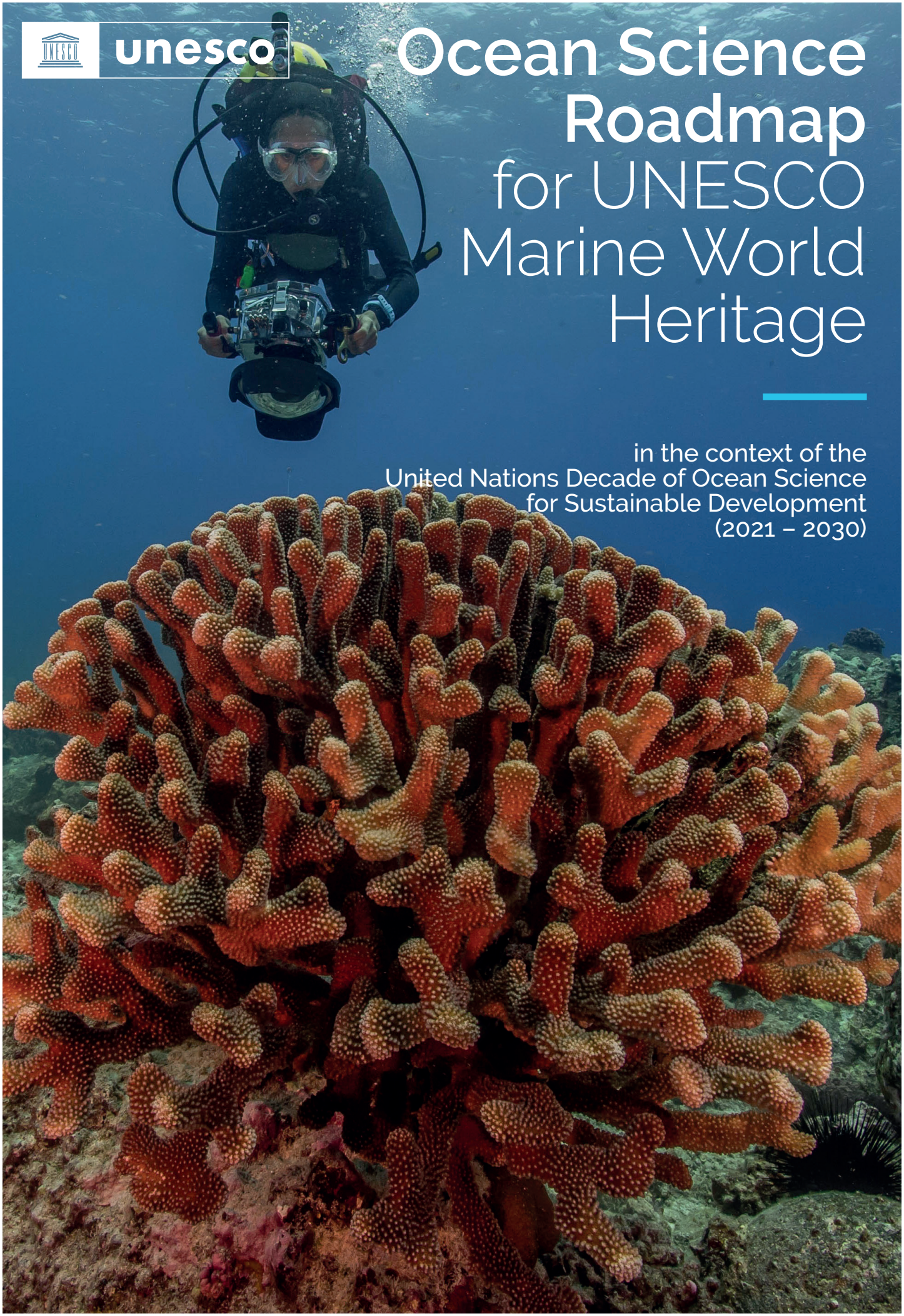

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Ocean Science Roadmap for UNESCO Marine World Heritage

in the context of the
United Nations Decade of Ocean Science
for Sustainable Development
(2021 – 2030)

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Cover photo: Diver in Hawaii, near the Papahānaumokuākea World Heritage site (USA). © Shaun Wolfe / Ocean Image Bank

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Diver with large school of fish at the Archipiélago de Revillagigedo World Heritage site (Mexico).
© Amanda Cotton / Ocean Image Bank

Executive summary

Climate change is altering our planet and the effects are felt from the highest mountains to the deepest parts of the ocean. While the world seeks to hold warming to 1.5°C, it is vital that we take steps now to protect some of the Earth's natural jewels and to preserve them for future generations.

The UNESCO World Heritage List includes the world's most iconic marine protected areas, recognised by the international community for their outstanding biodiversity, beauty, geology and natural habitats. Beginning with Australia's Great Barrier Reef in 1981, the List has since expanded to include a global network of 50 ocean places of Outstanding Universal Value (OUV), from the tropics to the poles, each of which helps to secure the future of our marine ecosystems.

Inclusion on the List is only the start of the work needed to protect these sites from warming seas and shifting weather. Indeed, some 70% of the marine World Heritage sites are currently under threat from climate change, according to the 2020 IUCN World Heritage Outlook. Under a business-as-usual emissions scenario, World Heritage Listed coral reef systems are expected to cease to exist by 2100. Action is necessary not just to protect these sites, but because between them they host over 20% of the world's blue carbon ecosystems - representing critical carbon sinks - and serve as refuges for vulnerable and threatened species.

Managers, scientists, and funders are enthusiastic and willing to help us achieve healthy oceans and marine World Heritage sites. But how? The 2021 UNESCO science assessment survey of marine World Heritage sites indicates that nearly 75% of sites lack knowledge on how to protect their OUV against the impacts from climate change. And about two thirds lack the tools to understand how climate change will impact their biodiversity and ecosystem functioning.We must find evidence-based solutions to address these questions and to help sites plan for the uncertain future.

In 2017, the United Nations General Assembly proclaimed that 2021-2030 would serve as the United Nations Decade of Ocean Science for Sustainable Development (or 'Ocean Decade'). The Ocean Decade provides a global framework to harness science to sustainably manage the oceans. Marine World Heritage sites are identified as priority areas in the Implementation Plan of the Ocean Decade. The Decade offers a way to convene diverse actors to co-design and co-deliver knowledge that will address scientific questions about the vulnerable sites, to plan the right response and to put them on a path to a sustainable future.

Climate change is a complex challenge, and we must use the best and most up-to-date research and data to guide our actions. Collecting ocean science data and identifying trends are critical to local management teams. Without this baseline knowledge, including where iconic species live or trends in environmental and socio-economic variables, effective management decisions cannot be made in ways that will ensure sites' protection 10 or 20 years from now.

Yet despite their iconic status, many marine World Heritage sites lack essential capacity, technology and resources to generate and process data, including the baseline observations crucial to gather the evidence to plan future steps. For many sites, budgets have not risen while challenges grow exponentially.

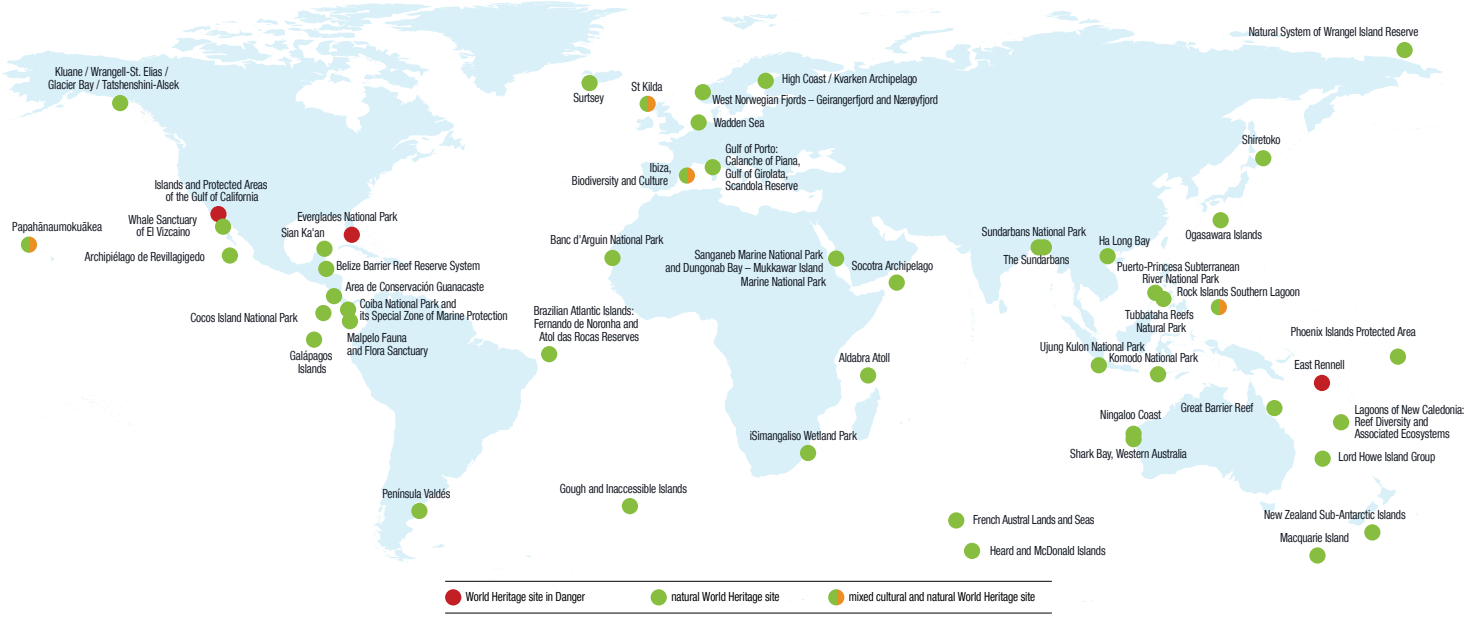
In response, UNESCO is launching a call for increased and strategic investment in the ocean science needed to safeguard marine World Heritage sites.

The ocean is a vast place and there is much to do. Within the framework of the Ocean Decade, this roadmap aims to help provide focus, to ensure research is carried out and used in an efficient, effective and sustainable way. It identifies knowledge that site managers and scientists need to conserve marine World Heritage sites and foster resilient marine ecosystems, highlights the value of science-based decision making, and tackles some key obstacles including resources and capacity.

This roadmap outlines key information to assess climate vulnerability, including on the use of targeted science to underpin conservation and management efforts. It also highlights current gaps in science capacity and infrastructure, including data collection and interpretation. Finally, it explores the technology and capacity required for action and the sustainable finance and resources needed to support the necessary research.

Marine World Heritage sites face a critical moment in time and we must act now. By developing this roadmap within the framework of the Ocean Decade, we have the chance to generate 'the science we need for the ocean we want' and preserve marine World Heritage sites and their services for future generations. This roadmap seeks to offer that help, by showing managers, supporters, and funders how science and research can be more cost-effectively directed to some of the most pressing problems. Together we can steer a path to a resilient and sustainable future, for the next decade and beyond.

THE 50 MARINE SITES INCLUDED ON THE UNESCO WORLD HERITAGE LIST (2021)



The names and boundaries shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations
Source: United Nations / Geospatial Information Section of the United Nations

1. Methodology

The conclusions of this roadmap derive from a UNESCO-led science assessment survey of the 50 marine World Heritage sites in 2021. It collected information on the current status of ocean science, structural science gaps, enabling conditions at sites to use science for decision making and desired short- and long-term ocean science investments.[1] A one-day UNESCO conference "Identifying Critical Science Gaps at Marine World Heritage Sites", held online on 4 October 2021, with over 100 leading scientists, managers and philanthropists, further investigated these gaps and priorities.

The roadmap builds on the UNESCO World Heritage State of Conservation Information System[2] — a comprehensive monitoring system that provides a trove of data on the state of conservation of World Heritage properties — and the 2020 IUCN World Heritage Outlook.[3] The roadmap has been prepared in the context of the United Nations Decade of Ocean Science for Sustainable Development ('the Ocean Decade'). The Ocean Decade Implementation Plan[4], which outlines ten Decade Challenges that represent the most immediate and pressing needs of the Decade, has been used to guide and align the science gaps identified across marine World Heritage sites.

The roadmap identifies key science gaps across sites and proposes priorities to help secure sound, science-based management and decision making in cost efficient ways over long periods of time. Managers need scientific understanding at the appropriate spatial and temporal scales to understand the effectiveness of management actions and inform proactive and preventative management actions. When addressed across the network, diverse types of ocean data and information will allow tracking of global trends in the conservation of the world's flagship marine protected areas and serve as reference points as the ocean changes rapidly because of global warming.

This roadmap is not a cure-all: each site is different, and local priorities need to be fine-tuned. Yet, **by providing a guidance framework to enhance science capacity at marine World Heritage sites** over the next ten years and beyond, the roadmap aims at helping to address some of the most critical gaps in ocean science at Marine World Heritage sites. Certain gaps might appear straightforward but are in reality often overlooked and part of what impedes sites' long-term sustainable development. The ocean is a dynamic and changing system. Where monitoring exists, it may need to be adapted to a changing environment, shifting knowledge needs, or outdated technology and methodologies. Once the climate vulnerability of OUV has been assessed, capacity-building strategies can be adapted to the needs of specific sites.

1 A completed Ocean Science survey was received for nearly 75% of the 50 UNESCO marine World Heritage sites
2 https://whc.unesco.org/en/soc/
3 https://worldheritageoutlook.iucn.org/
4 UNESCO-IOC. 2021. The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) Implementation Plan. UNESCO, Paris (IOC Ocean Decade Series, 20.)

2. The Role of Marine World Heritage Sites in the Science We Need For The Ocean We Want

By adopting the 1972 UNESCO World Heritage Convention, the international community has committed to ensure the protection of marine World Heritage sites.[5] The Ocean Decade has the potential to reinvigorate this commitment, and to mobilise a wide range of actors in the international community to develop innovative solutions to secure our ocean heritage.

Ocean science data is currently collected by 88% of marine World Heritage sites, ranging from fundamental physical, biochemical and biological observations, to applied science and socio-economic data. These include studies to monitor biodiversity and understand the impacts of tourism, as well as the socio-economic conditions. This transdisciplinary approach to research is crucial for the sustainable management of these sites, particularly with the threats associated with the impacts of a changing climate. Long-term scientific monitoring enables managers and governments to evaluate the effectiveness of their actions and investments and to forecast future conditions. It allows the international community to monitor the sustainable conservation of the oceans' most precious places. It also means that UNESCO marine World Heritage sites are in the unique position to both generate and apply knowledge.

> In today's rapidly changing ocean, only the best available science can preserve our marine World Heritage

Many sites provide a crucial financial contribution to their country, often through tourism. About half of the Belize population depends on the Belize Barrier Reef for their livelihoods and 15% of the country's gross domestic product (GDP) comes from the reef.[6] iSimangaliso Wetland Park in South Africa supports over 12,000 jobs for local and indigenous communities.[7] Understanding the contribution of marine World Heritage sites to the local economy and local communities helps better understand the sites' climate risks and informs the development of adaptation strategies. Most sites also support local communities who depend on their natural resources, which presents a unique opportunity for ocean scientists. Working together with local and Indigenous communities on co-designed and co-delivered projects will ensure impact for future generations.

The sites serve as incubators of innovative science, providing important data from around the world that can advance global ocean science and direct research to local challenges. In today's rapidly changing environment, only the best available science can preserve the OUV of sites. Research can highlight global trends in biodiversity, inform strategic policy advice and guide global investments across marine biodiversity and climate change.

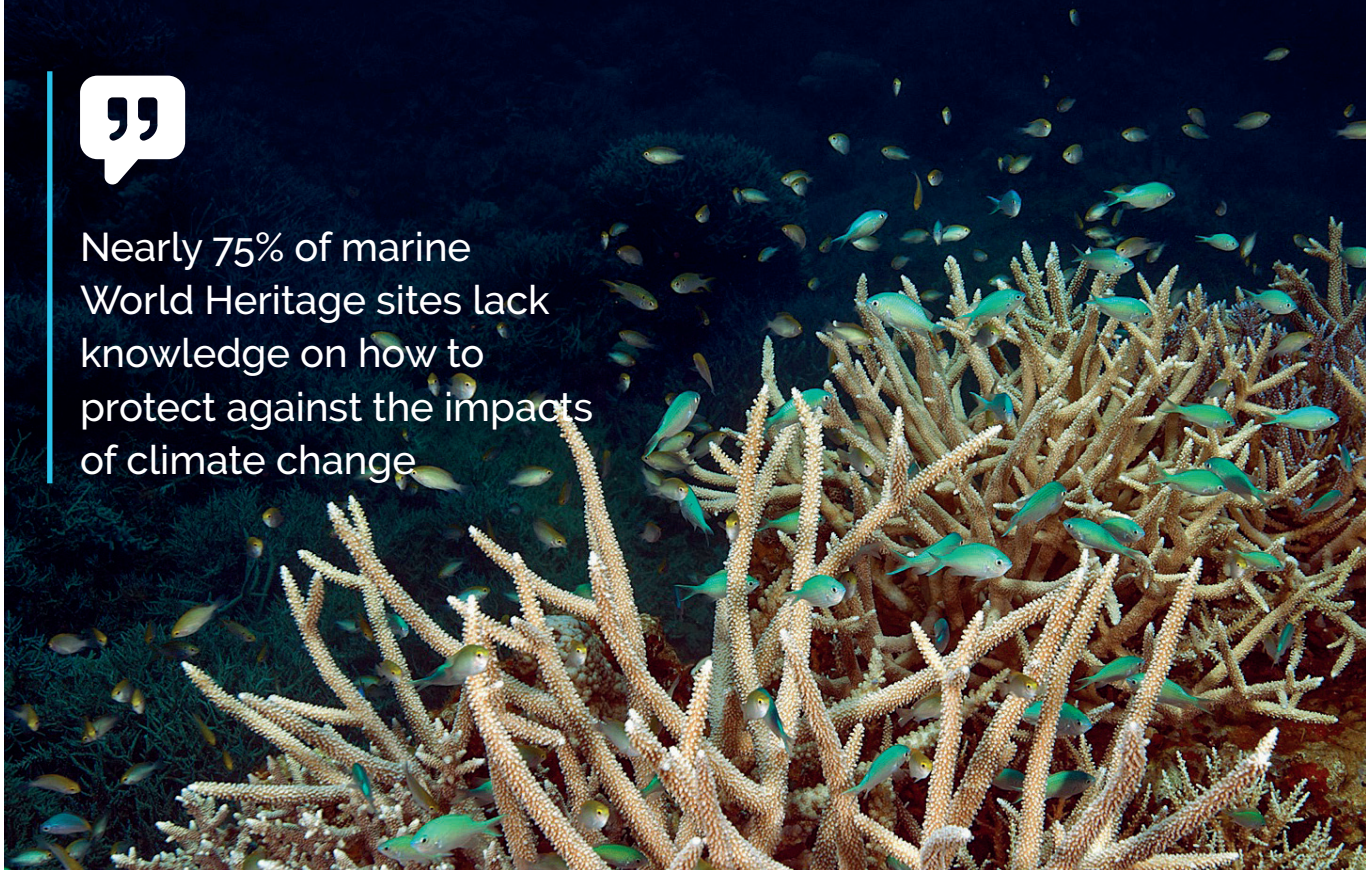
Marine World Heritage: Beacons of Hope in A Changing Ocean

In the Brazilian Atlantic Islands: Fernando de Noronha and Atol das Rocas Reserves (Brazil) and Galápagos Islands (Ecuador), migratory patterns of sea turtles are tracked using satellite telemetry. The satellite tags allow these vulnerable animals to be monitored over a wide geographical area, to identify their routes and critical areas of special use, as well as diving behaviour. Data collected help researchers better understand ecology, and set out appropriate protection measures.

Researchers working on the Great Barrier Reef (Australia) have pioneered a small-scale coral restoration initiative using a technique called Coral IVF (in vitro fertilization). During coral's annual spawning event, scientists capture coral eggs and sperm from healthy reefs, then cultivate millions of larvae in protective enclosures on the reef and in tanks. Released onto damaged reefs, they become polyps that settle and attach to the existing reef structure. As these corals grow and mature, they eventually contribute to future spawning events, continuing the reproductive cycle.[8] This project is one of over 100 reef-saving projects underway, as a flagship action of the Ocean Decade.

Researcher holds turtle in the Brazilian Atlantic Islands: Fernando de Noronha and Atol das Rocas Reserves World Heritage site (Brazil).
© Felipe Mairowski Muci / Shutterstock.com*

5 https://whc.unesco.org/en/conventiontext/
6 WWF. 2016. Protecting people through nature. Natural Heritage sites as drivers of sustainable development. https://c402277.ssl.cf1.rackcdn.com/publications/867/files/original/WWF_Dalberg_Protecting_people_through_nature_LR_singles.pdf?1459793033
7 https://whc.unesco.org/en/news/1659/
8 https://www.barrierreef.org/what-we-do/projects/coral-ivf



Coral reefs in the Lagoons of New Caledonia: Reef Diversity and Associated Ecosystems World Heritage site (France). © Ken Marks

3. The Climate Crisis

Although two thirds (66%) of marine World Heritage sites have a positive conservation outlook, 70% are currently threatened by climate change. **Global warming poses a high or very high threat to 31 of the 50 marine sites (62%) according to the 2020 IUCN World Heritage Outlook.**[9] A 2018 UNESCO report concluded that all World Heritage-listed coral reefs would cease to exist as functioning coral reef ecosystems by the end of this century under a business-as-usual emissions scenario.[10] Summer sea ice in the Arctic, which provides a critical habitat for numerous polar species, is predicted to disappear by the end of the century. Glaciers are rapidly melting, while sea level rise threatens coastal communities and habitats including low-lying mangroves, mudflats, and islands.[11,12]

The IPCC Sixth Assessment Report paints a bleak future for the global ocean. Ocean warming is likely to continue until at least 2300. Marine heatwaves at a global scale will become four to eight times more frequent in 2081–2100 compared to 1995–2014 depending on emission scenarios. Sea levels will continue to rise for centuries, while Arctic sea ice continues to shrink.[13]

At the same time, scientists are starting to better understand the critical role that blue carbon ecosystems — mangroves, seagrass meadows, salt marshes — play in climate mitigation and adaptation. A UNESCO assessment reported, for example, that although marine World Heritage sites represent less than 1% of the ocean surface, they harbour over 20% of the planet's blue carbon ecosystems and 15% of our blue carbon assets: storing carbon rather than releasing it into the atmosphere.[14] Protecting these habitats will keep billions of tonnes of carbon safely stored.

In the face of the looming climate threat, which for many sites is already a reality, marine World Heritage sites' biggest management challenge is conservation in a rapidly changing ocean. Yet local management teams are frequently ill-equipped to deal with the climate crisis. The science assessment survey carried out to inform this roadmap indicates that 74% of sites lack knowledge on how to protect against the impacts of climate change. Further, 70% are unclear about how climate change will impact local species. Faced with events that will disrupt sites' ecosystems, there is a shortage of science, technology and investment to support the actions needed to protect and manage the oceans.

No marine World Heritage site is immune to the impacts of climate change, accelerating ocean industrialisation, and increasing coastal development. Site managers typically have

9 Osipova, E., Emslie-Smith, M., Osti, M., Murai, M., Åberg, U., Shadie, P. 2020. IUCN World Heritage Outlook 3: A conservation assessment of all natural World Heritage sites, November 2020. Gland, Switzerland: IUCN. x + 90pp. https://doi.org/10.2305/IUCN.CH.2020.16.en

10 Heron et al. 2018. Impacts of Climate Change on World Heritage Coral Reefs: Update to the First Global Scientific Assessment. Paris, UNESCO World Heritage Centre. https://unesdoc.unesco.org/ark:/48223/pf0000265625

11 Bosson, J.-B., Huss, M., Osipova, E. 2019. Disappearing World Heritage Glaciers as a Keystone of Nature Conservation in a Changing Climate. Earth's Future. V7(4), pp. 469-479. https://doi.org/10.1029/2018EF001139 https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018EF001139

12 https://archive.ipcc.ch/ipccreports/tar/wg2/index.php?idp=459

13 IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/

14 UNESCO. 2020. UNESCO Marine World Heritage: Custodians of the globe's blue carbon assets. Paris, France https://unesdoc.unesco.org/ark:/48223/pf0000375565

their hands full with day-to-day management activities and have scant resources and few tools to plan for the long-term. But today's decisions will have major impacts years into the future.

At the local level, a central goal is to build resilience through climate adaptation strategies. Limiting global temperature rise to 1.5°C is essential for the future protection of the ocean and that needs a global response. At the same time, **conservation improvements at the site level allow sites to build resilience and adapt both their ecosystems and their communities to changing conditions**. These require substantial investments in ocean science: latest technology, increased capacity, and long-term financing.

For many sites, budgets have not risen while challenges grow exponentially. Critical areas where sites will need more support in the future to plan for and deal with climate impacts, include climate induced disasters, better monitoring of the characteristics that make up sites' OUV and the assessment of the vulnerability of these characteristics to changes in the ocean's temperatures, sea level rise, and ocean acidification. At the same time, new technologies emerge to deliver ocean science faster and at lower cost.

Marine World Heritage sites often provide critical sources of food and income for local and indigenous communities. An inclusive approach to science empowers people to work together to protect the site and adapt to the changing circumstances.

The ocean has no boundaries, so activities outside site boundaries still impact the unique biodiversity and ecosystems that make up the World Heritage designation. The good news is that work to preserve and restore the OUV of these sites will reap rewards far beyond their borders.

4. Priority Areas of Focus

Researcher counts Hawaiian limpets / 'opihi (Genus: Cellana) during a shoreline survey in the Papahānaumokuākea World Heritage site (USA).

While global warming is being limited in line with the global United Nations Framework Convention on Climate Change (UNFCCC) commitments, climate change is already happening and accelerating. The UNESCO survey found that **over 70% of marine World Heritage sites are not prepared for the challenges ahead**. To give them the best chance to adapt and survive, gaps in scientific knowledge, technology, innovation and investment must be addressed urgently.

World Heritage sites showcase the best nature has to offer. To safeguard them for future generations the world must take decisions based on evidence and the latest science. This roadmap is not a comprehensive summary of the science needed at the local level across each of the marine World Heritage sites. It does provide insights in critical areas where focus should be placed but tends to be overlooked. The approach used in this chapter allows to identify and organise research needs consistent with the building blocks of commonly used marine protected area management frameworks. When applying such approach, key gaps include prioritisation, surveillance, monitoring and trend analysis.

4.1. Research Prioritisation and Climate Vulnerability: What Do Sites Need To Know?

- 74% of sites are unclear on key actions to take to improve their resilience or adaptability in the face of a changing climate.
- Over 60% lack knowledge of how climate change will shift geographical distribution of species, which species are most at risk, or climate projections for their site under different emission scenarios.

To build resilience at the local level and implement climate adaptation projects, UNESCO marine World Heritage sites need to understand attributes of their OUV. The description of a site's OUV makes up its World Heritage recognition. To understand the impact of climate change, it can be hard to know what to measure, as well as to set priorities and areas of focus. But doing so is essential to protect these special ocean places. It is important to set realistic goals, so targeted science can underpin site management, resilience and climate change adaptation. A site's OUV is the benchmark used by the international oversight mechanism embedded in the 1972 World Heritage Convention to hold countries accountable for their action (or inaction) to protect sites for future generations. It is hence a primary point of departure to evaluate priorities and bring the needed focus.

Prioritisation at the site level seems an obvious first step, yet it is one of the most commonly overlooked areas of research. Research projects are to a large extent undertaken without a clear view to how they fit in the overall priorities for a certain location. While the research might be important, it might or might not be the most efficient area of attention to obtain the sites' sustainable conservation in the long term.

Assess climate vulnerability

In 2021, only a handful of sites, including Shark Bay, Western Australia (Australia), and Wadden Sea (Germany, Netherlands, Denmark) have identified key climate threats to their OUV, which allowed them to set priorities for action. Assessing climate vulnerability is not necessarily a costly or lengthy process,[15] yet many sites need finances and capacity to aggregate climate predictions and identify climate stressors, organise stakeholder consultations and produce their priorities and areas of focus. **A centrally coordinated approach to undertake climate vulnerability across the marine sites is vital** to reduce effort and costs and avoid duplication.

When expected impacts are understood, research needs can be more easily prioritised. Knowing which species, habitats or geographical areas are most vulnerable, or which socio-economic activities that support local livelihoods are most at risk, is essential. Working this out could include an extensive literature review, but the main priorities are often already known to local scientists, managers, volunteers or even photographers or resource users who have been observing the area for extended periods of time so their expertise should be consulted.

Prioritise research

Almost all **sites need support to conduct a research prioritisation exercise** to identify key research questions that science could answer, including climate vulnerability. Sites do science, but it is not always clear whether that is the right science to best understand change and improve decision-making for sustainable development. Prioritisation of research is increasingly critical to bring philanthropic funds on board as it demonstrates clear thinking and illustrates needs before a research project begins.

Research prioritisation should focus on sites' OUV — including iconic species and pristine seascapes. These could include fishing activities, ecological connectivity with areas outside of the site, human pressures in general, tourism and other socio-economic activities, or cultural heritage. Research prioritisation at sites requires convening traditional owners, academic researchers, citizen scientists, local communities, NGOs and the private sector, under the leadership of local management authorities. Sites need extra funds to pay for such research prioritisation, as well as staff to coordinate the process and organise stakeholder consultations. One way to make such efforts cost-effective would be to take a centrally coordinated approach across all sites.

In this way, local management authorities can prioritise the right science and science infrastructure and also feel empowered to act, rather than simply monitor. **A proactive approach identifies needs on the basis of key functional attributes rather than simply accepting any offered new science infrastructure.** Not doing this leads to an inefficient approach that could mean years of ongoing management effort for limited return. This roadmap calls for a better focus on this critical research gap and to increase the resources available to sites to address proactive prioritisation.

Build relationships

Few sites have a coordination mechanism in place to align knowledge needs with knowledge production. Such a mechanism should ensure early and frequent consultation between scientists and local managers and must embrace all knowledge systems, including local and indigenous knowledge holders. In Papahānaumokuākea (USA) for example, there is a special effort to integrate native Hawaiian culture into management plans and guidance notes.[16] One approach may be to require that local management authorities approve all research at a site so as to ensure the right research fills a knowledge gap and is made available to the sites.

Setting Comprehensive Science Priorities at Ningaloo Coast (Australia)

The Ningaloo Coast (Australia) is one of four pilot sites in the Resilient Reefs Initiative[17], an ambitious project in which World Heritage-listed coral reefs and their local communities take a leading-edge approach to develop new solutions to adapt to the effects of climate change and local threats.[18] The team performed an economic valuation study as part of a Resilience Strategy to guide local action, which revealed the marine environment contributes over AU$100 million and more than 1,000 jobs for the local community. A research prioritisation exercise carried out with prominent ecological and social scientists, and thorough stakeholder consultation, identified the most important research needed to guide resilience-based management. As well as underlining the need for greater understanding of ecosystem function under changing ecological conditions, this work highlighted the importance of applied research to actively inform management, and adaptively assess management actions and interventions.

Implementation of the Resilient Reefs Initiative in the Ningaloo Coast World Heritage Site. © Joel Johnsson/DBCA

15 https://whc.unesco.org/en/news/2225/
16 https://www.oha.org/news/new-guidance-document-to-integrate-native-hawaiian-culture-into-management-of-papahanaumokuakea/
17 https://whc.unesco.org/en/reefresilience/
18 https://whc.unesco.org/en/reefresilience/

Drones equipped with thermal cameras in the Wrangel Island Natural Reserve World Heritage site (Russian Federation) © Nature Reserve "Wrangel Island"

4.2. Science Capacity and Infrastructure Gaps: Data Collection and Data Interpretation

- 88% of marine World Heritage sites collect baseline ocean observations
- 70% use satellite observation and imaging/physical sensors
- 43% of marine World Heritage sites have a dedicated research station
- 63% lack equipment to monitor how climate change is impacting the OUV of the site

UNESCO marine World Heritage sites already act as valuable incubators to test new methods of data collection, but many lack the necessary equipment to collect reliable data in the most effective manner. Monitoring and research in marine environments is traditionally more expensive than its terrestrial equivalent. Several marine sites are in remote locations and span large areas, which makes sustained research extremely challenging.

Assess and predict ecosystem change

Sites need support to obtain downscaled climate projections to forecast changes to ecosystems at a local level. The 2021 IPCC Sixth Assessment Report was the first to provide such regional assessments but does not lay out the necessary levels of local detail. For this, sites require baseline meteorological and oceanographic data that allow for more accurate weather forecasts, climate projections, characterisation of local hydrography and flow patterns, and to monitor sea surface and sea floor water temperatures, as well as other stressors such as ocean acidification or projected changes of sea level. Sites need **financial support to buy, install and maintain observational moorings or other autonomous technologies**. Many sites currently lack any environmental monitoring over time.

Upgrade infrastructure and train staff

Sites and their research partners need financial support to upgrade existing research infrastructure, deploy the latest technologies for data collection, and train staff to operate technologies and interpret results in the context of long-term monitoring programmes. For many sites, continuous data sets are young and cover just a few themes. Where monitoring is in place, it must adapt to the changing environment, or new monitoring programmes may need to be set up. The rapid drop in income from tourism visits during the COVID-19 pandemic has illustrated how fragile support for research capacity is at various marine World Heritage sites. Some research programmes have been forced to close or downscale.

Specific needs include:

- Facilities upgrades (eg. repair of field stations or procurement of new research vessels)
- Oceanographic equipment: installation of basic equipment and training to collect essential ocean variables such as ocean temperature, salinity, dissolved oxygen, nutrients, fluorescence, currents, sea level rise and ocean acidification monitoring
- Advanced technologies: autonomous observation systems with a focus on biological observations to increase understanding of ecosystem interactions
- Standardised practices (eg. reef health monitoring program)
- Studies on income diversification to reduce pressures on the OUV
- Investments in human resources: international expeditions with local staff to understand ecosystem interactions and ecosystem connectivity, including between different sites, training for site staff to use new technologies, training for site staff in data analysis, data interpretation and reporting

Improve data management and interpretation

While nearly 90% of marine World Heritage sites conduct their own research, the conference highlighted how **centralised programmes to provide sites with ready-to-use information are more efficient than separate programmes or specialised training on data collection, processing and interpretation at individual sites**. In some high-income countries multiple datasets can be a challenge to process: user-friendly databases would improve site management. Many low-income countries lack the critical capacity to collect even basic data.

Given the complex modelling software required to process climate projections, for example, **most sites would benefit from long-term partnerships with research institutions to efficiently process and interpret data related to climate projections for their World Heritage site**. When several sites partner simultaneously, this can generate regional and global comparisons that serve as reference points for the wider ocean. Marine World Heritage sites are geographically spread across the globe and could easily serve as such reference points (see Map 1). These programmes could be part of existing platforms or partnerships, or form part of a centrally coordinated approach across all sites. A central, user-friendly web application which automatically analyses data for the sites would make research more efficient and effective. **Platforms and partnerships should aim to provide sites with user-friendly information rather than raw data.** Across the marine World Heritage network, a third of all sites currently lack staff with a higher academic education.

Some of the most cited priorities for information management include processed geospatial and remotely sensed data, downscaled climate data, large-scale oceanographic modelling that allows to understand bigger trends which will impact the World Heritage site in the future, training and exchange programmes for staff and; scholarships and in-depth training opportunities for local scientists.

4.3. Technology and Capacity to Improve Action on the Ground

- 66% of marine World Heritage sites lack innovative technology for fisheries surveillance
- 75% of sites are threatened by invasive alien species
- 100% of marine World Heritage sites are impacted by marine pollution[19]

UNESCO marine World Heritage sites are priority areas under the Ocean Decade. Ocean science informs effective action on the ground to combat some of the most serious threats to marine World Heritage sites impeding their protection and resilience building, including invasive species (threatening 75% of sites), unsustainable resource extraction (threatening 50% of sites)[20], or habitat destruction. Yet science is also used for monitoring the impacts of incidents, ensuring compliance standards with local regulations are high, or tourism frequencies and practices remain sustainable.

Access to technology and innovation

Sites need access to the latest technology and innovation to cope with accelerating change. For very large or remote sites not visited by scientists frequently, **autonomous instruments and remote sensing keep monitoring affordable and sustainable**. Elsewhere, technology makes the work of rangers safer and more efficient. Innovation allows the best science to be delivered in short time frames at low cost. A more centralised approach at global or regional levels might be the best way to deploy the latest technology and innovation across multiple sites.

Some of the most cited needs at marine World Heritage sites include access to satellite data and vessel tracking systems, more cost effective, efficient autonomous vehicles, innovative tools for ecosystem restoration or the use of algorithms to standardise the measurement of sites' conservation status.

Spatial Monitoring and Reporting in the Belize Barrier Reef Reserve System

The Spatial Monitoring and Reporting Tool (SMART) in Belize allows Compliance Officers and Fisheries Officers to efficiently plan, coordinate, and document patrol routes and activities across marine protected areas that make up its World Heritage designation and throughout the waters of Belize using mobile devices. It simplifies the gathering of a wealth of information that officers come in contact with during their patrols, such as vessels, fishers, area usage, catch sampling data, wildlife sightings and coastal developments to name just a few. This data assists in all aspects of aquatic resource management for the country. This software supports the creation of a National Enforcement database as the data gathered is standardised across managing organisations, which allows for the rapid querying of data and creation of reports that helps identify how best to use resources and deploy assets. Information collected is also used to support prosecutions in Belize's court of law.

Belize Barrier Reef Reserve System World Heritage site (Belize).
© Wata51/Shutterstock.com*

19 KIMO International. 2019. Marine Litter at UNESCO World Heritage Marine Sites https://www.kimointernational.org/news/report-unesco-marine-litter/#:~:text=Key%20findings%20of%20the%20report,land%20and%20in%20the%20air

20 https://worldheritageoutlook.iucn.org/

A range of skills and a coordinated approach

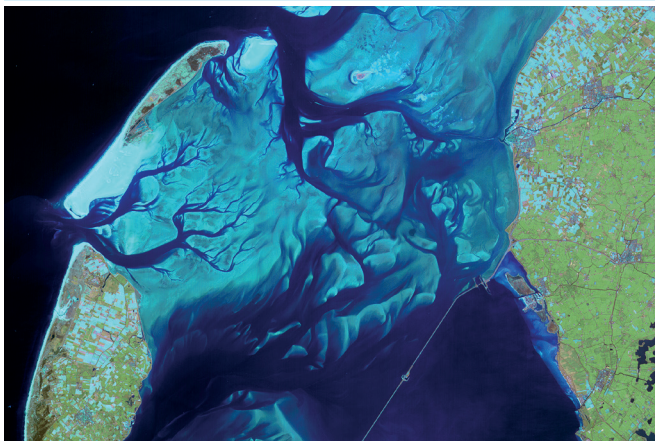
Multidisciplinary teams or cross-disciplinary partnerships bring increased knowledge and capacity to process and interpret data, for both site management and action programmes. Marine biologists are required to monitor coral reefs, computer scientists to organise data systems, engineers to design and maintain infrastructure. Other teams need oceanographers, economists, and geologists, as well as geneticists, educators, ecologists, managers, meteorologists, statisticians, and fundraisers. Often data is collected by project but needs a centrally coordinated approach for effective management and decision making.

Cooperation

Sites need greater cooperation, both North-South and at the regional level. **Strengthened international, multilateral and bi-lateral cooperation, including financial support, technology transfer and joint scientific research and patrols** is a clear need across sites. Access to a global pool of expertise and best practices can replicate management successes and avoid duplication of failures. Banc d'Arguin National Park (Mauritania) and the Wadden Sea (Germany, Netherlands, Denmark) have signed an official twinning agreement and undertake joint monitoring of the migratory birds they share. Glacier Bay National Park (USA) and West Norwegian Fjords: Geirangerfjord and Nærøyfjord (Norway) have exchanged protocols to study and reduce the impacts of cruise ships, while The Sundarbans (Bangladesh) and Sundarbans National Park (India) jointly undertake monitoring and patrols.

Satellites and Artificial Intelligence to Replace Thousands of Working Hours

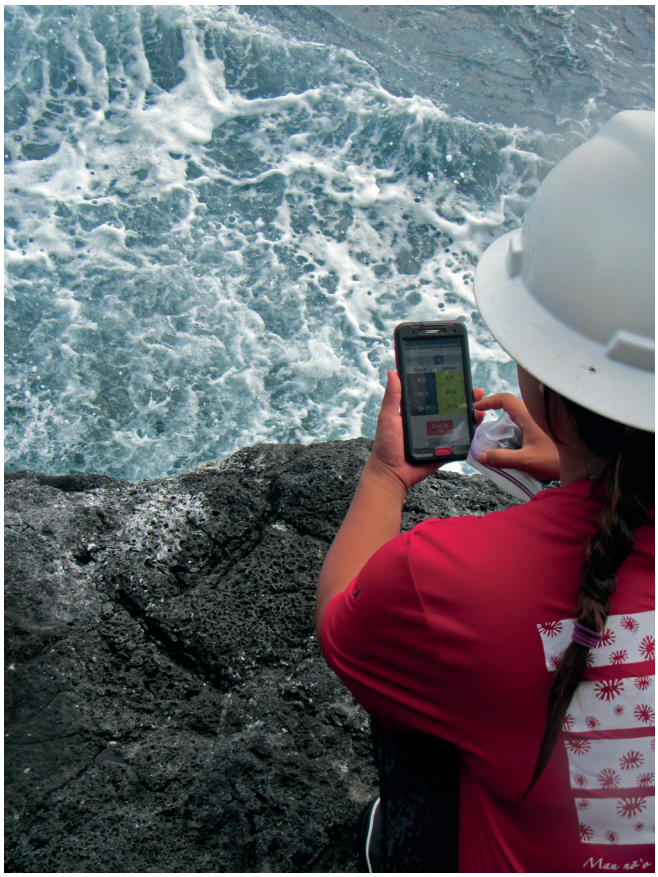
Artificial intelligence (AI) increasingly processes satellite and aerial images to monitor remote or extensive marine World Heritage sites. In the Wadden Sea (Germany, Netherlands, Denmark), aerial photographs since the 1930s have allowed the delineation and mapping of seagrass meadows. Now AI can assess seagrass health based on colour and evaluate actions taken to restore the meadows.[21]



ESA satellite image of the sandbanks in the Wadden Sea World Heritage site (Germany, Netherlands, Denmark). © CNES, Spot Image*. Source : esa.int

4.4. Only Sustainable Finance Can Underpin Necessary Science

It is unsurprising that a lack of financial capacity is the most pertinent obstacle to ocean research at marine World Heritage sites. In the last two years, **the fragile nature of ocean research funding at marine World Heritage sites has been further exposed by the COVID-19 pandemic**. Sudden drops in revenue significantly impacted revenues and halted funding for essential scientific monitoring in some cases.[22] Budgets have remained mostly flat while costly challenges are growing fast. Protecting marine World Heritage for future generations – and securing sound, science-based decision making into perpetuity– demands that finance for ocean science is sustainable over the long term.



Researchers use an app along the rocky shorelines of the Papahānaumokuākea World Heritage site (USA). © Hoku Johnson/NOAA, 2015

Increase budgets and focus expenses

As a priority, **recurrent budgets allocated to ocean science at site level should increase but also become more focused on the core science needed to underpin decision-making**. Tighter focus on priorities aligned with the OUV of the sites, and new technology, can contain costs. Research prioritisation exercises can help ensure that resources are targeted to where they have most impact and reduce costs by aligning more resources with readily available science instead of focusing only on funding new projects. Strengthening long-term collaborations between sites' local management authorities and international research institutes are another

21 https://www.awi.de/en/focus/north-sea/seegrass-in-the-wadden-sea.html

22 Thurstan, R. H., et al. 2021. Envisioning a resilient future for biodiversity conservation in the wake of the COVID-19 pandemic. People and Nature, V3(5), pp. 990-1013. https://doi.org/10.1002/pan3.10262

way to lower sites' financial burden in securing the science they need for the future they want over the long term.

Taking a business approach to long term financing

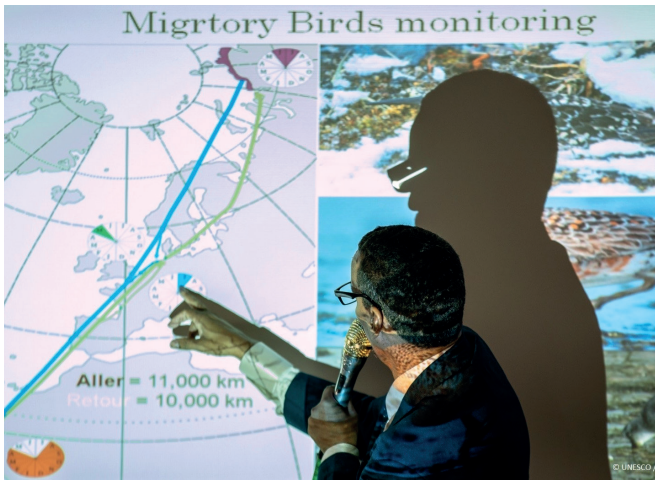
While 88% of sites conduct ocean science at their sites, the financial support to carry out this science comes from a variety of sources, including:

- governments: 83% of sites
- self-funded: 60% of sites
- NGOs: 54% of sites
- private sector: 28% of sites
- philanthropy: 23% of sites

Most sites rely on conventional funding, including governments and international development resources. **Yet a mix of financing sources is vital to fund ocean research over the long term**. Alternative financing mechanisms could include visitor or other user fees, higher penalties associated with stronger law enforcement or damage to heritage, trust funds and legacy grants, depth-for-nature swaps, green bonds, the use of carbon credits for areas with blue carbon assets or a stronger direct engagement with the private sector. Most marine World Heritage sites lack a clear understanding of the different financial resources available to them, what types of financing are most suitable to their needs and the cost-benefit of securing that funding.

Diverse needs also demand tailored approaches. Sites' most cited ongoing financial needs include staff support to coordinate science programs, liaise with policy makers, and mobilise resources. Climate vulnerability assessments, research prioritisation exercises and infrastructure or equipment are typically financed through one off grants while monitoring, outreach, communication and engagement requires long-term sustained funding. **Supporting sites with the development of a sustainable financial strategy could bring a more business-like approach to the funding of ocean research and help marine World Heritage sites move away from the project-to-project approach commonly in place.** It might also help investors to better understand how their support fits in the bigger picture of the sites' management and the impact it will have in the long term.

5. Outreach, Advocacy, and Awareness Raising



Participant from the Banc d'Arguin National Park (Mauritania) during a UNESCO meeting. © UNESCO / Daniel Correia

Among the greatest threats to UNESCO marine World Heritage sites is the common misconception that because they are internationally protected, they can withstand the challenges of a changing climate. To counter this perspective, clear communication about uncertainties is as important as the need to assess vulnerabilities and establish monitoring programs.

Marine World Heritage sites hold over 20% of the world's blue carbon assets and represent some of the last refuge areas for IUCN's red listed vulnerable, endangered and critically endangered species. Outreach, advocacy and awareness of sites' science needs and priorities is central in the protection of the ocean as a whole. State-of-the-art visitor centres or museums, virtual exhibitions and engagement activities should be aided by technology and innovation to reach broad audiences as well as key stakeholders and decision makers.

With the prestigious World Heritage brand as a lever to generate global attention, sites have the potential to play the role of essential multipliers over the course of the Ocean Decade and to deliver the science we need for the ocean we want. If World Heritage sites are threatened, the world takes notice.

Clean-up of 60,000 Flip-flops From Aldabra Atoll (Seychelles)

Marine debris accumulates on even the most remote and pristine UNESCO marine World Heritage sites.[23] On the coast of Aldabra Atoll in the Seychelles, vast quantities of plastic litter have been clogging up turtle nesting beaches. The "Aldabra Clean-Up Project"[24] was established to collect and remove waste from the remote atoll. Twelve young volunteers collected 25 metric tons of waste, including 60,000 individual flip-flops and discarded fishing gear. The project raised global awareness of marine debris and plastic pollution. Some of the waste collected was recycled or reused by conservation groups, artists and schools. Scientists hope to learn more by investigating the degraded plastic, while engineers will test marine litter in circular economy applications.

23 http://whc.unesco.org/en/news/1904/
24 https://www.youtube.com/watch?v=Kf3PcL8gUpU

Researcher in the iSimangaliso Wetland Park World Heritage site (South Africa). © WILDOCEANS / Casey Pratt

6. Accelerating Ocean Science Investments in Africa and SIDS

The UNESCO World Heritage List today counts 50 marine sites distributed across 37 nations. Ten of these are located in Africa or Small Island Developing States (SIDS).[25] According to the 2020 IUCN World Heritage Outlook, all **marine World Heritage sites in Africa or SIDS are threatened by climate change – in large measure due to coral reef ecosystems which are present in 90% of these sites**. Marine World Heritage sites in those areas are critically important ecosystems and often provide essential sources of income and services to local people who depend on them. Banc d'Arguin National Park in Mauritania, for example, hosts some of the world's largest blue carbon stocks while iSimangaliso Wetland Park (South Africa) hosts an environmental education program that reaches 150 schools.

The results of the survey conducted for this roadmap indicate no notable differences in the type of ocean science sites need in Africa or SIDS in comparison to other sites. Yet important differences are observed in how research is conducted and financed, access to innovation and the overall readiness to deal with the threat of climate change. Only 20% of sites, for example, receive private and philanthropy support for their ocean research activities, in comparison to nearly 50% across all marine World Heritage sites. Over 80% of sites in Africa or SIDS lack knowledge of how climate change will impact their biodiversity under different climate scenarios compared to 60% across all sites. Sites clearly also lack in greater proportion access to innovation with only 60% who use satellite observation (compared to 70% for other sites) and 80% lack equipment to monitor how climate change is impacting the OUV of their site.

A lack of technology and financing also means sites located in Africa or SIDS find it difficult to access oceanographic data produced by international research institutions. They often lack the skills and resources needed to collect, process and exploit this data on site. All sites in SIDS and Africa reported the need for on-site training in scientific management techniques, monitoring methods, data collection and documentation, data analysis and interpretation.

Collectively, marine World Heritage sites in SIDS and Africa are most likely to experience disproportionately more effects from climate change in comparison to other locations in the marine World Heritage network. Yet their readiness to conduct the science needed for sound decision making and to build resilience is clearly far lower than for the rest of the marine World Heritage sites. An increase of ocean science investments in SIDS and Africa is an essential priority.

25 In this document, 'Africa' refers to the marine areas surrounding the African continent (including Socotra Archipelago, Yemen), not the UNESCO region Africa.

National Park Service conducts research in the Glacier Bay National Park and Preserve (USA). © Mark Kelley

7. The Bigger Picture

The Earth's climate is changing. The effects of global warming are severe and will worsen in the future. While the world reduces emissions in line with the Paris Agreement, priority must also be placed on adapation and how best to mitigate the impact of human activity on the natural world.

Similarly, at UNESCO marine World Heritage sites, scientific solutions will provide the best way forward to increase the chances of their survival. Though the overall mandate of the 1972 UNESCO World Heritage Convention is to protect sites' OUV for present and future generations, actions to protect sites also bring positive benefits well beyond their boundaries. Science underpins decision making, for conservation efforts on site and for global impact.

Ensuring that future generations can continue to enjoy the UNESCO marine World Heritage sites requires a broader application of science and innovation. Many sites' OUV feature iconic migratory species that venture far beyond site boundaries. Innovative legal frameworks to protect those species once they are out of individual countries' reach or technological advances to reduce underwater noise of international maritime traffic are equally crucial for the long-term protection of the world's flagship marine protected areas.

Fundamental transformations are necessary in all aspects of society — how we grow food, use land, transport goods, and power our economies.[26] The transition to a circular economy could end the scourge of plastics in the ocean[27] and innovative finance mechanisms to ascribe value to sites' nature-based solutions, including blue carbon resources, are urgently needed.

The ocean holds the keys to an equitable and sustainable planet. Now more than ever, stakeholders from diverse sectors must help to accelerate scientific knowledge and harness advances in ocean science. This will help us achieve a better understanding of the ocean system, and to deliver science-based solutions to achieve the ocean we want by 2030.

8. Next Steps and Call to Action

The Ocean Decade presents a timely opportunity to mobilise diverse actors and the resources required to sustainably manage marine World Heritage sites as a priority for future generations, and to build global ocean science capacity.

Once the critical science gaps that hinder adaptation to future conditions are identified, site managers can use the Ocean Decade framework to partner with academic institutions, local and indigenous communities, NGOs, private industry and with relevant Regional or National Decade Committees to co-develop and co-deliver Decade Actions (for example, programmes, projects or contributions to the Ocean Decade).

Regional and National Ocean Committees can help by building appropriate partnerships and identifying the expertise needed to collect, analyse and interpret datasets or to deploy and maintain instrumentation. Once Actions have been developed they can be submitted for formal endorsement via twice-yearly Calls for Decade Actions that will be tailored to meet regional or thematic gaps.

26 https://www.un.org/en/un75/climate-crisis-race-we-can-win
27 https://www.unido.org/stories/circular-economy-solution-marine-plastic-litter

Member States, funding platforms, philanthropists, NGOs or research institutions are encouraged to use this roadmap to guide support for ocean science, or to step up investments in ocean science to benefit marine World Heritage sites.

Decade Actions could provide a mechanism to align science programmes across UNESCO marine World Heritage sites. Examples of Decade Actions could include undertaking an assessment of climate vulnerability at sites, develop a new scholarship programme for rangers, focus on regional priorities through joint scientific programmes for a cluster of sites, or go in-depth into the needs of an individual site to conduct a climate vulnerability and research prioritisation assessment, and to strengthen infrastructure and training.

Once endorsed, Decade Action advocates become part of a collective global ocean science movement and can support the creation ofsynergies and new partnerships, develop capacity, and eventually access new sources of in-kind or financial resources for implementation, including via the Ocean Decade Alliance. The Ocean Decade Alliance is a network of eminent partners of the Ocean Decade that are leading by example to catalyse support for the Ocean Decade through targeted resource mobilisation, networking, and influence. The Alliance will bring together resource providers and advocates of Decade Actions that align with Ocean Decade priorities.

Ocean health is rapidly deteriorating amid intensifying change. This is a critical moment to protect the ocean and the situation demands coherent, representative, resilient, and connected marine protected areas. **Actions based on the priorities outlined here in this roadmap will to a large part define how the UNESCO marine World Heritage sites will be protected in the future** and how well they will be able to build resilience in the face of a warming ocean.

How to Submit a Decade Action?

To learn more about the Ocean Decade and to submit a Decade Action, please visit www.oceandecade.org and join the Global Stakeholder Forum (forum.oceandecade.org), which will serve as the primary engagement mechanism for the Ocean Decade, announcing opportunities for funding and partnerships, workshops and trainings, meetings, conferences, and input on calls for future Decade Actions.

THE OCEAN DECADE ACTION FRAMEWORK

Source: IOC-UNESCO, 2020

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http://ioc-unesco.org
http://oceandecade.org

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