Department of Primary Industries and Regional Development) at the workshop. Plots use satellite data from www.esrl.noaa.gov/psd/.

3.3.4 Marine heatwaves

Shark Bay has experienced two significant marine heatwaves, in 1999 and 2011 (Figure 7). In the summer of 2010/11, SST increased to up to 5°C above average along Western Australian coast due to the combined effects of long-term warming, a strong La Niña, and strengthening of Leeuwin Current.

3.3.5 Leeuwin Current

The Leeuwin Current is influenced by large-scale processes such as the Pacific Decadal Oscillation and ENSO. During La Niña, there is strengthening of the Leeuwin Current resulting in higher sea levels and warm waters are transported further south along the Western Australia coast. Conversely, during El Niño, there is lower sea levels and a weaker current.

3.4 Looking to the future

With the past climate no longer being a good indicator of what we can expect in the future, climate projections are useful tools for planning ahead. Climate projections are developed using global climate models, which simulate the future climate based on emissions scenarios (see *Representing emissions*, next page). They can be from an individual model, or the mean of many models (known as the multi-model mean). Projections are presented as averages over 20-year periods. For convenience they are referred to by the central year in the period, so projections for 2070 actually cover 2060–2079. Projections are relative to a baseline time period (e.g. 1986–2005), so if a projection was for a 2°C increase in temperature, it is relative to the baseline period and can be presented as the change between the historic and the future (e.g. an increase of 2°C), or change applied to an observational dataset (e.g. mean annual temperature of 30°C).

Climate projections are not predictions. A prediction estimates a sequence of events in the future, including the effect of climate change and variability. Given the timescale and uncertainties (such as emissions concentrations) associated with climate change, predictions are not possible. Instead, we use projections, which tell us about the likely response of the climate system to a possible future scenario. Climate projections do not tell us the climate of a particular day or month or predict a specific series of events, but rather how the probabilities of climate conditions (including the changing odds of extremes) may change in our changing climate.

3.4.1 Global climate models

Global climate models (GCMs) are mathematical representations of the climate system based on the laws of physics. They take into account interacting processes that shape the global climate, including atmospheric dynamics and physics, oceans and sea ice, land surface processes, and aerosols, carbon and biogeochemical cycles. The models are very complex and run on powerful supercomputers.

GCMs have been developed in many centres around the world and are continually being improved. A global project – the Coupled Model Intercomparison Project (CMIP) – coordinates experiments and data archiving of climate model simulations. The most recent phase of this project, CMIP5, contains simulations from 60 models from 28 modelling centres (including ACCESS, Australia’s national climate model).[17]

GCMs are tested for their ability to reproduce past climate, including mean values; seasonal cycle; major processes (e.g. monsoon). The better they are at reproducing the past, the more confidence we have in their simulations of the future.

3.4.2 Representing emissions

GCMs are comprised of various sub-models that interact to project rates of global warming for different concentrations of greenhouse gases and aerosols. While the laws of physics govern the climate system, they cannot tell us about social, political and economic aspects of the future, which will have a bearing on emissions. Instead, the science community defined a set of four future scenarios called representative concentration pathways (RCPs) that represent a range of economic, technological, demographic, policy and institutional futures (Table 1).

[17] https://pcmdi.llnl.gov/mips/cmip5/availability.html

Table 1. Summary of representative concentration pathways (RCPs)

	At the end of the century (2100)		
RCP	**CO_2 concentration***	**Radiative forcing****	**Warming*****
2.6 (low emissions)	420 ppm	2.6 W m^{-2}	0.3°C to 1.7°C
4.5	540 ppm	4.5 W m^{-2}	1.1°C to 2.6°C
6.0	660 ppm	6.0 W m^{-2}	1.4°C to 3.1°C
8.5 (high emissions)	940 ppm	8.5 W m^{-2}	2.6°C to 4.8°C

* 2018 CO_2 concentration is 407 ppm
** Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere; more forcing = more warming.
*** Global mean surface warming for 2081–2100 relative to 1986–2005.

Because of natural variability in the climate, results from the different emissions scenarios are quite similar to 2030 – after this time, the higher the emissions, the more climate change signal is evident by 2100.

It is worth noting that these RCPs were developed prior to the Paris Agreement, so they do not align directly with the Paris targets of 1.5°C and 2.0°C (relative to pre-industrial) by 2100. However, RCP2.6 *could* be regarded as a trajectory that would arrive at around 1.5°C warming by 2100 – but this change is relative to 1986–2005, not pre-industrial (mid 1800s).

3.4.3 Confidence in projections

Our confidence in climate change projections is determined by considering climate model results along with our physical understanding of the climate system and past observations. Confidence is higher for some projections (e.g. temperature) than others (e.g. rainfall).

Confidence is based on the direction and size of the long-term trend, not the ups and downs each year (Figure 8). This is why projections are delivered as 20- or 30-year averages – to account for the year-to-year variability and so capture the overall trend.

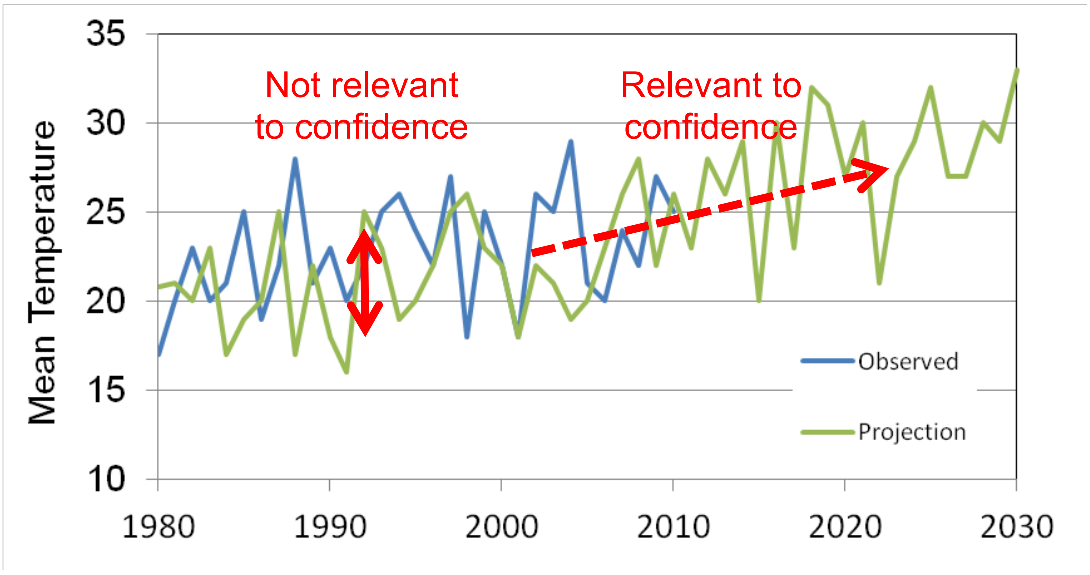

Figure 8. Confidence in climate change projections is based on the direction and size of the long-term trend, not the year-to-year variability. (source: workshop presentation by Vanessa Hernaman)

3.5 Shark Bay's future climate

While we do not know exactly how the future will unfold in the decades out to 2100, we can draw on climate change science to tell us what the future climate might be like.

We can use science-based climate change information to provide the evidence for understanding risk and developing 'climate smart' policies and plans for sectoral adaptation and disaster risk management.

Using the latest climate science and modelling, climate projections can help us plan for a smaller range of options by narrowing down the range of possible future climates.

3.5.1 Australia's national climate change projections

Australia's national climate change projections[18] were developed by CSIRO and the Bureau of Meteorology in 2015 for the Commonwealth Natural Resource Management funded projections project. They are reported on the basis of clusters, which correspond to the broadscale climate and biophysical regions of Australia (Figure 9). Shark Bay is in the Rangelands (South) sub-cluster.

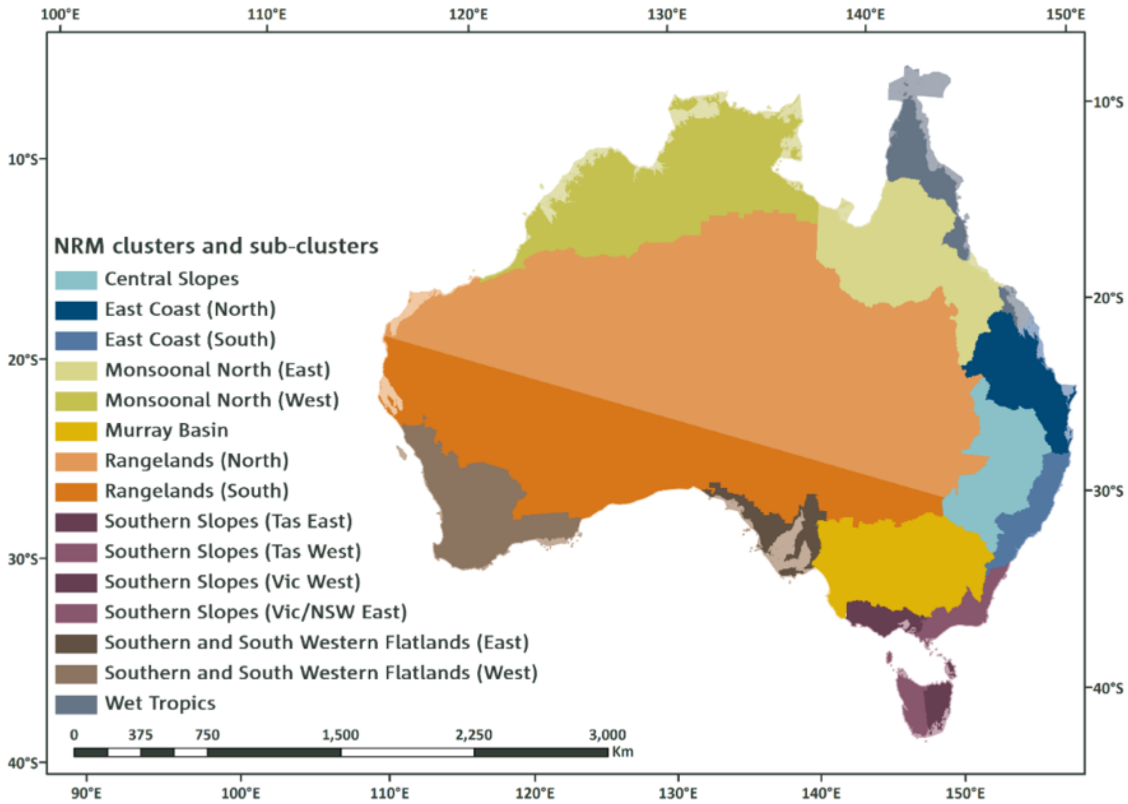

Figure 9. Clusters and sub-clusters used in Climate Change in Australia

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[18] Climate Change in Australia, www.climatechangeinaustralia.gov.au

The following projections are for the Rangelands (South) sub-cluster taken from the Rangelands cluster report[19] unless noted otherwise. The appendix of the Rangelands report contains a table of annual and seasonal projections for nine climate variables (temperature, daily maximum temperature, daily minimum temperature, rainfall, wind speed, solar radiation, relative humidity, evapotranspiration, soil moisture) for three emission scenarios (RCP2.6, RCP4.5 and RCP8.5) and two time periods (2030 and 2090). Projections for five marine variables (sea-level rise, sea surface temperature, sea surface salinity, pH and aragonite saturation) are also included. Where available, this workshop report also provides some projections for 2050.

3.5.2 Temperature

Average temperatures are projected to continue to increase in all seasons (*very high confidence*).

Table 2. Projected annual average warming (°C) relative to 1986–2005

	RCP 2.6	RCP 4.5	RCP 8.5
2030	0.6–1.2	0.6–1.2	0.7–1.3
2050	0.7–1.5	1.0–1.8	1.4–2.4
2090	0.6–1.7	1.3–2.6	2.8–5.1

3.5.3 Extreme temperature

More hot days and warm spells are projected with a substantial increase in the temperature reached on hot days, the frequency of hot days, and the duration of warm spells (*very high confidence*). What we currently consider an extreme will become the new norm as we move through the century. For example, in 2030, an average year is slightly warmer than the 2013 record (Figure 10).

Table 3. Projected number of extreme heat days (>35°C and >40°C) for Denham and Carnarvon in 2030 and 2090[20]

	Historic (1981–2010)	2030 (RCP4.5)	2090 (RCP4.5)	2090 (RCP8.5)
Annual average no. days max temp >35°C				
Denham	27	34 (32–35)	42 (38–47)	65 (52–77)
Carnarvon	26	34 (31–36)	43 (37–48)	69 (53–84)
Annual average no. days max temp >40°C				
Denham	6	9 (8–10)	12 (10–13)	19 (15–23)
Carnarvon	5	7 (6–8)	10 (8–12)	19 (13–24)

19 https://www.climatechangeinaustralia.gov.au/media/ccia/2.1.6/cms_page_media/172/RANGELANDS_CLUSTER_REPORT_1.pdf

20 Extracted from www.climatechangeinaustralia.gov.au

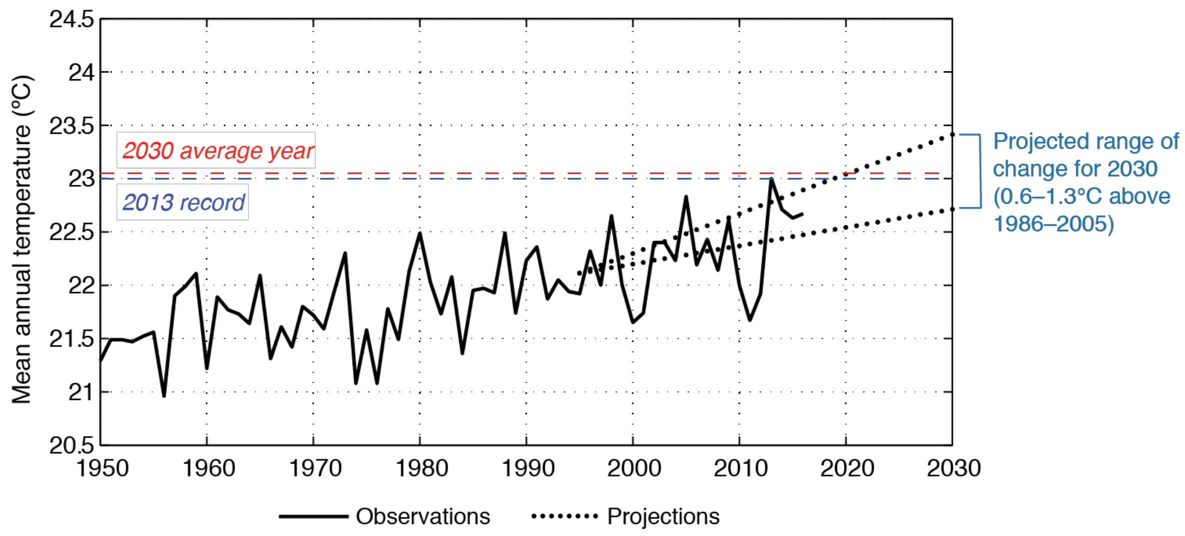

Figure 10. Temperatures that we currently consider extreme will become the norm in the future (source: Using climate change information to 2030[21])

Projections for additional temperature extremes for the Shark Bay council area are available on the CoastAdapt website (coastadapt.com.au). These projections are the multi-model means from eight climate models, averaged over 30-year periods (so 2030 is 2016–2045). Only the mean is provided in the table below. See the website for information about the range.

Table 4. Projected number of extreme hot days, warm nights and heatwaves for Shark Bay shire in 2030 and 2090[22]

	Historic (1981–2010)	2030 (RCP4.5)	2090 (RCP4.5)	2090 (RCP8.5)
Hot days Mean annual no. days max temp >30°C	89	110	131	183
Warm nights Mean annual no. days max temp >30°C	7	14	24	58
Heatwaves Average of longest run of days in each year with max temp >30°C	14	20	26	56

3.5.4 Rainfall

In the near future (2030) natural variability is projected to dominate over trends from greenhouse gas emissions. Winter rainfall is projected to decrease (*high confidence*), due to the southward shift of winter storm systems together with rising mean atmospheric pressure. Changes to summer and autumn rainfall are possible but are less clear because changes in these seasons are more strongly linked to the large-scale pattern of tropical sea surface temperature which varies considerably among models.

[21] http://nespclimate.com.au/wp-content/uploads/2017/10/Using-climate-change-information-to-2030.pdf

[22] https://coastadapt.com.au/sea-level-rise-information-all-australian-coastal-councils#WA_SHARK_BAY

Table 5. Projected average change in rainfall (%) for 2030 and 2090 relative to 1986–2005

	2030 (RCP4.5)	2090 (RCP4.5)	2090 (RCP8.5)
Annual	–14 to 7	–19 to 7	–29 to 13
Summer	–22 to 10	–24 to 12	–24 to 21
Autumn	–23 to 18	–25 to 22	–42 to 29
Winter	–25 to 18	–36 to 6	–46 to 1
Spring	–18 to 17	–26 to 15	–53 to 22

3.5.5 Extreme rainfall

Extreme short-duration rainfall (e.g. hourly, daily) is projected to intensify with *high confidence*, even in regions where mean rainfall decreases. This is because a warming atmosphere can hold more moisture. Increases in rainfall extremes have already been observed for short duration (3-hour or less) rainfall.

The increase in intense rainfall can be even greater when the increased moisture in the air provides more energy for storms. This is already evident in the most extreme hourly rainfall, particularly in summer storms. Almost all models agree that the wettest day of the year will get wetter, regardless of the scenario.

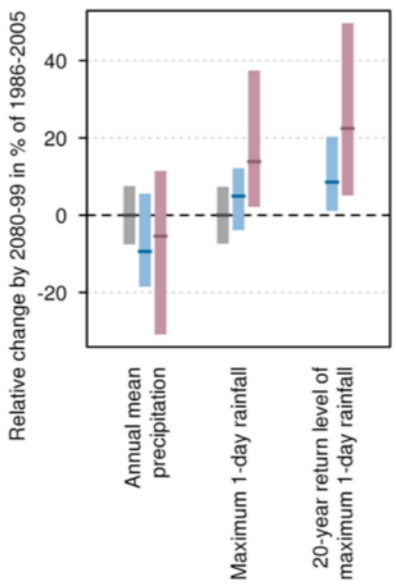

Figure 11. Projected change in rainfall extremes (%) for 2090 relative to 1986–2005. RCP4.5 (lower emissions scenario) in blue and RCP8.5 (high emissions scenario) in pink. The grey bars represent natural climate variability.

Changes in the frequency of short-duration rainfall events are more difficult to project, because global climate models run at too coarse a resolution to simulate the small-scale systems that lead to these events, and because frequency is also influenced by future circulation changes that will affect changes in storms and weather systems. This is an active area of climate research.

3.5.6 Tropical cyclones

Fewer but more intense tropical cyclones are projected (*medium confidence*).

3.5.7 Wind

Average surface winds over the Rangelands are mostly south-easterly in summer and westerlies in winter. A small winter decrease in wind associated with the southward shift of westerlies in winter is projected. Due to limited understanding of physical mechanisms, there is only *low confidence* in the projections for an increase in wind speeds in spring despite strong model agreement.

3.5.8 Fire weather

Bushfire in the Rangelands depends highly on fuel availability, which mainly depends on rainfall. Given sufficient fuel availability, ignition, fuel dryness, and suitable weather conditions for fire spread (i.e. hot, dry, and/or windy) are also factors. Future fire weather risk can be projected using the Forest Fire Danger Index (FFDI), which captures two of the factors (fuel dryness and conditions for spread) and is calculated using daily maximum temperature, relative humidity, wind speed, rainfall, and an estimate of fuel state provided by the drought factor, which is estimated from 1- and 5-day rainfall plus a soil moisture index. A tendency toward increased fire weather risk is expected in future, due to higher temperature and lower rainfall, but there is *low confidence* in the magnitude of fire weather projections.

3.5.9 Evaporation

Potential evapotranspiration is projected to increase in all seasons as warming progresses (*high confidence*).

3.5.10 Humidity

Little change in relative humidity is projected for the near future (2030) while later in the century a decrease is projected in winter and spring (*high confidence*) and in summer and autumn (*medium confidence*). The decreasing trend in winter and spring is due to the increased moisture holding capacity of warming atmosphere, and greater warming of land compared to sea. This leads to increases in relative humidity over the ocean and decreases over continents.

3.5.11 Solar radiation

There is little change projected for solar radiation in the near future (2030), and for later in the century, increased radiation is projected in the south in winter (*medium confidence*). Increased winter radiation is related to decreases in cloudiness associated with reduced rainfall. Changes to radiation can be caused by changes to cloud cover or to the presence of aerosols in the atmosphere, or can decrease due to thermally driven increases of water vapour in the atmosphere.

3.5.12 Sea level

Mean sea level will continue to rise and height of extreme sea-level events will also increase (*very high confidence*).

The following projections (Table 6 and Figure 12) are for open coast. They account for thermal and dynamic influences on sea level, including changes in ocean currents (but not wave height), but not for local land movements. Additional changes are possible for closed bays or estuaries.[23]

Table 6. Sea-level rise for Shark Bay shire area relative to 1986–2005 (source: Coast Adapt)

	2030	2050	2070	2090
RCP2.6	0.11 (0.07–0.16)	0.20 (0.13–0.28)	0.30 (0.18–0.42)	0.38 (0.22–0.56)
RCP8.5	0.12 (0.08–0.17)	0.24 (0.16–0.33)	0.41 (0.26–0.55)	0.61 (0.39–0.84)

The rate of change at 2100 under RCP2.6 is 4.1 mm/year, or 11.0 mm/year under RCP8.5.

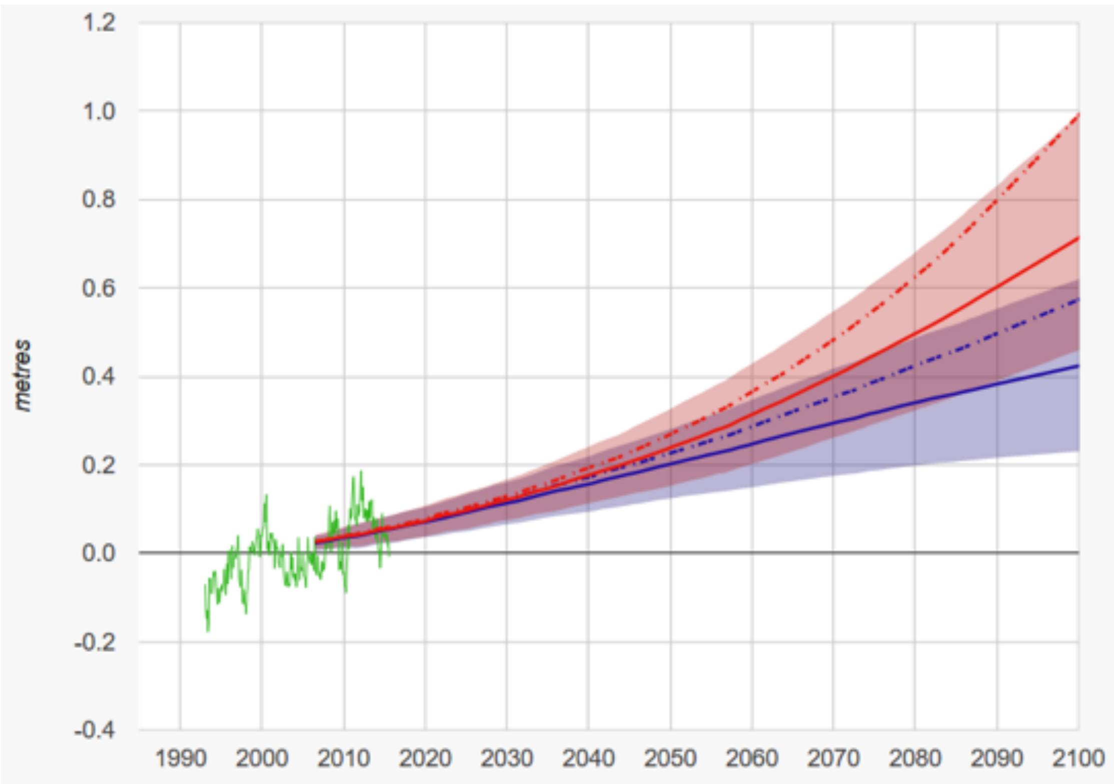

Figure 12. Sea-level rise (solid lines) and allowances (dashed lines) for Shark Bay shire area (RCP2.6 purple, RCP8.5 red). An allowance is the height that coastal defences would need to be raised in order to provide the same level of protection as they do today. Green line is observed data (satellite); sea-level rise is relative to 1986–2005 average; shaded area is likely range for each scenario. (source: CoastAdapt)

[23] www.coastadapt.com.au

3.5.13 Coastal extremes

Long-term sea-level rise can exacerbate event-based extreme sea levels caused by combination of factors including astronomical tides, storm surge and wind-waves.

3.5.14 Sea surface temperature

Table 7. Median sea surface temperature projections (°C) for Carnarvon relative to 1986–2005

Time	RCP	SST (°C)
2030	RCP4.5	0.7 (0.4 to 0.9)
2090	RCP4.5	1.3 (1.1 to 1.7)
2090	RCP8.5	2.6 (2.4 to 3.5)

3.5.15 Ocean chemistry

Projections are available for a number of ocean chemistry variables, including salinity, pH and aragonite saturation (aragonite is the form of calcium carbonate used by corals, clams, oysters and foraminifera to build shells and skeletons).

Time	RCP	Sea surface salinity (g/kg)	Ocean pH	Aragonite saturation
2030	RCP4.5	-0.08 (-0.23 to 0.18)	-0.07 (-0.07 to -0.06)	-0.34 (-0.37 to -0.29)
2090	RCP4.5	-0.15 (-0.43 to -0.04)	-0.14 (-0.15 to -0.14)	-0.73 (-0.77 to -0.68)
2090	RCP8.5	-0.14 (-0.63 to 0.30)	-0.31 (-0.32 to -0.30)	-1.45 (-1.53 to -1.33)

Salinity projections span a wide range that includes increases and decreases. Salinity will also be affected locally by increased fresh water from river discharges.

Around 30% of all anthropogenic carbon dioxide emitted over the past 200 years has been absorbed by oceans, which has led to 0.1 unit decrease in global surface ocean pH.

The projections provided above are for the open ocean, but for estuaries and bays, such as Shark Bay, local hydrodynamics are also important as they can modify the seawater characteristics such that the salinity and temperature within the bay can be very different to that outside it (Figure 13).

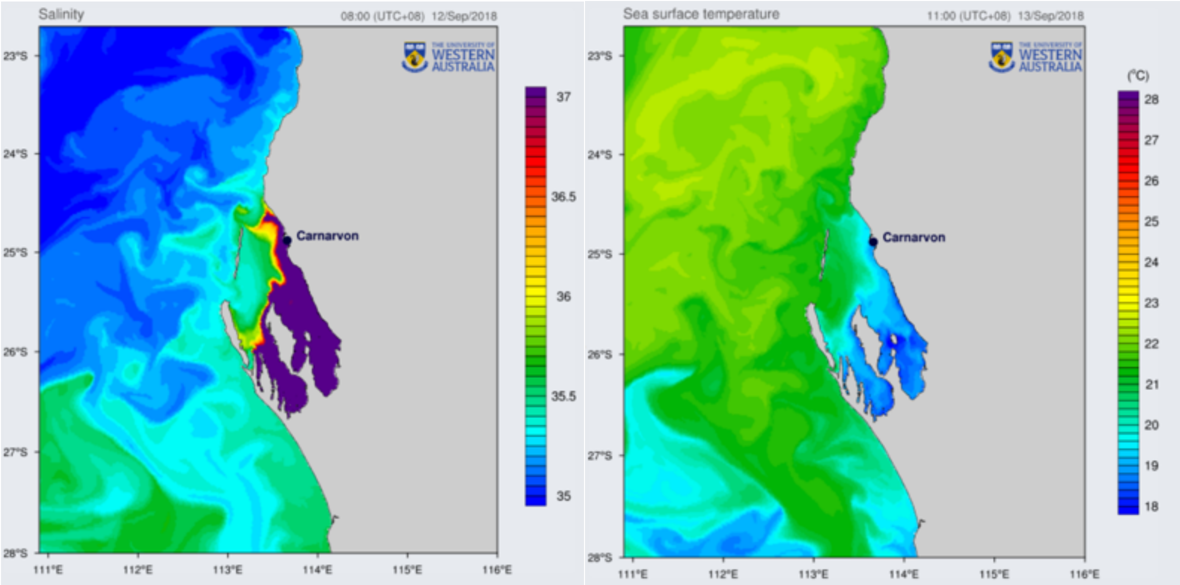

Figure 13. Salinity (left) and sea surface temperature (right) within Shark Bay can be very different to that outside it due to local hydrodynamics.[24]

3.5.16 Leeuwin Current

While most climate models project a decrease of the strength of the easterly trade winds along the equatorial Pacific, there are uncertainties about the magnitude of the changes. A decrease in the easterly winds corresponds to a weakening trend of the Leeuwin Current.

[24] www.wamsi.org.au/sites/wamsi.org.au/files/files/3_Workshop_Pattiaratchi_oceanography_s.pdf

4. How will climate change affect the values of the Shark Bay World Heritage Area?

This section outlines the process and results of a rapid risk assessment tool used in the workshop to lay the foundations for the development of a Climate Change Adaptation Strategy and Action Plan for the Shark Bay World Heritage Property.

The Climate-change Vulnerability Index (CVI) is being developed by Jon Day, Scott Heron and Imogen Zethoven to provide a method for systematically assessing climate change impact across all World Heritage properties. Its use at this workshop served to:

- Road test the methodology
- Identify possible areas of focus for the development of a climate change adaption strategy and action plan.

4.1 Developing the CVI

Workshop participants worked through the following steps to develop the CVI for the Shark Bay WHA:

1. Reviewing the significant values for Shark Bay – including attributes of OUV and other values.
2. Identifying relevant climate drivers[25] (potential climate stressors).
3. Identifying the potential impacts of climate change on these values.
4. Conducting a high-level risk assessment (likelihood and consequence) of these impacts to identify the three key potential climate stressors likely to impact on the Shark Bay values within a specified time frame.
5. Considering related physical, ecological, economic and social impacts.
6. Considering the likely adaptive capacity in relation to the three key potential climate stressors.
7. Using a spreadsheet-based model to consider the vulnerability of Shark Bay's OUV to the three key potential climate stressors.

The CVI framework followed that of the *North American MPA Rapid Vulnerability Assessment Tool*[26], which was modified from the IPCC Vulnerability Framework[27]. As noted

[25] The CVI process uses the term 'climate drivers' to refer to aspects of the climate system that will be affected by climate change and impact on Shark Bay. However, in climate change science, a 'climate driver' is understood to be something that alters the energy balance of the climate system (e.g. aerosols, greenhouse gases, solar radiation, land surface properties). This report uses the term 'potential climate stressors' to avoid confusion with reports and data in wider climate change literature.

[26] http://www3.cec.org/islandora/en/item/11733-north-american-marine-protected-area-rapid-vulnerability-assessment-tool-en.pdf

[27] https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch19s19-1-2.html

in the latter, assessment of vulnerability involves scientific uncertainty and value judgements.

For the rapid assessment of the CVI, framework components (Figure 14) were evaluated using a categorical system, with category thresholds drawn from various existing resources. Since the Shark Bay workshop, and with further consultation with vulnerability experts and practitioners, the CVI framework has adopted the (unmodified) IPCC Vulnerability Framework (as applied in the Third and Fourth Assessment Reports). In this the elements Likelihood, Consequence and Risk are substituted by Exposure, Sensitivity and Potential Impact, respectively. However, the process of the rapid assessment of the CVI is such that the outcomes identified for Shark Bay will remain valid under both versions of the framework.

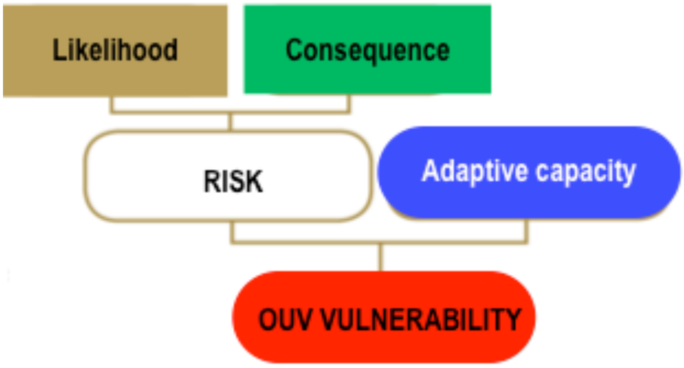

Figure 14. The Climate-change Vulnerability Index framework

4.1.1 Significant values and relevant potential climate stressors

The values considered in this rapid risk assessment were the attributes of Shark Bay's OUV at the time of listing. These values are fixed. There may be global (e.g. Ramsar, CITES) and local values that will need to be identified and considered in addition to OUV in the development of a climate change adaptation strategy and action plan.

A list of 15 potential climate stressors (seven atmospheric, eight marine; Table 8) was provided to streamline and standardise the rapid risk assessment process. The list is for application across all World Heritage sites, with relevant stressors for each site identified during the CVI process. Stressors were identified as either chronic (persistent over long periods) or acute (high intensity, short period). The CVI uses the synonyms in Table 8 to facilitate understanding of these stressors.

Table 8. Potential climate stressor used to develop the Climate-change Vulnerability Index.

Potential climate stressor	Synonyms	Time frame
Atmospheric		
Air temperature change	*Warming; seasonal shift; hotter average weather; increase evaporation; desiccation; fire frequency and intensity*	Chronic
Change in wind	*Gale; gusts; storms … also changes in wind direction?*	Chronic
Drought frequency and severity	*Aridity; dehydration; below average rainfall; prolonged water shortage*	Chronic
Extreme temperature events	*Heatwaves, bleaching; hot spell; desiccation*	Acute
Humidity change	*Evaporation; moisture content; oppressiveness; condensation; clamminess; sweatiness*	Chronic
Precipitation change	*Rainfall; rainstorms; showers; drizzle; heavy dew; hailstorms; sleet; snow*	Chronic
Storm intensity and frequency	*Cyclone; hurricane; typhoon; blizzard; tornado; storminess*	Acute
Marine		
Water temperature change	*SST; warming; seasonal shift*	Chronic
Storm surge	*Storm floods; storm tides; coastal flooding; cyclones; hurricanes*	Acute
Storm intensity and frequency	*Cyclone; hurricanes; typhoon; waterspout; blizzard; storminess*	Acute
Extreme marine heat events	*Heatwaves; bleaching; hot spell; desiccation*	Acute
Sea level change	*Sea level rise; flooding; subsidence; post-glacial rebound; coastal vulnerability; coastal inundation*	Chronic
Precipitation change	*Rainfall; rainstorms; showers; drizzle; heavy dew; hailstorms; sleet; snow*	Chronic
Ocean acidification	*OA; pH change; acidity; calcification rate; chemical reaction; chemical change; CO_2/O_2 concentration*	Chronic
Changing ocean currents	*Ocean circulation; ocean dynamics; ocean 'conveyor belt'*	Chronic

Potential climate stressors likely to impact on each key value (i.e. attribute of OUV) were determined by workshop participants. The outcomes are recorded in Table 9.

Table 9. Potential climate stressors impacting on Shark Bay's OUV

Key values	Excerpts taken from Statement of OUV	Potential climate stressors impacting on key values
Seagrass	the Wooramel Seagrass Bank. Covering 103,000 ha, it is the largest structure of its type in the world one of the largest seagrass meadows in the world with the most seagrass species recorded from one area	air temperature change, change in wind, extreme marine heat events, extreme temperature events, precipitation change; ocean acidification; other water quality changes (salinity, dissolved oxygen, primary production)
Stromatolites	the most diverse and abundant examples of stromatolites (hard, dome-shaped structures formed by microbial mats) in the world	storm intensity and frequency, air temperature change, change in wind, extreme marine heat events, storm surge, precipitation change, sea level change, ocean acidification, salinity change
Geological significance	great geological interest due to the extensive deposit of limestone sands associated with the bank, formed by the precipitation of calcium carbonate from hypersaline waters	sea level rise, storm surge, storm intensity and frequency, change in wind, flooding events
Carbonate dominated marine environment	one of the few marine areas in the world dominated by carbonates not associated with reef-building corals	water temperature change, precipitation change, storm intensity and frequency, storm surge, extreme marine heat events, sea level change, ocean acidification

Key values	Excerpts taken from Statement of OUV	Potential climate stressors impacting on key values
Hypersaline waters	hydrologic structure of Shark Bay, altered by the formation of the Faure Sill and a high evaporation, has produced a basin where marine waters are hypersaline (almost twice that of seawater) the steep gradient in salinities, creating three biotic zones that have a marked effect on the distribution and abundance of marine organisms hypersaline conditions in Hamelin Pool have led to the development of a number of significant geological and biological features including the 'living fossil' stromatolites	water temperature change, storm surge, storm intensity and frequency, precipitation change, air temperature change, change in wind, extreme marine heat events, sea level change, ocean acidification, changing ocean currents, salinity change
Aesthetics	extensive beaches consisting entirely of shells profusion of peninsulas, islands and bays create a diversity of landscapes and exceptional coastal scenery	sea level change, precipitation change, storm surge, storm intensity and frequency (leading to increased water turbidity)
Evolutionary processes	one of the world's best examples of a living analogue for the study of the nature and evolution of the earth's biosphere up until the early Cambrian outstanding examples of processes of biological and geomorphic evolution taking place in a largely unmodified environment… including: evolution of the Bay's hydrological system the hypersaline environment of Hamelin Pool the biological processes of ongoing speciation, succession and the creation of refugia	storm intensity and frequency, air temperature change, change in wind, extreme temperature events, storm surge, precipitation change, sea level change, ocean acidification, drought frequency and severity, salinity change
Botanical significance	located at the transition zone between two of Western Australia's main botanical provinces a refuge for many globally threatened species of plants	precipitation change, extreme temperature events, drought frequency and severity, air temperature change, storm intensity and frequency, extreme marine heat events; sea level change
Threatened species	the only or major populations of five globally threatened mammals: • the burrowing bettong (now classified as Near Threatened) • rufous hare wallaby • banded hare wallaby • Shark Bay mouse • western barred bandicoot	air temperature change, change in wind, drought frequency and severity, extreme temperature events, humidity change, precipitation change, sea level change, storm surge
Marine turtles	sheltered coves and lush seagrass beds are a haven for marine species, including green turtle and loggerhead turtle (both Endangered), and the property provides one of Australia's most important nesting areas for this second species	marine heatwaves (affecting seagrass), air temperature change (at nesting beaches), storm intensity and frequency, change in wind (affecting water circulation), flooding (run-off and sediment into the bay) [timescale: short term]
Sharks and rays	large numbers of sharks and rays are readily observed, including the manta ray which is now considered globally threatened	water temperature change; other water quality changes

Key values	Excerpts taken from Statement of OUV	Potential climate stressors impacting on key values
Dugongs	one of the world's most significant and secure strongholds for the protection of dugong, with a population of around 11,000	marine heatwaves (affecting seagrass and habitat), flooding (mobile if they need to look for food in an event), water temperature change (changes in the distribution), storm intensity, sea level change [timescale: short term]
Whales and dolphins	increasing numbers of humpback and southern right whales use Shark Bay as a migratory staging post a famous population of bottlenose dolphin lives in the bay	water temperature change (chronic; the dolphin community in the east more affected than the west in the heat events?), storm intensity and frequency, more intense rainfall change, air temperature change [timescale: short term], whale foraging may be impacted
Integrity	impacts from pastoralism (grazing leases) and feral animals ecosystems in Shark Bay appear relatively unaltered by human impact, although this could change if terrestrial mining of mineral sands were to take place industrial activities such as salt and gypsum mining in the region, could comprise threats marine environment has undergone some modification through historically intensive pearl shell, fishing, trawling and whaling activities potential threats from: • improved technology in producing drinking water which would lead to increased tourism and residential density • upgrading of road access • agricultural developments to the east (dependent on water supply) • expansion of gypsum mining • introduction of intensive aquaculture or fishing technologies • petroleum exploration and extraction • unsustainable visitor use	storm intensity and frequency, precipitation change, extreme temperature events, air temperature change, extreme marine heat events, sea level change, water temperature change, drought frequency and severity (catchment flooding), ocean acidification, change in ocean currents, change in wind

Vulnerability to OUV was assessed for a 'business-as-usual' scenario (RCP8.5). When evaluating the likely impacts of the identified potential climate stressors, participants considered climate changes out to 2030 and 2050, having determined that impacts in the coming decades should take higher priority than those in the latter half of the century. With this time frame in mind, further discussion identified the most important potential stressors (up to three) for each key value (Table 10). The occurrence of each stressor was counted, allowing identification of the three most important stressors overall: **storm intensity and frequency** (eight occurrences), **extreme marine heat events** (five occurrences) and **air temperature change** (four occurrences). No other stressor was recorded more than three times. The methodology of counting the occurrence of each stressor implies equal weighting to all identified key values. Workshop attendees reflected on the priority of each key value and confirmed that the three potential climate stressors identified were the three most important.

Table 10. Most important potential climate stressors impacting on Shark Bay's key values (that contribute to OUV)

Key value	Most important potential climate stressors		
Seagrass	**extreme marine heat event**	**storm intensity and frequency**	
Stromatolites	**storm intensity and frequency**	change in wind	
Carbonate dominated marine environment	**extreme marine heat event**	**storm intensity and frequency**	
Hypersaline waters	water temperature change	**air temperature change**	
Aesthetics	**storm intensity and frequency**	storm surge	sea level change
Evolutionary processes	precipitation change	drought frequency	extreme temperature events
Geological significance	sea level change	change in wind	**storm intensity and frequency**
Botanical significance	drought frequency	precipitation change	**air temperature change**
Threatened species	drought frequency	precipitation change	**air temperature change**
Marine turtles	storm surge	**storm intensity and frequency**	**air temperature change**
Dugongs	**extreme marine heat event**	**storm intensity and frequency**	
Whales and dolphins	**extreme marine heat event**	**storm intensity and frequency**	water temperature change
Sharks and rays	water temperature change	**extreme marine heat event**	
Integrity			

4.1.2 Likelihood, consequence and risk

The likelihood of each of the three key potential climate stressors impacting OUV out to 2030 was assessed using the following scale:

Likelihood based on IPCC	**Very likely** >90%	**Likely** 67–90%	**Possible** 34–66%	**Unlikely** 10–33%	**Very unlikely** <10%

Similarly, the measure of consequence on OUV from each of the three key potential climate stressors was assessed using the following scale:

Consequence based on IUCN	**Catastrophic** Loss or substantial alteration of majority of values (esp. the key values comprising OUV) will occur	**Major** Loss or alteration of many values comprising OUV will occur, leading to a significant reduction of OUV	**Moderate** Some loss or alteration of some values comprising OUV will occur; but not causing a significant reduction of OUV	**Minor** Some loss or alteration of a few values comprising OUV will occur; but not causing persistent or lasting effects on OUV	**Negligible** All elements of OUV will remain essentially intact; overall condition of property is stable or improving

For each of the three key potential climate stressors, risk was determined using the following matrix:

Likelihood	Consequence				
	Negligible	Minor	Moderate	Major	Catastrophic
Very unlikely	low	low	low	low	low
Unlikely	low	low	moderate	moderate	moderate
Possible	low	moderate	moderate	high	high
Likely	low	moderate	high	high	extreme
Very likely	low	moderate	high	extreme	extreme

The likelihood, consequence and initial risk assessment are summarised in Table 11.

Table 11. Assessments of likelihood and consequence, and the initial risk assessment for the three most important potential climate stressors

	Air temperature change	Storm intensity and frequency	Extreme marine heat events
Time frame	Chronic	Acute	Acute
Likelihood	Very likely	Likely	Very likely
Consequence	Moderate	Major	Catastrophic
Initial risk	HIGH	HIGH	EXTREME

4.1.3 Applying modifiers

The CVI applies modifiers to both likelihood and consequence to account for temporal scale and trend (likelihood) and spatial scale and compounding factors (consequence). The effect of the modifiers above Level 1 is to amplify the likelihood and/or consequence (scaling by 1.0–1.3 in increments of 0.1 for each level), and thus increase the assessed risk. Modifiers were applied using the following scale:

Modifier	Level 1	Level 2	Level 3	Level 4
Likelihood				
Temporal scale The occurrence of each stressor and whether they are…	<1 event/ decade	1–5 events/ decade	5–10 events/ decade	on-going
Trend How the recent trend of the stressor has developed	declining/static	increasing slowly	increasing moderately	increasing rapidly
Consequence				
Spatial scale Extent (%) of WH property affected by climate change stressors at any one time	restricted <10%	localised 11–50%	extensive 51–90%	very widespread 91–100%
Compounding factors Is climate change likely to influence or interact with other non-climate stressors (e.g. invasive species) in the near future?	very unlikely/ unknown	low probability	medium probability	high probability

Table 12. Modified likelihood and consequence, and the final risk assessment for the three most important potential climate stressors in Shark Bay

	Air temperature change	Storm intensity and frequency	Extreme marine heat events
Time frame	Chronic	Acute	Acute
Modified likelihood	Very likely	Likely	Very likely
Modified consequence	Moderate–Major	Major–Catastrophic	Catastrophic
Modified risk	EXTREME	EXTREME	EXTREME
Value/s	Turtles – nest temperature, greater risk; Vegetation – lesser risk. Individual values can be affected differently.	Seagrass, habitat	Seagrass, marine fauna, coral
Notes	Don't know the ripple effect of one component being impacted interacting with another (unknown interactions/ unknowns)	Noted to have occurred and interacted with marine heatwave in 2011. Extreme rainfall (intense downpour) can occur in either winter or summer rains, not just cyclone-related rain.	A marine heatwave is an extreme event, driven by climate processes (ENSO, IOD)

The risk ratings for each of the three key potential climate stressors are **EXTREME**. It is notable that the consequence of extreme marine heat events is rated as catastrophic.

4.1.4 Adaptive capacity

Adaptive capacity describes the potential, capability or ability of a World Heritage property to adjust to climate change, to moderate potential damage, to take advantage of opportunities, or respond to the consequences.[28] In the CVI framework, adaptive capacity is considered in terms of the local management response, the level of scientific and/or technical support, and the effectiveness of these to address the climate stressor being considered (see the following matrix for scoring and In a situation where the resources available provide no effect to address the climate stressor, any identified adaptive capacity is nullified; where there is an effect, the adaptive capacity mitigates the risk of potential impact.

Table 13 for Shark Bay result).

Score	4	3	2	1
Local management response Capacity (i.e. resources, budget, knowledge) for management to respond at local level	high capacity	medium capacity	low capacity	no capacity and/or resources
Scientific/technical support Level of technical support for management at the local level	high level of support	medium level of support	low level of support	no support and/or scientific understanding

[28] After Foden et al. 2018. Climate change vulnerability assessment of species. *WIREs Climate Change*, doi: 10.1002/wcc.551

Effectiveness to address the climate stressor Extent to which local management will effectively address the climate stressor	high level of effectiveness	medium level of effectiveness	minimal/low level of effectiveness	very low/ negligible level of effectiveness

In a situation where the resources available provide no effect to address the climate stressor, any identified adaptive capacity is nullified; where there is an effect, the adaptive capacity mitigates the risk of potential impact.

Table 13. Adaptive capacity component scores and assessed level of adaptive capacity for the three key potential climate stressors in Shark Bay. Note that the order of colours is reversed from other usage to reflect that very low adaptive capacity is the least preferred category.

	Air temperature change	**Storm intensity and frequency**	**Extreme marine heat events**
Time frame	Chronic	Acute	Acute
Local management response	2	3	2
Scientific/ technical support	3	3	3
Effectiveness to address the climate stressor	1	2	1
Adaptive capacity	VERY LOW	LOW	VERY LOW

Where the adaptive capacity has an effect, it serves to mitigate the vulnerability of OUV, according to the vulnerability matrix below. This provides the OUV vulnerability for the property from the CVI framework, which for Shark Bay is the highest category – **HIGH**.

Risk	**Adaptive capacity**			
	Very low	Low	Moderate	High
Low	low	low	low	low
Moderate	moderate	moderate	low	low
High	high	moderate	moderate	low
Extreme	high	high	moderate	low

Table 14. Assessed risk and adaptive capacity combine to indicate the OUV vulnerability to the three key potential climate stressors and the overall OUV vulnerability for Shark Bay. Note that the order of colours is reversed from other usage to reflect that very low adaptive capacity is the least preferred category.

	Air temperature change	**Storm intensity and frequency**	**Extreme marine heat events**
Time frame	Chronic	Acute	Acute
Modified risk	EXTREME	EXTREME	EXTREME
Adaptive capacity	VERY LOW	LOW	VERY LOW
Vulnerability (climate stressor)	HIGH	HIGH	HIGH
Vulnerability (OUV)	HIGH		

Beyond assessment of OUV vulnerability, the CVI framework considers socio-economic sensitivity and capacity to determine vulnerability of the broader community (e.g. residents, industries). While these aspects were introduced during the Shark Bay workshop, the time available was not sufficient to pursue further consideration. Additionally, the participants self-assessed that they had insufficient expertise to address these components.

4.2 Implications for climate change adaptation planning

The CVI methodology provided a useful framework to assess the vulnerability of the OUV of Shark Bay to the key potential climate stressors in a changing climate and identified focal points for more detailed climate change impact assessment in Shark Bay.

The outcome confirmed that the vulnerability of OUV of the Shark Bay WHA to climate change is considered to be high. This rating provides reason and momentum to proceed further with climate change adaptation planning to better protect the WHA OUV of Shark Bay for future generations. The marine heatwave event of 2010/11 reinforces the immediate need for management plans for and monitoring of impacts of climate change, and also reinforced the potential for climate stressors to interact with each other to exacerbate impacts.

The workshop did not examine social and economic consequences, other than an initial discussion of effects and to note that they represent a further critical consideration. The workshop also did not consider in any detail the strategy or range of management actions to facilitate climate change adaptation for the Shark Bay area. These activities were noted to be critical to the development of a climate change adaptation strategy and plan, and hence remain as part of a number of next steps in facilitating climate change adaptation.

A further implication considered in the final session of the workshop was the identification of the significant planning and coordination required to implement climate change adaptation actions. The ownership of strategy and plan, and the individual actions will require not only identification of actions (with owners), but incorporation into the planning cycles (including budgeting), responsibilities and activities of a range of organisations relevant to Shark Bay, including DBCA, DPIRD, FESA, Shires of Shark Bay and Carnarvon, landowners (including pastoralists and conservation NGOs (Bush Heritage, Australian Wildlife Conservancy), as well as local industries and communities. The list above is not based on any substantive assessment and serves only to point out the significant challenge ahead and the need to inform, involve and facilitate broadly to maximise the ability to plan for climate change within the Shark Bay WHA.

5. Next steps

The way forward was briefly considered at the workshop and is summarised in Figure 15.

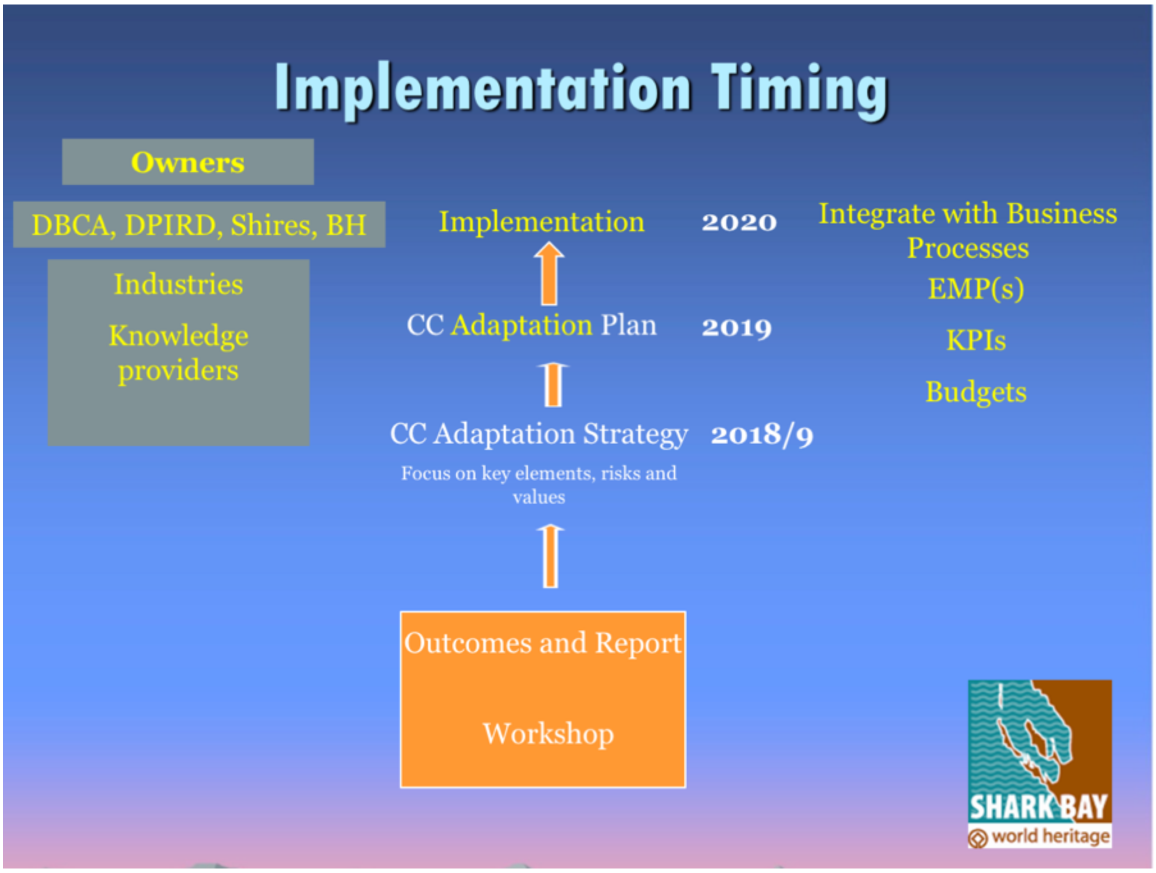

Figure 15. Summary of the path to a climate change adaptation plan for the Shark Bay World Heritage Area

There are several action pathways starting from this workshop (see Figure 16):

- Further discussion on the role of climate change science to inform climate risk assessment and the development of the climate change adaptation strategy for Shark Bay
- ESCC Hub and SBWHAC to conduct a case study using climate change science information to determine the impact of climate change on Shark Bay's seagrasses.
- Identification of the specific pathway and funding to develop the climate change adaptation strategy and plan for Shark Bay
- Identification of economic and social consequences of climate change on Shark Bay
- Acceptance and alignment across relevant organisations of a mandate to proceed and a vision for what can be achieved
- Development and implementation of a climate change adaptation strategy and plan for the Shark Bay WHA
- Identification of the specific knowledge gaps needed to inform the plan
- Development of the CVI methodology and its application to other WHA sites.

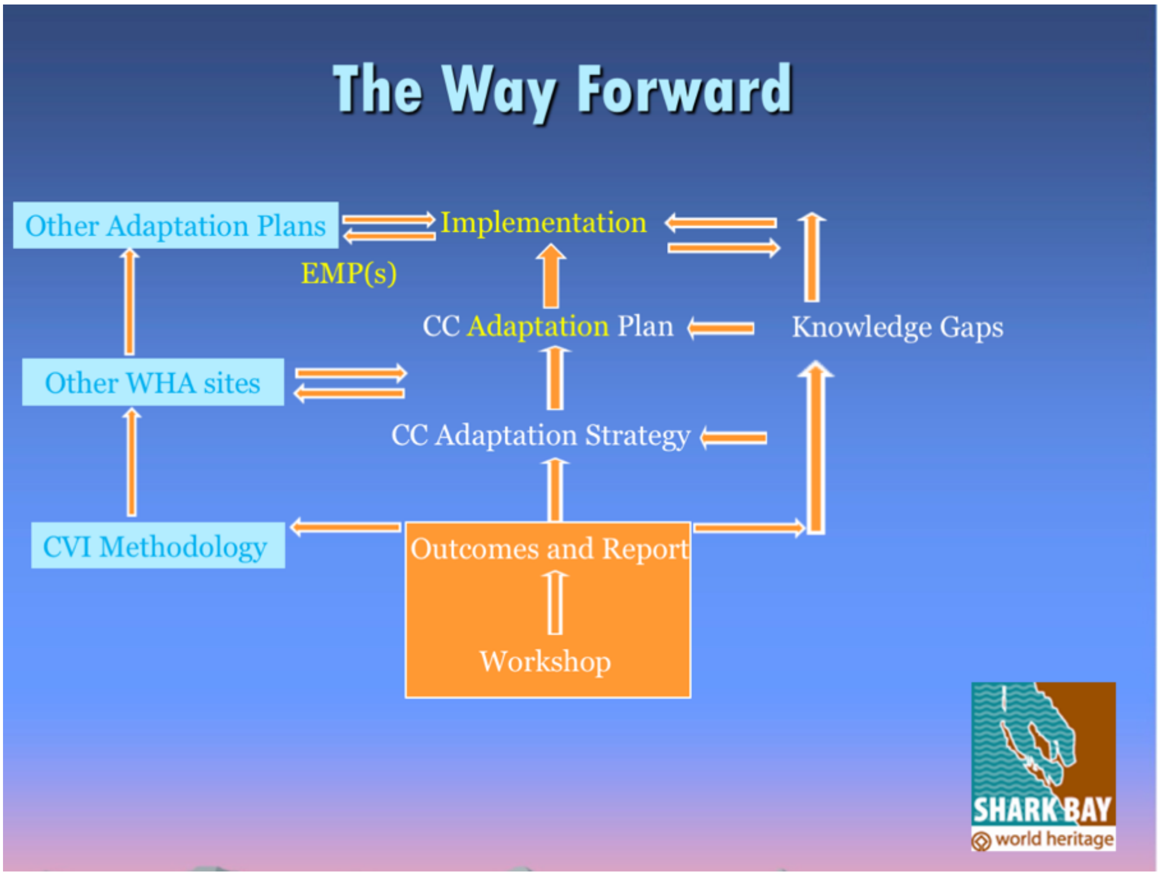

Figure 16. Action pathways starting from this workshop

5.1 Climate change adaptation strategy

The workshop commences a process that is identified as action section 4.3.15 of the Shark Bay World Heritage Property Strategic Plan:[29]

> Investigate the potential vulnerability of WHP species and communities to climate change (in particular species and communities of special conservation significance or likely to be highly vulnerable to climate change) and facilitate and complement delivery of broader climate-biodiversity research priorities.

The rapid assessment using the CVI framework has identified some of the key climate change risks to the OUV of Shark Bay and provided a focus for future management planning. It has highlighted the complexity of responsibility for actions, and the need for input to develop ownership for specific adaptation actions. Coordination between agencies with responsibilities for different areas, activities and information will be an essential component of success in developing adaptation strategy.

[29] Shark Bay World Heritage Property Strategic Plan 2008–2020. 2008 Department of Environment and Conservation. Perth, Western Australia.

5.2 Climate change adaptation action plan

The workshop focused on identifying key climate change stressors, rating the risk they represent to OUV and the potential for effective response to determine vulnerability. It did not attempt to speculate on specific climate change adaptation actions, to convey any input with respect to economic, social and other factors that will have a significant bearing on the development of meaningful and effective climate change adaptation actions. That input will need to be developed via other processes and will necessarily involve a broader range of people – many without a science background.

The complexity of ownership of actions, coordination of action and the identification and assessment of adaptation actions means that an effective action plan is expected to take considerable time (years), effort (by many good people, organisations), to require a mandate (from government), to require significant tools (understanding of thresholds, data, monitoring, investment decision making) and to have a shared vision of what we can achieve.

What the workshop did highlight was the significance of potential impact that key climate stressors are likely to have on OUV, and that the processes that operate on an acute basis provide urgency in planning for climate change, as they are noted to be already having an influence on the biology of the bay.

5.3 Knowledge gaps

While a considerable amount of research has been conducted in Shark Bay, leading to considerable advancements in knowledge, there were some key knowledge gaps highlighted by the workshop:

- Specific requirements of stromatolites to continue to survive and grow in Hamelin Pool (additional condition data on stromatolites is needed)
- Linkages between marine water conditions, chemical processes, seagrass, and organomineralisation processes in carbonate dominated marine environment, and thresholds for impacts on key attributes of OUV
- Thresholds for the protection of key elements of OUV
- The effect of compounding and interacting factors
- Consistent monitoring data relevant to OUV of Shark Bay
- Key strategy decisions – do the things we are capable of, or develop capability for dealing with the most significant impacts, or develop capability for the impacts we are likely to be able to influence. Assessment tools to help make these investment decisions.

Whilst there are some clear lines of responsibility for adaptation planning and actions, the protection of the OUV of Shark Bay potentially falls to many agencies and organisations. It is also clear that for actions to be owned and implemented, they need to be included in organisations individual planning, budgeting and performance management processes, and this needs to be coordinated. There is a gap in knowledge of how best to achieve this.

5.4 Implementation

The Western Australian Marine Science Institution (WAMSI) will facilitate the preparation and implementation of the climate change adaptation plan.

WAMSI has a shared vision for a cross sectoral focussed program to address the integrated management of Shark Bay under global climate change for the values as outlined in the World Heritage Site documentation and for sustainable tourism, commercial and recreational fishing and industry.

An appropriate science plan to support the management of Shark Bay in a changing climate will be collaborative, and research will be undertaken from gap analysis of the existing data and in areas where we think climate change is most likely to have significant impact (e.g. synergistic impacts of extreme marine heat events and turbidity on key species). There is already good existing information, but it's scattered, this needs to be collated and made available to all.

Appendix 1: Workshop program

Pre-workshop: Sunday 16 September
Venue: Denham Recreation Centre, Francis Street

Welcome dinner 6.00 pm. Background presentations to cover community and economic, marine heatwave event of 2010-11 (L Twomey, C Cowell, D Walker, T Morris, S Allen, S Heron)

Day 1: Monday 17 September
DBCA Offices. 61 Knight Terrace Denham

Introduction.

0830 In plenary (Scott and Phil to facilitate)

1. Overview of aims and introduction to key concepts of the workshop, use of plenary and small-group sessions, logistics (toilets, lunch, etc.).

Day 1 am. AIM 1: Understand the significant values that comprise the Outstanding Universal Value (OUV) plus the other significant (but non-OUV) values for Shark Bay

In plenary (Phil to facilitate)

2. Present OUV and Values tables
3. Ensure all participants are aware of the Statement of OUV for Shark Bay (Attachment 1) and how Table 1 was derived from the SoOUV
4. Ask participants to check/confirm that Table 2 comprises other key values of significance to Shark Bay (Attachment 2), and ensure they understand the distinction between Tables 1 and 2.

Day 1 am. AIM 2: Agree on consistent terms to describe CC drivers. Discuss the list of CC drivers and their potential to impact the values of Shark Bay.

In plenary (Scott to facilitate)

5. Show list of CC drivers – check for (i) missing? (ii) understanding? (iii) timescales? Briefly introduce IPCC scenarios. Do example together of brainstorming key CC drivers impacting ONE value from Table 1. Discuss driver linkages, cascading impacts.

In small groups

6. Using the list of CC drivers as agree above, ask participants in small groups to brainstorm what are the key CC drivers likely to impact the values in Tables 1 and 2. Split OUV and non-OUV lists of values between groups.

In plenary

7. Bring outputs from #6 back to plenary and ensure all participants agree on which CC drivers have the greatest potential to impact the values in Tables 1 and 2.

Day 1 pm. AIM 3: Discuss possible future CC scenarios facing Shark Bay…. and agree to consider two scenarios for future of Shark Bay *('Business as Usual'* and *'Paris Agreement')*

In plenary

Presentation: Vanessa Hernaman CSIRO. Understanding climate variability, extremes and change. Current, changing and future climate of the Shark Bay World Heritage Area. Projections for BAU and Paris

8. Provide overview of CC scenarios and what they might mean for Shark Bay – stromatolites for example. Ensure all participants understand the two scenarios being proposed for further consideration in the workshop.

Day 1 pm. AIM 4: To provide focus, conduct a high-level risk assessment (likelihood and consequence) of all CC drivers impacting the values (prioritising the OUV) of Shark Bay – identifying the drivers representing the highest risks to OUV…. and then prioritise those risks

In plenary (Scott to facilitate)

9. Introduce likelihood and consequence categories, as well as the risk matrix that combines these. Do example together for ONE OUV value from Tables 1 and 2.

In small groups

10. Participants in groups to assess the risk (ie. the likelihood and consequence) of the key CC drivers which will impact the values in Tables 1 and 2 using a risk assessment matrix - do this for both scenarios (as agreed in 7) with the objective to determine which are High or Extreme risks under both scenarios.

In plenary

11. Bring outputs from #9 back to plenary and ensure all participants agree on the risk levels caused by CC drivers impacting upon the values in Shark Bay (i.e., in both Tables 1 and 2). After consideration of both scenarios, then prioritise all the risks.

Day 2: Tuesday 18 September

Day 2 am. AIM 5: Commence development of diagrams of key CC drivers impacting the highest risk values of Shark Bay…. and then determine what are the related physical, ecological, economic and social impacts

In plenary (Scott to facilitate)

12. Show blank worksheet that links CC drivers to physical, ecological, economic and social impacts. Do example for ONE identified key CC driver (High or Extreme risk).

In small groups

13. Participants in groups develop diagrams of the values assessed as High or Extreme risk, for only the values that comprise OUV. Plot the key CC drivers and determine the related physical, ecological, economic and social impacts (using Worksheet at Attachment 3).
14. Repeat #12 (in small groups), for the High or Extreme risk non-OUV values

In plenary

15. Bring outputs from #12 and #13 back to plenary and get consensus from all participants on the physical, ecological, economic and social impacts on values of Shark Bay (i.e., endorse final versions of Worksheet at Attachment 3).

Day 2 pm. AIM 6: Discuss proposal for Climate Vulnerability Index (CVI) and test its applicability using Shark Bay as a case study

In plenary (Scott to facilitate)

16. Provide full overview of CVI concept, followed by questions.
17. Participants in plenary work through CVI worksheet under a '*Business as Usual'* scenario, getting consensus on relative scores.

In small groups

18. Participants in small groups work through CVI worksheet under a '*Paris Agreement*' scenario.

In plenary

19. Bring outputs from #17 to plenary, raising any issues about the worksheet/process.

AIM 7: Discuss possible adaptation strategies to address the priority impacts.

In plenary – Discussion on adaptation – what it is, how to plan for it.

20. Participants (in plenary) get consensus on the priority impacts and discuss possible adaptation strategies for those that are agreed as High or Extreme vulnerability.
21. What climate change science information is needed for risk assessment?

Day 3: Wednesday 19 September – 8.30 am – 12.30 pm

Review of Workshop Outcomes

Appendix 2: Workshop participants

NAME	ORGANISATION	EXPERTISE
Simon Allen	UWA	Dolphins
Peter Barnes	DBCA Marine	Ningaloo Marine Park
Kim Branch	DBCA	Conservation
Patrick Cavalli	DPIRD - FISHERIES	Fisheries
Arani Chandrapavan	DPIRD - FISHERIES	Fisheries
Cheryl Cowell	SBWHAC	WHA OUV/Shark Bay
Vanessa Hernaman	NESP ESCC Hub	Climate change
Scott Heron	National Oceanic and Atmospheric Administration	CVI – **co-facilitator**
Mandy Hopkins	NESP ESCC Hub	Climate change
Alan Kendrick	DBCA Marine Science Program	Marine science
Elisabeth McLellan	Bush Heritage, SBWHAC	Ex-pastoral lease management
Therese Morris	Ex-SBWHAC member	Sedimentology
Steve Nicholson	DBCA	Shark Bay
Karen Pearce	NESP ESCC Hub	Science communication
Phil Scott	SBWHAC	WHA OUV – **co-facilitator**
Luke Twomey	WAMSI	Marine science
Ricky Van Dongen	DBCA	Remote sensing
Diana Walker	SBWHAC	Seagrass
Shaun Wilson	DBCA Marine Science Program	Marine science
Simon Woodley	NCWHAC	Ningaloo Coast WHAC Chair

Earth Systems and Climate Change Hub

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