A Policymakers' Handbook for

Addressing the Impacts of Ocean Acidification

Commonwealth Blue Charter Action Group on Ocean Acidification

About this Handbook

The Commonwealth Blue Charter is an agreement by the 54 Commonwealth countries and adopted at the Commonwealth Heads of Government Meeting in London, April 2018. The Charter of the Commonwealth provides the underlying principles for the Blue Charter, ensuring that the Commonwealth takes a fair, equitable, inclusive, and sustainable approach to ocean economic development and protection.

Under the Blue Charter, Commonwealth countries agree to actively cooperate to tackle ocean-related challenges and meet commitments for sustainable ocean development, with particular emphasis on the UN Sustainable Development Goals (SDGs), especially SDG 14 (Life Below Water). Implementation of the Commonwealth Blue Charter is through Action Groups, which work to unlock the power of all Commonwealth nations and guide the development of tools and training. Each Action Group is member-driven and led by one or more Champion countries. To date, 15 countries have stepped forward to champion 10 Action Groups.

In February 2019, New Zealand hosted the Commonwealth Ocean Acidification Action Group Workshop in its role as Champion of the Commonwealth Blue Charter Action Group on Ocean Acidification. Scientific experts and observers were joined by 23 government officials from 17 Commonwealth countries: Antigua and Barbuda, Australia, Cook Islands, Fiji, Ghana, Kenya, Mauritius, Mozambique, New Zealand, Samoa, Seychelles, Solomon Islands, South Africa, Tonga, Tuvalu, United Kingdom, and Vanuatu.

During this meeting, attendees discussed how to enhance Commonwealth members' ability to address the impacts of ocean acidification by identifying strategies for marine monitoring, capacity development, ocean literacy, governance, and management. Through these discussions, participants recognised that most available ocean acidification resources require technical expertise and implementation capacity that are not readily accessible to policymakers and often not available in Commonwealth countries. This Handbook addresses this gap by identifying and contextualising existing resources to facilitate the identification and implementation of strategies to address ocean acidification.

Citation

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Foreword

We all benefit from the generosity and nourishment of the ocean. For many, it is our food source, the source of spiritual and cultural tikanga, and our identity. The health of the ocean is critical to all these elements and it is our responsibility to take care of it. In Aotearoa New Zealand we call this obligation 'kaitiakitanga'. We are the protectors and stewards of intergenerational well-being. That is why the 54 countries of the Commonwealth Blue Charter, which works for sustainable ocean development, talk about a 'shared ocean and shared values'.

We know that ocean acidification has serious consequences for sea life. It affects the ability of shellfish, urchins, corals and plankton to build and maintain their shells and calcium carbonate structures. It also affects fish behaviour, leaving some species more vulnerable to damage and predators. Ocean acidification is contributing to the degradation of coral reefs and shifting the phytoplankton community structure that forms the base of the food web. This puts at risk the communities that depend on fish and shellfish or rely on coral reefs for protection. Small island developing states and indigenous communities are especially vulnerable.

This *Policymakers' Handbook for Addressing the Impacts of Ocean Acidification* is an important resource. The Handbook is a product of the Commonwealth's Blue Charter Action Group on Ocean Acidification. It is designed for people who make decisions about how we use and protect our oceans. It introduces them to the steps needed to address ocean acidification. It enables them to act as kaitiaki or guardians.

This Handbook draws from inputs to the Commonwealth Ocean Acidification Action Group Workshop, which brought together experts from a range of Commonwealth countries. Only by working together can we tackle the challenge of ocean acidification.

Toitū te marae a Tāne-Mahuta
Toitū marae a Tangaroa
Toitū te tangata.
If the land is well and the sea is well, the people will thrive.

Hon Nanaia Mahuta
Minister of Foreign Affairs/ Te Minita o Te Manatū Aorere

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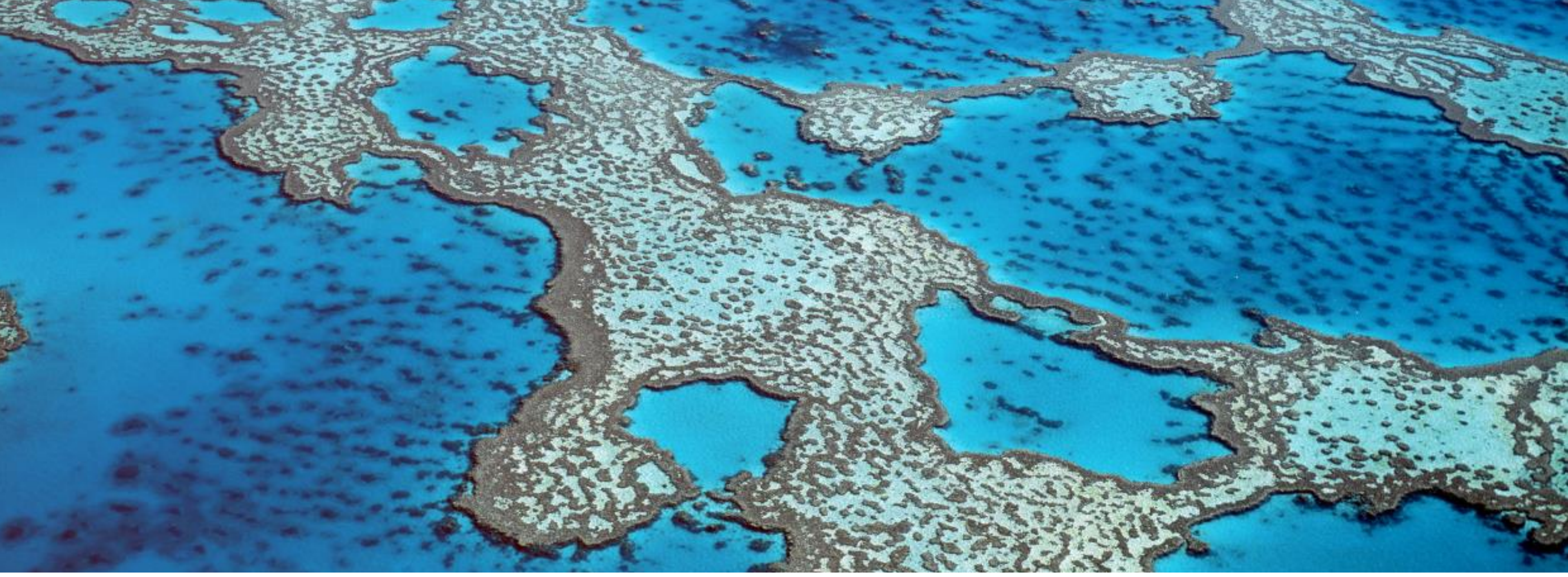


Ocean acidification

What is ocean acidification?

Ocean acidification is the long-term decrease in seawater pH that results from the absorption of excess carbon dioxide (CO_2) released into the atmosphere by human activities, primarily through the burning of fossil fuels, deforestation, and cement production (Friedlingstein et al., 2019). The global ocean has absorbed approximately 30% of the total greenhouse gas emissions over the last 250 years, helping to slow the impacts on climate change (Doney et al., 2009). However, as CO_2 is absorbed by seawater it reacts with water to form carbonic acid. This process increases the acidity of seawater and lowers the saturation state of calcium carbonate minerals. If the saturation state becomes sufficiently low, the dissolution of unprotected calcium carbonate shells and skeletons is expected. Globally, the average surface seawater pH has already decreased from 8.2 to 8.1 over 250 years, corresponding to a 30% increase in acidity (Doney et al., 2020). At the current rate of CO_2 emissions, the global surface ocean pH is projected to decline to 7.8 by 2100 (Hurd et al., 2018).

The chemical changes associated with ocean acidification, in particular the lowering of saturation states of calcium carbonate minerals, have been shown to have detrimental effects on the calcification, growth, and mortality of calcifying marine organisms, such as shellfish and corals. The lower saturation state makes it energetically much more costly to maintain shells and skeletal structures and has particularly adverse impacts on larval and juvenile development (Waldbusser et al., 2015). Other chemical aspects of ocean acidification have been shown to impact fish behaviour and metabolism (Heuer and Grosell, 2014). While many phytoplankton species may not be negatively affected by ocean acidification, or may even benefit from increased CO_2, various zooplankton species that feed on them have been shown to be negatively affected (Wang et al., 2018). Collectively these interactions may alter ecosystems and affect food web dynamics (Doney et al., 2020).

Ocean acidification is just one of the many aspects of global climate change. The effects of ocean acidification may be exacerbated by compounding stressors, such as ocean warming, pollutants, increased storm run-off, and overfishing. Since anthropogenic CO_2 emissions are the primary cause of ocean acidification, action to address ocean acidification should be considered one pillar of climate change efforts.

Although the full ecological impacts remain to be determined, ocean acidification is predicted to have wide-reaching impacts on marine ecosystems, food security, cultural identity and values, livelihoods, water quality, tourism, and recreation. Therefore, it is imperative that local mitigation and adaptation approaches are implemented to address this threat. This Handbook takes users through the steps needed to develop a clear and tractable strategy to address ocean acidification.

Using the Handbook

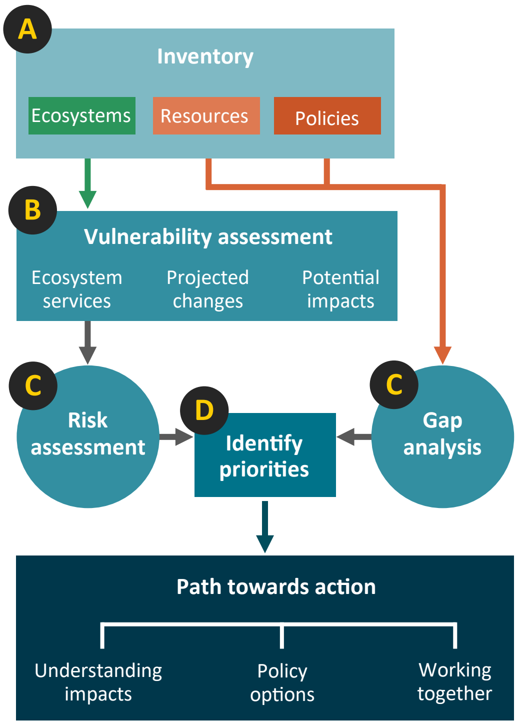
This Handbook is designed to help policymakers utilise existing resources to identify and implement strategies to address ocean acidification. This first chapter summarises marine assets vulnerable to ocean acidification, adaptation and mitigation options, and global networks to increase national capacity. The remaining chapters provide a framework for developing region-specific actions and implementation plans. The foundation of this framework is the **Path towards action**, which provides a step-by-step guide to identifying the priorities that will inform the development of policy to address ocean acidification. This identification of priorities is facilitated by the five steps described in Establishing pathways towards action:

A An inventory of ecosystem types, resources, and existing policies allows identification of vulnerable regions and key resources, expertise, and infrastructure that can be adapted or leveraged.

B A vulnerability assessment is used to identify potential impacts on key marine resources.

C A risk assessment is used to estimate the adverse effects of ocean acidification on key resources. A gap analysis is used to effectively allocate resources.

D Finally, priorities for action can be identified by considering the risks, costs, and ease of implementation.



To assist with each of these steps, the last section of the Handbook contains 8 Templates, with example text, that demonstrate the steps in the **Path towards action**. The Templates are also available as fillable document files at the Blue Charter Action Group on Ocean Acidification website.

The later chapters describe specific steps that can be used to develop a **Path towards action**, once priorities for action have been identified, including:

- Improving the regional understanding of ocean acidification through targeted monitoring, modelling, and forecasting.
- Building partnerships by raising awareness and engaging stakeholders.
- Developing an action plan and identifying policy vehicles to address ocean acidification.
- Increasing capacity, strengthening stakeholder engagement, and facilitating policy development by working together to address the impacts of ocean acidification.

By following the steps in the **Path towards action**, users will identify effective and tractable actions to address ocean acidification at local, national, and regional levels. The effectiveness of these actions will be enhanced if they are done in collaboration with other members of the Blue Charter Action Group on Ocean Acidification and in conjunction with work of other Blue Charter Action Groups. Opportunities for these collaborations are introduced in Working together to address the impacts of ocean acidification.

Considering marine assets when identifying strategies to address ocean acidification

Throughout this Handbook, **asset** categories are used to describe ecosystems and marine resources, including infrastructure, which provide services of economic, environmental, and cultural value that are threatened by ocean acidification. **Assets** have been organised into five categories that allow their features, values, and mitigation strategies to be addressed collectively.

Fish refers to small-to-large pelagic and demersal fish and includes both wild stocks and aquaculture.

Shellfish refers to wild stocks and aquaculture production of molluscs, including bivalves (e.g. oysters, mussels, and clams), and crustaceans (e.g. crab, shrimp, and lobsters).

Coral reefs include both warm and cold water reef-forming coral species.

Marine plants refers to all primary producers, including mangroves, seagrasses, kelp forests, and salt marshes.

Coastal services refers to land-ocean interactions and human factors in coastal systems, such as eutrophication, urbanisation, infrastructure, and cultural and recreational use.

These **asset** categories will help refine actions around resources with similar features and mitigation strategies when developing the path towards action, appraising intervention options, raising awareness, and engaging stakeholders.

Assets

Fish	Shellfish	Coral reefs	Marine plants	Coastal services
Role of Asset				
Finfish play a critical role in the balance of marine ecosystems and connecting trophic levels. They are a primary human food source and an important commercial and recreational resource.	Shellfish play an important role as a food source for higher trophic level predators. They are habitat-forming filter feeders that improve water quality. Shellfish are a primary human food source and an important commercial and recreational resource.	Coral reefs provide important habitat for ecosystems with high biodiversity, supporting local fisheries and tourism. They provide protection for coasts from storm surge, and limit flood damage and erosion.	Marine plants absorb CO_2 through photosynthesis, thereby removing CO_2 from the water and buffering against ocean acidification and climate change. They provide high-biodiversity habitats, protection from storm surge, and limit flood damage and erosion.	Healthy coastal waters and habitats provide numerous services of ecological, cultural, and economic value. These waters support 40% of the world's population that live within 100 km of the coast.
Global Economic Value				
$115.2 billion in total with $30.8 billion in marine aquaculture and $84.4 billion in wild harvest.[1]	$54 billion.[1]	$36-375 billion ($14,705 ha^{-1}), including tourism, fisheries, storm protection, and water quality.[2]	Blue Carbon Economic Potential $1.5 trillion.[3] Mangroves $181 billion ($12,067 ha^{-1}).[4] Seagrass $228 billion ($19,000 ha^{-1}).[5] Kelp Forest $175 billion ($30,000 ha^{-1}).[6]	$3-6 trillion, including employment and ecosystem services.[7]
Effects of Ocean Acidification				
Direct effects include changes in behaviour, fitness, and larval survival. There are also indirect effects related to prey interactions, prey avoidance, and habitat losses.	Direct negative impacts include reduced growth, calcification, and survival rates, particularly in juveniles. Reductions in fertility and reproduction have also been shown.	Direct negative impacts include reduced calcification and increased dissolution and bio-erosion. There are additional synergistic effects due to warming and acidification, e.g. bleaching.	General increase in photosynthesis due to increased CO_2. This may buffer other organisms, such as shellfish and coral, against ocean acidification.	Wide-scale impacts due to the combined effects of ocean acidification and other stressors, including overfishing, pollution, eutrophication, and hypoxia. Examples include major shifts or collapse of ecosystems and deterioration of habitats and water quality.

All economic estimates given are in US dollars. [1] FAO Yearbook of Fishery and Aquaculture Statistics (2018); [2] Doney et al. (2020), Spalding et al. (2017), and Costanza et al. (1997); [3] Steven et al. (2019); [4] Sarhan and Tawfik (2018); [5] Dewsbury et al. (2016); [6] Blamey and Bolton (2018), Krumhansl et al. (2016); [7] United Nations The Ocean Conference Fact Sheet (2017).

Appraising intervention options

The most direct solution to ocean acidification is the cessation of CO_2 emissions. However, this is fraught with technical, political, and social challenges. Therefore, critical components of a strategy to address ocean acidification are intervention to eliminate or mitigate ocean acidification and adaptation to build resilience in coastal communities and marine ecosystems. Adaptation is often more practical and affordable at local scales and is generally more compatible with existing approaches to other environmental issues. In addition, adaptation approaches may have co-benefits, such as wastewater treatment to freshwater inputs in coastal regions. Mitigation approaches are often more targeted, including the translocation of ocean acidification tolerant strains and species in threatened environments and coastal economies.

There is no one-size-fits-all approach, particularly as different interventions are appropriate to different assets and scales. Therefore, the most effective intervention strategies will be developed as part of a clear action plan or policy response based on the identification of priorities for action. The relative merits of selected intervention approaches are assessed on the next page, with consideration of four mitigation techniques and four adaptation approaches.

The table below presents mitigation and adaptation options, including scale, cost, uncertainties, and co-benefits with reference to the 5 **asset** categories. Further details and assessments of different intervention options can be found in published reviews including Albright and Cooley (2019), Cooley et al. (2016), and Strong et al. (2014).

	Scale and feasibility	Cost	Gaps and uncertainty	Co-benefits	Asset
Mitigation					
CO_2 emission reductions	Global Low	Very high	Technical, political, and social challenges Vested economic interests	Slow climate change	
Reduce other stressors, e.g. water quality improvement	Regional-local Medium	Low-medium	Scale of benefits in addressing ocean acidification	Biodiversity, conservation, water quality, recreation, and tourism	
Alkalinisation / liming	Regional-local Low	Medium	Source materials Technical constraints Ecosystem impacts	Biodiversity, conservation	
Aeration	Local Medium	Medium	Effectiveness Limited scale	Improved oxic status	
Adaptation					
Marine spatial planning and protection (including refugia and connectivity)	Regional-local High	Low	Effectiveness Competing interests in coastal waters	Biodiversity, resilience	
Translocation of resilient strains and species, selective harvesting	Local High	Low - medium	Unintended impacts, including ecosystem impacts Scalability	Biodiversity, tourism, recreation, job creation, flood and storm protection	
Phyto-remediation	Regional-local Medium	Low	Effectiveness Scalability	Biodiversity, job creation, flood and storm protection	
Genetic engineering and assisted evolution	Local Low	High	Scalability Ecosystem impacts	Habitat	

CASE STUDY:
Buffering Tampa Bay with seagrass restoration

By working collaboratively to achieve a shared, community-driven goal, the Tampa Bay region has restored seagrass beds, reducing local acidification.

Coastal water pollution led to the decline of important seagrass habitat

Tampa Bay (USA) contributes $22 billion to the regional economy. However, sustained impacts from pollution and coastal development led to declines in water quality, pH, and important marine habitats, including a reduction of seagrass beds by 50% over 4 decades.

Seagrass, mangroves, and other marine plants help buffer against coastal ocean acidification by absorbing CO_2 in seawater. Thus, the removal of seagrass habitat led to increased acidification in the bay, and declines in the shrimp, crabs, manatees, and sea turtles that feed on and within seagrass fields. While water quality laws reduced sources of pollution, more work was needed to restore seagrass and the associated marine services.

Restoration of seagrasses in Tampa Bay

The Tampa Bay Estuary Program (TBEP) was founded as a partnership between local, state and federal governments to restore and protect the bay through community-based management. TBEP brought together regional industry, farmers, business, and government to reduce coal fired power production, limit fertiliser intrusion to the bay, and work on restoration through fine-scale management and a robust monitoring program.

A full rebound

Through persistent efforts by TBEP and community stakeholders, seagrasses have rebounded to 1950's levels, regaining over 6015 hectares, and raising the mean pH in the bay. The tangible results produced through these efforts could only be captured through the long-term monitoring record, which reinforces the political and societal investments. Continued monitoring aids adaptive management to ensure Tampa Bay's seagrass recovery continues despite an ever-increasing coastal population and anticipated impacts from ocean acidification and climate change.

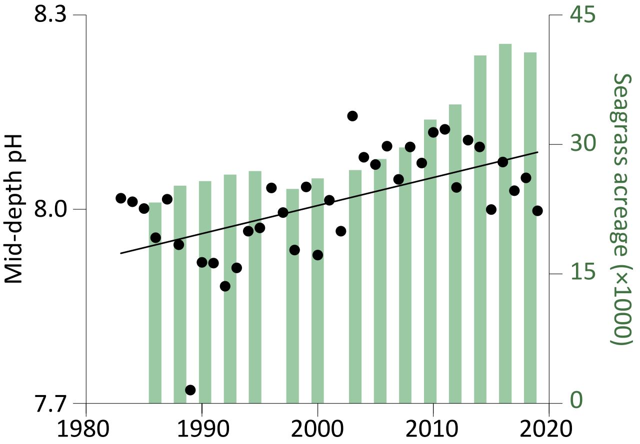


Figure: Tampa Bay pH (●) is increasing with the recovery of the seagrass (■).

Lead contact Ed Sherwood, Tampa Bay Estuary Program, esherwood@tbep.org

Monitoring in Tampa Bay from 2010 - 2014 shows the increasing spatial extent of seagrass.

Global ocean acidification networks

Although some countries have limited technical expertise and implementation capacity to address ocean acidification, resources may be available from international, regional, and non-governmental entities. For example, developing countries may benefit from strengthening research, oceanographic, and socio-economic institutions via technical cooperation with, and assistance from, regional and international institutions (UN DESA Policy Brief #1). Some international organisations that support capacity development are listed below. Policymakers are also advised to investigate potential national sources. Certain Commonwealth countries have funding to address climate change and these funds may also support capacity development and response to ocean acidification. For example, Tuvalu's Climate Change and Disaster Survival Fund Act 2015 supports adaptation to climate change.

Global Ocean Acidification Observing Network (GOA-ON)

GOA-ON is a collaborative international network to detect and understand the drivers of ocean acidification in estuarine-coastal-open ocean environments, the resulting impacts on marine ecosystems, and to make the information available to optimise modelling studies. It provides key input to communities, industry, and governments seeking to develop action plans, best practices, and mitigation or adaptation strategies to address ocean acidification impacts. GOA-ON also supports the development of regional hubs, provides training through the Pier2Peer mentorship program (see the GOA-ON in a Box case study), and supports a data portal for sharing and viewing metadata.

International Alliance to Combat Ocean Acidification (OA Alliance)

The OA Alliance is a network of national, regional, and local organisations dedicated to raising awareness and stimulating action to address ocean acidification and protect coastal communities and livelihoods. The OA Alliance's Ocean Acidification Action Plan Toolkit provides a framework and suggestions for the development of ocean acidification action plans.

The IAEA Ocean Acidification International Coordination Centre (OA-ICC)

Launched in 2012 by the IAEA, the OA-ICC promotes international collaboration by disseminating information on ocean acidification and organising training courses. The OA-ICC database contains references, data compilations, abstracts, citations, policy, country reports, and training announcements.

The Ocean Foundation

The Ocean Foundation's International Ocean Acidification Initiative has trained personnel from over 20 countries and hosts the *Pier2Peer Scholarship*, which facilitates financial support for GOA-ON's Pier2Peer program. Together with the OA-ICC and GOA-ON, The Ocean Foundation created the first low-cost monitoring system, *GOA-ON in a Box* (see the GOA-ON in a Box case study). The Ocean Foundation has also produced an Ocean Acidification Guidebook for Policymakers, advises on ocean acidification legislation, solutions and strategies for resilience, and supports ocean acidification integration into the UN Framework Convention on Climate Change (UNFCCC) process.

Commonwealth Blue Charter Action Group on Ocean Acidification

The Commonwealth Blue Charter is an agreement by all 54 Commonwealth countries to actively cooperate to solve ocean-related problems and meet commitments for sustainable ocean development. Members of the Blue Charter Action Group on Ocean Acidification are working towards improving the capacity of Commonwealth countries to address the impact of ocean acidification through increased technical capacity, development of cross-Commonwealth connections, facilitation of policy, and sharing of knowledge.

Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO)

As the lead UN Agency for marine science issues, the IOC is responsible for reporting towards Sustainable Development Goal (SDG) 14.3 and collaborates with regional ocean acidification sub-committees including IOC-WESTPAC, IOCAFRICA, and IOCARIBE.

International Ocean Carbon Coordination Project (IOCCP)

The IOCCP promotes the development of a global ocean carbon observation network via technical coordination and communication services, and agreements on standards and methods.

Commonwealth Climate Finance Access Hub (CCFAH)

CCFAH assists small and climate-vulnerable Commonwealth states in applying for international funds that address climate change, such as the Green Climate Fund. The CCFAH helps with the integration of climate change concerns into national institutional architecture and the implementation of environmental laws relating to climate change.

The Green Climate Fund (GCF)

The GCF is the largest global fund assisting developing countries to reduce greenhouse gas emissions and enhance their ability to respond to climate change. The GCF was set up by the UNFCCC in 2010, and channels climate finance to developing countries that have joined other nations in committing to climate action. The fund focuses on highly vulnerable states, including Least Developed Countries, Small Island Developing States, and African States. It has established a direct funding mechanism to these countries that bypasses international intermediaries to enable direct investment in low-emission and climate-resilient development.

National funding for climate change adaptation

Commonwealth countries may have funding to address climate change. For example, the Climate Change and Disaster Survival Fund Act 2015 (Tuvalu) supports responses to natural disasters and helps facilitate adaptation to climate change.

CASE STUDY:
Building capacity with GOA-ON in a Box and Pier2Peer

A **GOA-ON in a Box** kit enabled the first coastal monitoring of ocean acidification in South Africa.

Knowledge and technology is required to understand and address ocean acidification

Cost and complexity remain hurdles to establishing monitoring programs, which are needed to understand the local impacts of ocean acidification on ecosystems and services. These hurdles are exacerbated in small and developing nations, where resources are limited.

GOA-ON in a Box kits and the Pier2Peer mentorship programme provide access to technology and expertise

Working with The Ocean Foundation, NOAA, Scripps Institute of Oceanography, IAEA OA-ICC, and Sunburst Sensors , GOA-ON developed a low-cost kit (**GOA-ON in a Box**) that includes the equipment needed to monitor ocean acidification. **GOA-ON in a Box** training is through workshops, manuals, and instructional videos. Long-term monitoring efforts are supported through GOA-ON's Pier2Peer mentorship program, which fosters international collaboration and supports scientific development and knowledge exchange.

The Ocean Foundation has purchased and distributed **GOA-ON in a Box** kits to countries across the Pacific Islands, Africa, and Latin America.

Building capacity and paying it forward

As an early career scientist, Carla Edworthy was awarded a **GOA-ON in a Box** kit that she used to set up a coastal monitoring programme in South Africa. This monitoring data facilitated her PhD research by informing the pH values used in laboratory studies to assess the impact of ocean acidification on the physiology and behaviour of important species in local fisheries. During an Ocean Foundation workshop associated with the ApHRICA programme, Carla met Professor Sam Dupont from the University of Gothenburg. Sam became Carla's mentor through Pier2Peer and this relationship has led to further East African collaborations. This also provided Carla opportunities to take lead roles in experimental research, securing grant funding, and leading training workshops. With the knowledge gained through three years in Pier2Peer, Carla has moved from mentee to mentor and will be a teaching assistant for future workshops held in Africa.

Lead contacts

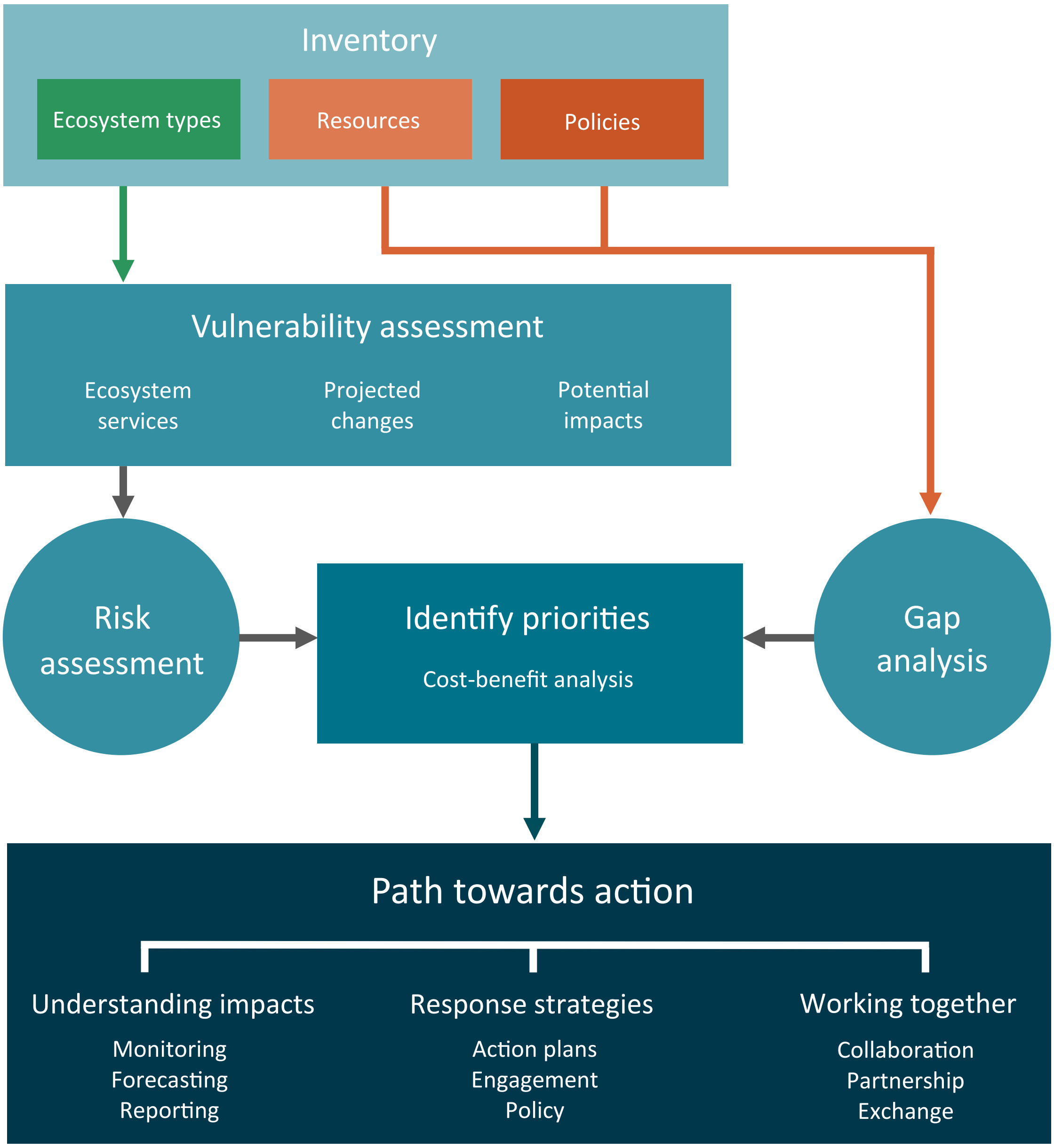
GOA-ON in a box kit: Alexis Valauri-Orton
avalauriorton@oceanfdn.org
Pier2Peer: Libby Jewett, Libby.Jewett@noaa.gov
Carla Edworthy, South African Institute for Aquatic Biodiversity, carlaedworthy@gmail.com

Establishing pathways towards action

This chapter will guide users through development of a Path towards action to identify practical strategies to address ocean acidification. The process starts with an inventory of ecosystems, resources, and existing relevant policy. The ecosystem inventory is then used to develop a vulnerability assessment, which informs the development of a risk assessment. A gap analysis of existing policy and resources is then integrated with the risk assessment to identify priorities and potential actions.

Identifying practical strategies to address ocean acidification with the Path towards action

The development of a **Path towards action** is facilitated by taking an inventory of all available resources, followed by a vulnerability assessment, risk assessment, and gap analysis. These assessments are then used to identify the priorities that will inform the **Path towards action**.



The Path towards action is used to identify practical strategies to address ocean acidification.

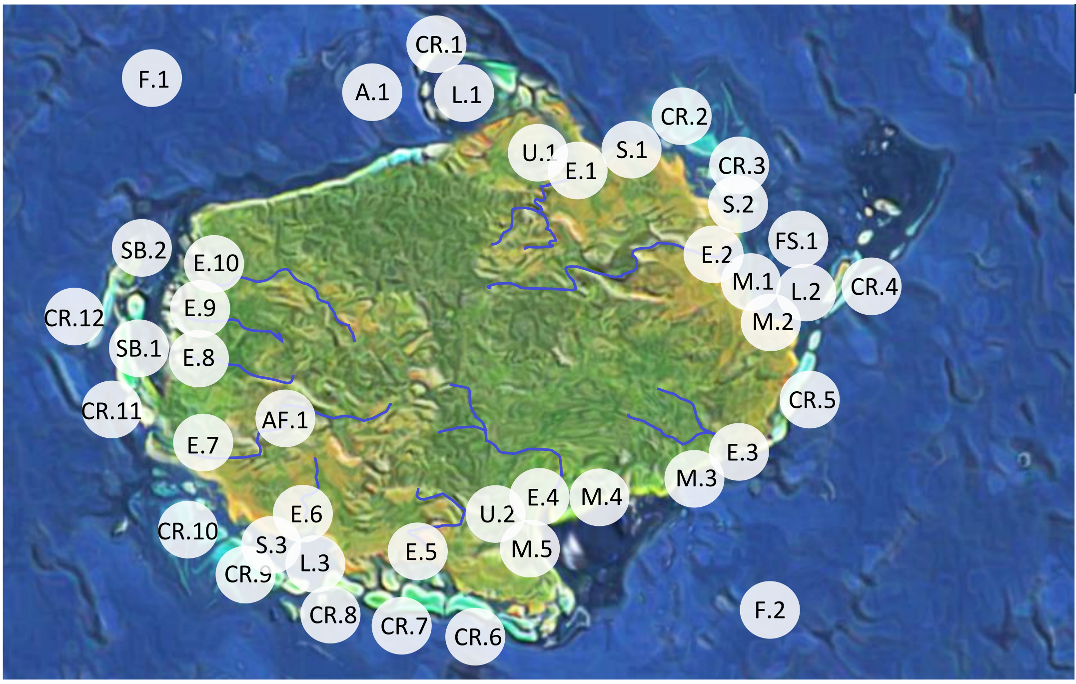
Taking inventory

The first step in the development of a **Path towards action** is to identify the types of ecosystems that may be under threat due to ocean acidification, and the existing policy, infrastructure, and expertise that can be adapted or leveraged. The **Taking inventory templates** (Templates 1 - 5) will guide users through the process of inventorying ecosystem types, available resources, and existing policy.

Taking inventory: ecosystem types

An inventory of the different ecosystem types within a region provides the basis for determining which areas are particularly vulnerable to ocean acidification. This enables the targeting or prioritisation of observations, management strategies, and policy requirements within the limitations of financial, institutional, and human resources. Using local knowledge, maps, and GIS information, policymakers can collate an inventory of the different types of ecosystems in the region. This inventory can be in the form of a map or a table, and should include marine reserves and pristine environments, such as coral reefs, mangrove areas, kelp forests, shellfish beds, and rocky shores. Impacted or altered environments should also be included, including areas used for aquaculture and those impacted by terrestrial pollution. As the Path towards action is developed, the detail and granularity of the inventory can be refined.

Coastal ecosystems may have already been mapped from the terrestrial point of view, as part of regional and national coastal planning processes. Some countries may also have developed an appraisal of the condition and trends of ecosystems and services, including coastal areas, as part of the Millennium Ecosystem Assessment or in the development of marine spatial planning. Such assessments and inventories can be adapted or updated to reflect the current status of coastal ecosystems. Deep sea areas, including fisheries, and seamounts should also be included, as should areas that are used for aquaculture (shellfish, seaweed, finfish) and mariculture. Although the emphasis will be on ecosystem types that will be directly impacted by ocean acidification, areas that can provide baseline conditions should also be included. The inventory should include location information (e.g. area name, latitude and longitude, and depths), ecosystem and species information, and notes with other relevant information. A cross-referencing system is also useful, linking this information to other components of the Path towards action. Countries with a geospatial database or national inventory can use a more sophisticated approach to make a detailed inventory of the ecosystem types.



Ecosystem Feature	Symbol
Coral reef	CR
Seagrass	S
Lagoon	L
Estuary	E
Mangroves	M
Fishing area	F
Aquaculture (marine)	A
Aquaculture (freshwater)	AF
Fish spawning area	FS
Shellfish Bed	SB
Urban area	U

A map-based approach to taking an **Inventory of ecosystem types** on a fictional island.

Template 1 will assist users in taking an **Inventory of ecosystem types**. Blank, fillable versions of all templates are available on-line.

Taking inventory: resources

An inventory of the existing infrastructure, technology, expertise, and available funding will help identify resources that can be leveraged and gaps that need to be filled. Infrastructure resources include existing monitoring programmes that collect samples or are instrumented for other purposes. It can be cost-effective to leverage these by adding additional sensors or collecting water samples to measure parameters relevant to ocean acidification. Such programmes include sea temperature monitoring sites, nutrient monitoring projects, and coral reef monitoring programmes. Consider organisations, such as regional councils, port authorities, and conservation programmes which may have resources that can be utilised. Research institutes or universities may also have existing programmes or projects that can provide infrastructure or historical data that are directly useful (such as temperature records) or provide supplementary information (such as nutrient or chlorophyll concentrations). Include physical infrastructure, such as moorings and deployed instruments. Also include associated services, such as dive surveys, aquaculture monitoring obligations, citizen science initiatives, and fish stock assessments.

Other resources that can be leveraged for inclusion include laboratory facilities and equipment, computing resources, IT and education expertise, and technology. Specific examples include analytical chemistry knowledge, climate change expertise, and remote sensing and GIS capability. Existing collaborations between national and international institutions and initiatives can be included in the resources inventory.

An inventory of existing funding resources will help to identify budgets that could be used in an ocean acidification context. This may include research funding streams, climate change action funds, and industry funds and partnerships. Some countries may have foreign aid or assistance programmes that could provide ocean acidification relevant funding, for example for business development opportunities (aquaculture), or local environmental issues (seagrass restoration). Conservation funds could also be relevant, for example, for coral habitat protection projects.

Template 2, Template 3, and Template 4 will assist users in taking an **inventory of existing resources**. Blank, fillable versions of all templates are available on-line.

Taking inventory: policy

Most countries have existing policy, by-laws, frameworks or conventions that encompass aspects of ocean acidification. Examples include oceans policy, climate change policy, coastal management guidelines, fisheries policy, environmental protection laws. Many countries will also be signatories to, or have made commitments under, international Conventions or Frameworks such as the Convention on Biological Diversity or the UN SDGs.

SDG 14 “Conserve and sustainably use the oceans, seas and marine resources for sustainable development” and the associated targets and indicators are directly relevant, particularly SDG14.3 “Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels” and SDG13 “Take urgent action to combat climate change and its impacts”. The associated indicator SDG14.3.1 “Average marine acidity (pH) measured at agreed suite of representative sampling stations” encourages signatory countries to report ocean acidification relevant data, and extensive methodology and other resources are available to assist countries to report such data.

Template 5 will assist users in taking an **inventory of existing policy**. Blank, fillable versions of all templates are available on-line.

Vulnerability assessment

Conducting a **vulnerability assessment** enables identification of the potential impacts of ocean acidification and other environmental stressors on key ecological, cultural, and economic marine resources and services, as well as the communities that depend on them. This assessment also assists in the design of a monitoring programme and community and stakeholder engagement strategies.

A detailed description of conducting a comprehensive vulnerability assessment is beyond the scope of this Handbook. A simple assessment, however, can provide preliminary information, which can be refined as resources allow. An example of a comprehensive ocean acidification vulnerability assessment is given in the following Pacific Island ocean acidification vulnerability assessment case study. Such detailed vulnerability assessments can be commissioned from specialist businesses.

A simple **vulnerability assessment** (Template 6) combines information on ecosystem types, resulting from Taking inventory: ecosystem types (Template 1), with an evaluation of the ecosystem services provided by each ecosystem type. The projected changes for each ecosystem service are estimated using knowledge of current environmental conditions, potential future impacts, and the adaptive capacity of each ecosystem type and **asset**. This allows a list of potential threats and impacts to be collated for each **asset**. This list of threats and impacts can be used to infer areas of higher risk and higher resilience, allowing prioritisation of resources and targeting of effort.

For each separate **asset** associated with the inventory of ecosystem types, the ecosystem services provided should be identified and evaluated. Ecosystem services include aspects of food security, livelihoods and economic stability, resilience, as well as cultural identity. Specific services to consider include coastal protection provided by coral reefs and mangroves, fishing for domestic, local and commercial purposes, tourism industry access to healthy reef environments, access to quality water for commercial aquaculture and native shellfish beds, employment of local people, and specific economic contributions.

Information on current environmental conditions and projections of future scenarios for each location is then added to the **vulnerability assessment** (Template 6). The effects of ocean acidification on each species and location may not be known. Thus, in the absence of specific ecological impact studies, more general impacts of ocean acidification could be included, such as:

- Sensitivity of coral reefs to decreased carbonate saturation states, resulting in impaired reef structure and general reef degradation.
- Degraded reef structure, resulting in changing fish stocks.
- Decreased carbonate saturation states, resulting in impaired shellfish development and growth.

Template 6 will assist users in taking a **vulnerability assessment**. Blank, fillable versions of all templates are available on-line.

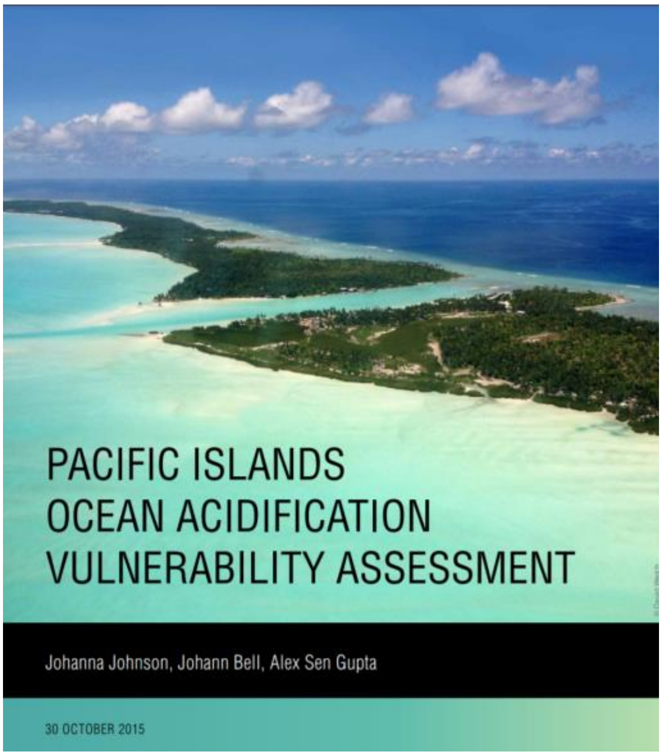
CASE STUDY:
Pacific Island ocean acidification vulnerability assessment

Empowering local communities with ownership in the process and outcome while addressing livelihoods is key to success.

Understanding the risks of ocean acidification and identifying priorities for management

The Pacific Island region is home to 22 countries and territories. Although the islands are diverse, they have in common a high dependence on, and cultural value for, their ocean resources.

Ocean acidification was identified as a serious emerging threat to Pacific communities during the UN SIDS Conference in 2014. Recognizing the need for monitoring and development of capacity, resilience, and adaptation strategies, the New Zealand Ministry of Foreign Affairs and Trade and the Gouvernement Princier, Principaute de Monaco, in collaboration with the Secretariat of the Pacific Regional Environmental Programme, the University of the South Pacific, and the Secretariat of the Pacific Community, supported the development of the New Zealand Pacific Partnership on Ocean Acidification (NZPPOA) to address these issues.



Completion of a vulnerability assessment of South Pacific Islands

Given the limited resources of many SIDS, a thorough vulnerability assessment of assets was needed to identify actions and establish priorities. Observations and model projections were first used to summarise climatological changes in the Pacific Island region. The vulnerability assessment utilised a widely accepted framework: using the highest "business-as-usual" IPCC emission scenarios, the framework assessed vulnerability as a function of exposure, sensitivity, and adaptive capacity. Inventories of national reef and land areas, fish consumption, and economic importance of coastal fisheries were also catalogued. The direct and indirect effects of ocean acidification on coastal resources were used to estimate impacts on food security, economic development, and livelihood under existing policies. Adaptation strategies and future research plans led to a set of recommended actions.

Successful monitoring and mitigation

Findings from the vulnerability assessment guided the selection of Fiji, Kiribati, and Tokelau to serve as pilot site countries for ocean acidification monitoring programmes and mitigation strategies. Stakeholder consultations were held on action plans for adaptation, leading to restoration programs for seagrasses, mangroves, and coral reefs. Reef fishing pressure and other stressors were reduced through the development of aquaculture and locally managed marine areas. The assessment also led to collaborations between the NZPPOA and the Korea Institute of Ocean Science and Technology to establish ocean acidification monitoring buoys in Palau, Samoa, and the Federated States of Micronesia.

Lead contact Robert Duncan McIntosh, SPREP
Secretariat of the Pacific Region Environment Programme, robertmc@sprep.org

Risk assessment

A **risk assessment** can be used to identify and estimate the adverse effects of ocean acidification on **assets** and the services they provide. Environmental risk assessment is widely used when evaluating the effects and impacts of climate change, land use change, and other activities. Detailed and extensive risk assessments can be carried out by specialist consultants or departments. A simple risk assessment can provide initial guidance on potential mitigation actions, then be refined and expanded as resources allow. Indeed, any risk assessment should be regularly re-evaluated as further information becomes available and as mitigation approaches or additional stressors change.

The standard procedure for developing a **risk assessment** is to combine estimates of the severity of the potential consequence with the likelihood of occurrence for each vulnerability. The Climate change effects and impacts assessment provides a detailed example of this process for a New Zealand context, which can be adapted for other locales.

In the **Path towards action**, the potential ocean acidification impacts on each **asset** identified in the **vulnerability assessment** (Template 6) is assessed with respect to the likelihood of occurrence and the consequence, resulting in an estimate of the relative risk arising from each impact. Following the **risk assessment** process below (and in Template 7a), Template 7b can be used to list the potential impacts for each **asset** and numerical values for likelihood, consequence, and risk. To communicate risk to stakeholders, a colour-coded scale of relative risk can be incorporated into the **risk assessment matrix** as shown in Template 7a.

The risk assessment process:

1. Itemise each potential ocean acidification impact from the vulnerability assessment.
2. Assess the **likelihood** of each impact occurring, using the scale:
   5 = Almost certain, 4 = Likely, 3 = Possible, 2 = Unlikely, 1 = Rare
3. Assess the **consequence** of each impact occurring, using the scale:
   5 = Catastrophic, 4 = Major, 3 = Moderate, 2 = Minor, 1 = Negligible
4. Multiply the **likelihood** and the **consequence** together to get a **relative risk**, on the scale:
   1 – 3 = Low; 4 – 6 = Moderate; 8 – 12 = High; 15 – 25 = Extreme
5. The potential impacts can then be ranked according to the relative risk, with those impacts having the higher relative risk being the ones that should be investigated further (Template 7b).

A matrix and worked example are included in Risk Assessment Templates (Template 7a and Template 7b).

Gap analysis

A **gap analysis** can be used to prioritise actions and effectively allocate resources to address ocean acidification. A **gap analysis** aims to identify gaps between the *current* knowledge and resources and the knowledge and resources *required* for an effective ocean acidification management strategy. Here, **knowledge** may refer to scientific data (e.g. environmental conditions, species or ecosystem responses to ocean acidification), economic valuation, the technical expertise needed to carry out tasks such as designing and deploying a monitoring network, or an understanding of demographic or cultural impacts. While knowledge can be considered a resource, **resources** here refer to funding sources, institutions, physical infrastructure, cyber infrastructure, equipment and materials, political support, and policy or laws that may be leveraged to implement ocean acidification mitigation strategies.

A **gap analysis** should begin during the taking inventory process by making note of the missing knowledge, resource limitations, and potential actions needed to address the lack of information. Additionally, it may be useful to consider framing strategic questions regarding current knowledge and resources (see below). Use Template 8a to guide this process.

Example strategic questions

Current knowledge

Inventory: ecosystem types

- What vulnerable species do we have?
- What further information is needed?
- What GIS information do we have?
- What is missing?

Inventory: policy

- What government departments are responsible for climate change, ocean, and environmental policy?
- How is our SDG14.3 reporting procedure encapsulated?
- Do we have political support, directive, or momentum?

Vulnerability assessment: ecosystem services

- Do we know the consequences of decreased coastal protection from coral reef CR.4?
- Do we know the economic contribution of aquaculture farm A.1 to the local economy?

Current resources

Inventory: resources

- Is there a laboratory capable of undertaking ocean acidification chemistry measurements?
- Do we have a mooring or monitoring site or programme that we can leverage to include ocean acidification relevant monitoring?
- Do we have existing budgets that may support educational outreach for raising awareness about ocean acidification?
- Do we have the data, software, cyber infrastructure and technical expertise to model the impacts of ocean acidification?
- Can we forecast acidification and other ecosystem stressors?
- Do we have the information, incentives, and political leverage to coordinate stakeholders and implement protected marine reserves?
- Can we support alternative livelihoods and economic shifts for downscaled fisheries?

Once gaps in knowledge and resources are identified and strategic framing questions have been developed, use Template 8b to complete the **gap analysis** and begin to prioritise actions. This template collates the knowledge and resource gaps around specific **assets**, documenting the current and desired, or target, status. Potential actions are then defined. The current capacity to reach the target is determined to be *adequate*, *partial*, or *absent*. Additional items that should be included in this analysis are: (1) the potential economic impacts to the **asset** that were determined through the vulnerability assessment and (2) the estimated monetary costs associated with implementing each response, strategy, or action. From this rubric, a ranking priority for each action can be identified as *low*, *medium*, or *high* by taking into consideration the current capacity, the ease of implementation, and cost vs. benefit of a particular action.

Template 8a and Template 8b will assist users in developing a **gap analysis**. Blank, fillable versions of all templates are available on-line.

Identify priorities

Identifying priorities is a critical step towards meaningful action to address ocean acidification. Through the taking inventory and vulnerability assessment processes, potential actions can be determined. These actions can then be prioritised using the information documented in the **risk assessment matrix** (Template 7b) and the **gap analysis** (Template 8a and Template 8b).

This process begins by identifying **assets** with the highest regional value and the highest risk of negative impacts from ocean acidification (Template 7b). Next, map the gaps in knowledge, capacity, and resources associated with those assets (Template 8b). From there, the priority ranking that was determined for each action in the gap analysis (Template 8b) is considered. **Assets** with high risk and high priority are readily identified as top priorities. These priorities may be refined as necessary after consideration of the financial costs, ease of implementation, and the potential impact in order to develop the appropriate strategy to address ocean acidification.

1. Align gaps with the most vulnerable assets
2. Identify the high-priority gaps
3. Evaluate the cost and effort of implementation
4. Prioritise actions relative to impact, cost, and benefit

Understanding ocean acidification

This chapter provides guidance on the establishment of the evidence base for policy intervention through improved understanding of baseline ocean acidification measurements, on-going monitoring options, ocean acidification modelling and forecasting, and data reporting networks.

Baseline measurements and on-going monitoring

Knowledge of the current ocean acidification status of an area gives a baseline against which to measure future change. Measurement of existing local conditions, and establishment of an on-going monitoring programme, are key components in the understanding of ocean acidification. A long-term monitoring programme will provide the basis for detecting changes in water chemistry (e.g. pH, aragonite saturation state, calcite saturation state, deoxygenation, temperature, and other indicators) and ecosystem health due to anthropogenic carbon dioxide input and other stressors. Local field data will also contribute to research and to development of mitigation options. The data can also contribute to reporting towards the United Nations SDG target 14.3.

The priorities identified while conducting the inventory of ecosystem types, inventory of resources, and the gap analysis will help to identify sites where monitoring is required. Although ocean acidification is a global phenomenon, some locations will be additionally affected by local anthropogenic stressors, such as terrestrial run-off. Less impacted sites should be included in a monitoring programme as well as sites that are predicted to be more affected, or are more vulnerable. Deployment of sensors measuring pH, temperature and salinity, and a bottle sampling component for measurement of alkalinity and pH comprise a basic monitoring programme. The bottle data are used to calibrate the field sensors and to calculate the carbonate saturation states.

A biological monitoring programme will provide a greater understanding of the biological impacts of ocean acidification, particularly when linked with a chemical monitoring programme. The parameters included are highly dependent on the particular ecosystem type. The Global Ocean Acidification Observing Network (GOA-ON) biological working group is evaluating the needs and requirements of a biological monitoring programme and will publish recommendations on the GOA-ON website.

Resources:

- SDG 14.3.1 Indicator Methodology describes the methodology and instrumentation required for monitoring chemical ocean acidification parameters: alkalinity (A_T or TA), total dissolved inorganic carbon concentration (DIC or C_T), pH on the total scale (pH), and the partial pressure of carbon dioxide in equilibrium with seawater (pCO_2). SDG 14.3.1 Indicator Methodology also provides guidance on sampling strategy, standard operating procedures, and data and metadata requirements.

- GOA-ON Implementation Strategy provides practical information on improving understanding of ocean acidification conditions and ecosystem response, and on acquiring the data and knowledge necessary to optimise ocean acidification modelling.

- GOA-ON in a Box is a low-cost kit containing the equipment and chemicals necessary for establishing a basic monitoring programme. Standard operating procedures and guidelines have been developed for use with the kit, and training opportunities are available. Well-equipped chemical laboratories can analyse samples for alkalinity, pH, and DIC using SOPs detailed in The Guide to Best Practices for Ocean CO_2 Measurements. The GOA-ON website includes a directory and links to these resources, and other useful publications.

- The IOCCP maintains a directory of "off-the shelf" sensors and instruments developed and used by the ocean carbon research community.

CASE STUDY:
A national ocean acidification monitoring programme

New Zealand's Ocean Acidification Observing Network provides a foundation for understanding ocean acidification at a local level

Sustained measurements are necessary to understand the impacts of ocean acidification

Long-term monitoring using standard methods is critical to detecting changes in the environment and facilitates our understanding of ecological processes. It is the foundation for understanding how ocean acidification is affecting our local environment. New Zealand's Munida Time Series, the longest record of ocean carbon in the Southern Hemisphere, has been pivotal in establishing the long-term decline in ocean pH in the region. However, there remained a need to understand ocean acidification in coastal environments.

The New Zealand Ocean Acidification Observing Network (NZOA-ON)

NZOA-ON was developed through a grass-roots cooperative research approach. Scientific requirements were determined by members of the New Zealand Ocean Acidification Community. Sites were selected in consultation with stakeholders from industry, local and national government agencies, and academia to address specific issues such as aquaculture, wild fisheries, land-use, and water management, with the aim of achieving a comprehensive understanding of the effects of ocean acidification on New Zealand's diverse coastal ecosystems.

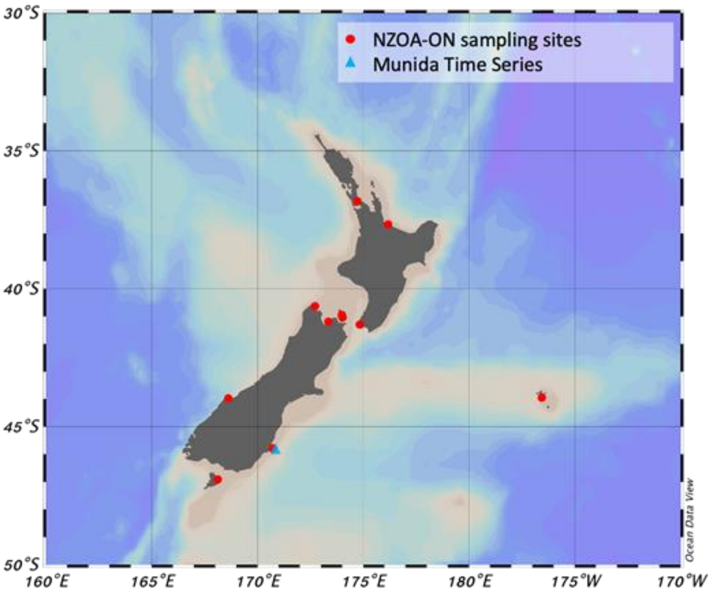
A foundation for understanding

The 10 sites in the NZOA-ON programme provide vital information about the seasonal cycle and interannual variability of coastal pH. NZOA-ON data shows which areas are experiencing undersaturation of calcium carbonate – a key indicator for shellfish production – and which sites are sources and sinks for atmospheric carbon dioxide. The variability of data within a site provides an indication of how long it will take detect a trend in acidification, which is often longer in coastal environments than the open ocean, which can guide future sampling strategies. Recently, a collaboration with the Department of Conservation added 10 more marine-reserve based sites to the NZOA-ON.

The NZOA-ON data complements other research into biological responses to ocean acidification and allows resource managers and policymakers to better understand and strategise response to future scenarios. Additionally, NZOA-ON and Munida data is shared through GOA-ON and provides the basis of New Zealand's reporting toward SDG14.3.

Contact

Kim Currie, National Institute of Water and Atmospheric Research (NIWA), New Zealand
Kim.Currie@niwa.co.nz



Data reporting networks

The sharing of data and metadata allows for global assessment of ocean acidification conditions by a multitude of users and in alignment with FAIR principles (data are Findable, Accessible, Interoperable, and Reusable). However, it should be recognised that some data and information is locally sensitive and may belong to local peoples or specific stakeholders. Appropriate consideration and design of data synthesis products ensure that end users, including policy makers, have access to the data and the findings in a useful and usable way.

National reporting towards the SDG 14.3 is an important avenue for data sharing, and is an incentive for sustaining monitoring programmes. Each year, the UN, via the custodian agency IOC-UNESCO, calls for country reporting towards SDG 14.3 "Average marine acidity (pH) measured at agreed suite of representative sampling stations". The Methodology associated with SDG14.3 includes information on the required data and metadata, and support on how to submit the data. The SDG14.3.1 data portal is a tool for the submission, collection, validation, storage and sharing of ocean acidification data and metadata submitted towards the Goal. Countries with an active National Oceanographic Data Centre (NODC) should submit via that pathway.

Metadata for chemical ocean acidification data (e.g. the information describing the observing site location, analytical methods, and PI contact details) should be lodged with the GOA-ON data portal which, via the GOA-ON data explorer, provides access and visualisation to ocean acidification data and data synthesis products from an interactive website.

Carbon observing and data management communities:

- The Surface Ocean CO_2 Atlas (SOCAT) is a synthesis activity for quality-controlled, surface ocean fCO_2 (fugacity of carbon dioxide) observations by the international marine carbon research community. Surface fCO_2 data can be submitted and downloaded via the website. The Global Ocean Data Analysis Project (GLODAP) is a synthesis activity for ocean surface-to-bottom biogeochemical data, including ocean acidification-relevant data, collected through chemical analysis of water samples. Bottle sample data collected throughout the water column can be submitted and downloaded via the website.

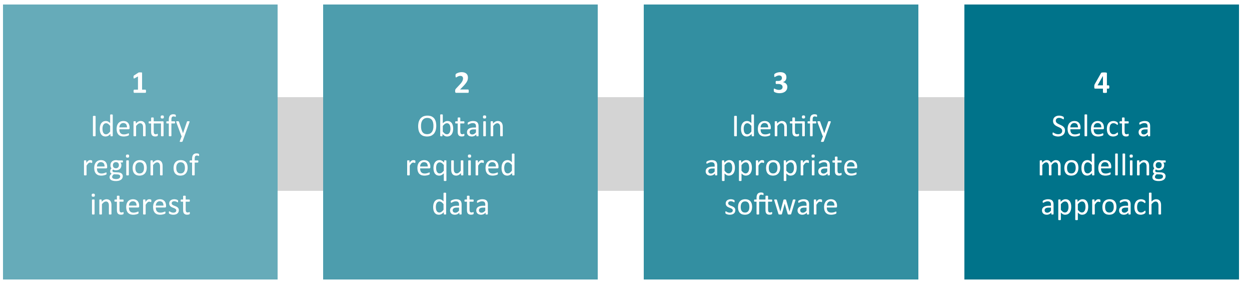
- A compilation of published ocean acidification biological response data, standardised to intercomparable units and scales, is hosted at PANGAEA Data Publisher for Earth and Environmental Science and maintained in the framework of the International Atomic Energy Agency (IAEA) project Ocean Acidification International Coordination Centre (OA-ICC).

- Many countries have National Oceanographic Data Centres (NODCs), and organisations that are registered as Associate Data Units (ADUs). The International Oceanographic Data and Information Exchange (IODE) maintains a list of these, with contact information.

- Commonwealth countries with active NODCs include Australia Ocean Data Network (IMOS), British Oceanographic Data Centre (BODC), and Indian National Centre for Ocean Information Services (ESSO-INCOIS).

Modelling and forecasting

Predicting future ocean conditions is critical for estimating the impacts of ocean acidification. When combined with ecosystem response data, modelling and forecasting of ocean chemistry on a local or regional basis can be used to infer areas of higher risk and higher resilience, aiding the prioritisation of resources and strategic mitigation. The appropriate dataset and modelling approach will depend on individual needs, capabilities, and the scale of interest. Investments, where possible, in modelling capacity increases scientific understanding of ocean acidification, climate change and the interactions with adjoining watersheds in coastal marine ecosystems. This informs the development of effective management and mitigation strategies.



The steps required to develop a model to predict future ocean conditions.

Methods for modelling ocean acidification

The wide range of modelling approaches can be broadly grouped into three categories of increasing complexity, computational expense, and required expertise. **Extrapolating** an existing time series is the most basic method for estimating future conditions. This method does not require highly specialised expertise or computing power. However, it does require a time series of sufficient length for a trend to emerge from the natural variability, which may take multiple decades in coastal areas. Extrapolation indicates the expected condition in the future but does not explain any underlying processes and interactions. **Downscaling global models** considers that processes like ocean circulation, temperature, wind and precipitation patterns, and ecosystem processes will change in response to climate change. This approach parameterises these to model the effects of continued anthropogenic CO_2 emissions on ocean acidification. **High-resolution regional models** are the most comprehensive option for assessing which factors will contribute to ocean acidification in coastal areas and include much finer spatial detail appropriate for planning. The last two approaches rely on representing oceanographic processes numerically, so additional data and computational power is needed.

Modelling approach	Complexity	Computational requirements	Expertise requirements
Extrapolating time series	Low	Low	Low
Downscaling global models	Medium	Medium	Medium
High-resolution regional models	High	High	High

Obtaining data

Where regional or national monitoring programmes are not in place or do not include ocean acidification parameters, global datasets are available to help understand regional variability over seasonal to decadal timescales. The table below summarises data resources that provide the oceanographic and meteorological data needed for understanding the processes contributing to ocean acidification. These resources provide open-source data freely available to the public. These datasets can be used to visualise spatial variability and investigate temporal patterns of variability and long-term trends, as well as be incorporated into models for predicting future conditions.

Data resource	Description
Copernicus - The European Earth Observation Programme	Copernicus is a European Union collaborative data hub that brings together remotely sensed data, field measurements from buoys, moorings, and ships, and modelled data products that include forecasts and reanalysis hindcasts for the physical and biogeochemical parameters in the global ocean.
NOAA ERDDAP - Scientific Data Server	ERDDAP provides standardised comparable data from multiple monitoring sites as well as gridded data at various spatial and temporal scales. ERDDAP provides a range of scientific data that include physical and optical oceanographic parameters and meteorological measurements in a variety of data formats.
SOCAT - Surface Ocean CO_2 Atlas	SOCAT provides a synthesis of quality-controlled surface ocean fCO_2 consisting of 28.2 million observations from 1957-2020 for global and coastal seas. Data are available in point measurements or gridded at various temporal scales and for regional extents.
ODV - Ocean Data View	ODV is a software platform for viewing geospatial oceanographic and atmospheric data. The ODV website also provides links to numerous oceanographic datasets that have been formatted for viewing in ODV.
PODAAC - Physical Oceanography Distributed Active Archive Center	PODAAC is an archive of large geospatial datasets with multiple pathways to access, subset, retrieve, and visualise data related ocean circulation and colour.
WOA - World Ocean Atlas	WOA is synthesis of approximately 3 million oceanographic casts that have been quality controlled, providing physical and biogeochemical data in the global ocean.
ARGO	ARGO is an international programme that uses a fleet of drifters to understand ocean circulation. Some floats are fitted with instruments that collect biogeochemical profile data in addition to physical data.
NOAA PSL - Physical Sciences Laboratory	PSL is an archive of large geospatial datasets of network profilers and remotely sensed meteorological and climate data, including heat and gas fluxes.
NOAA ESRL - Earth System Research Laboratory	ESRL is an archive of time series measurements from the Global Monitoring Laboratory for atmospheric gases, including pollutant and trace gases, and meteorological measurements across network sites.

Raising awareness and engaging stakeholders

This chapter provides guidance on building partnerships and engaging stakeholders. The development of a tractable strategy to address ocean acidification, e.g. an Action Plan, requires that shared goals and a strategic vision are developed in consultation with communities, local experts, scientists, and stakeholders.

Ocean acidification talking points

Ocean acidification is a multi-sectorial issue that requires communication and coordination across a broad spectrum of stakeholders. Partnership building is a critical prerequisite of ocean acidification action and effective communication is central to establish trust, share knowledge, identify risks and requirements, agree to visions and targets, and enable planning. Establishing consistent and common language at an early stage is important to enable cross-sector discussion. To assist this, some **Ocean acidification facts and talking points** (below) can be deployed to maximise impact and awareness.

Ocean acidification facts and talking points

- Ocean acidification results from the transfer of atmospheric carbon dioxide (CO_2) released from fossil fuels into the ocean.
- The oceans have become 30% more acidic over the last 250 years, and are projected to acidify by 150-200% by 2100.
- This rate of change in ocean pH is unprecedented in recent geological time.
- Reductions in CO_2 emissions will reduce the rate of ocean acidification.

- The sensory system and behaviour of fish may be affected at lower pH. For example, under lower pH, some species swim towards predators, while others can't locate food as well.
- Marine animals regulate their internal pH, but this requires more energy under low pH, which is diverted from other processes like growth and reproduction.
- Fish and other larger marine organisms may be indirectly affected by the influence of ocean acidification on their diet.
- A reduction in other stressors, such as fishing and habitat restoration, may reduce the effect of ocean acidification on fish.

- Organisms with carbonate shells are susceptible to ocean acidification. Early life stages are particularly vulnerable as they need to grow their shell rapidly.
- Ocean acidification results in thinner shells in some adult shellfish, which provides them with less protection.
- High mortalities in the shellfish aquaculture industry along the western US coastline have been attributed to ocean acidification.
- Local solutions, such as artificially raising pH in coastal waters and aquaculture farms, may reduce the impacts of ocean acidification.

- Coral reefs are facing bleaching due to warmer seas and damage from pollution. Ocean acidification is making things worse.
- Ocean acidification results in a reduction in dissolved carbonate which corals require to grow and maintain their exoskeletons.
- Projections for 2100 indicate that less than 30% of existing coral reefs will be in waters containing sufficient carbonate to maintain their skeletons.
- Reef protection, reef restoration, and reductions in other stressors, such as fishing and destructive reef practises, may reduce the impacts of ocean acidification.

- Some marine organisms may respond positively to ocean acidification, such as plants and algae that may benefit from increased dissolved CO_2.
- The uptake of CO_2 by plants and algae may buffer against ocean acidification in coastal waters and also provide long-term carbon storage ("Blue Carbon").
- Blue carbon options such as salt marshes, mangroves, seagrass and seaweed beds, provide other benefits, such as coastal protection and increased habitat.

- Coastal waters provide many ecosystem services - including economic, recreational, and aesthetic - that may be affected by ocean acidification.
- Coastal waters often have lower pH than open-ocean waters as there are more sources of acidity (natural and anthropogenic).
- Ocean acidification combines with other climate stressors (warming) and local stressors (pollution) to impact coastal ecosystems.
- Reducing the sources of acidity, such as reducing nutrient and organic inputs in freshwater run-off, may give more time for coastal organisms and ecosystems to adapt.

Engaging stakeholders

There are a wide variety of communication options, depending on the audience, content type, and channel (see the following three tables). Key considerations in determining which communication method to use are the target audience, the associated scale of audience (local, regional, national, international), the media platforms and channels available to both recipients, and the type and format of the information. Narrative-based pathways are valuable as these tend to resonate, particularly when framed in meaningful language and local values (see the local language posters case study). In addition, the grounding of ocean acidification awareness in local and regional issues and campaigns may have greater resonance and potential for engendering policy and action response than if presented as a "distant" problem (in both time and space).

It is critical to communicate broadly and engage all relevant parties and organisations. Relationships and familiarity are key ingredients to successful communication and subsequent action and there is value in using appropriate individuals as ambassadors who can link custodians, those with customary rights, and the public to stakeholders and regulatory bodies.

Audience	Benefits of communication and dialogue
School and educators	Ocean literacy can stimulate action.
Public, including public interest groups	Key stakeholders; may increase demand for science-based decision-making and accelerate regional responses.
Indigenous parties	Key participants; inter-generational knowledge and viewpoint critical.
Local government and regional councils	Interface with regional and national policy and legislation.
Industry and economic stakeholders	Economic investment in resources may stimulate action.
NGOs	Often motivated by environmental concerns.
International organisations	Interface with regional and national policy and legislation provides potential for leverage and action at national scale.

Pathways for communication

Content type	Value
Calls to action	Clear and direct, inspire action
Key messages	Clear, direct, repetition across mediums and channels
Infographics and data visualisation	Explaining, providing evidence
Factsheet	Informative, authoritative
Images, graphics, and videos	Engaging, explaining
News stories	Engaging
Narratives, e.g. localised context	Resonate and motivate

Message is simpler and more accessible

Message is more detailed and personalised.

Communication channels and options

Channel	Value
Meetings, phone calls	Effective for direct feedback
Ambassadors	Passionate people who engage others
Email, newsletters	Control messages, reach target audience
Client report	Requested by client
Presentation, e.g. conference	Clear messaging for a specific audience
Poster, e.g. conference	As per presentation, but more passive
Websites and social media	Wide audience, but need to cut through noise
Media release	Wide audience
Trade journals, scientific papers	Specific audience
Partner channels	Increased reach and endorsement

More impact, but high effort and cost per person reached.

Connect with a larger audience, but potentially lower impact.

CASE STUDY:
Community engagement through local-language posters

The development of ocean acidification posters with authoritative translators ensured that concepts were accurately conveyed.

Barriers to communication and understanding

Communicating the science of ocean acidification to diverse stakeholders is challenging, but is essential to raising awareness and engagement. Language and cultural differences can remain barriers to communication and these aspects should be addressed when engaging stakeholders. Overcoming challenges to communication and engagement is key to promoting understanding and positive action toward mitigation for the sustainability of marine ecosystems and the services they provide.

Development of local language presentation

The New Zealand Pacific Partnership on Ocean Acidification (NZPPOA) managed by the Secretariat of the Pacific Region Environmental Programme (SPREP), worked with translators to develop an ocean acidification poster published in English, French, and Pacific languages of Fiji, Kiribati, Niue, Samoa, Tokelau, Tonga, and Vanuatu. The posters communicate the science of ocean acidification, the threats to ecosystem services, and what communities can do to address the issue. The graphical representations of these concepts help communities and stakeholders understand the science of ocean acidification and mitigation options.

Increased awareness and engagement

To distribute the posters, NZPPOA worked with Pacific meteorological services, fisheries offices, education departments, schools, village councils, and community groups. The posters were also distributed at community-based awareness-raising events, including science camps in Samoa and educational workshops in Fiji, Tokelau, and Kiribati. Posters were printed on waterproof paper durable enough to withstand the harsh local environmental conditions.

Lead contact Robert Duncan McIntosh, SPREP Secretariat of the Pacific Region Environment Programme, robertmc@sprep.org

Identifying policy vehicles to address ocean acidification

This chapter provides guidance on procedures to respond to the priorities identified in the Path towards action process. It considers the components of an Action Plan, relevant international networks, and a range of policies for addressing ocean acidification.

Developing an ocean acidification action plan

An **Action plan** requires a clear strategic vision and a roadmap of tractable actions to achieve it. The development of an **Action plan** consists of a series of key components with the overarching aim of achieving practical and implementable change.

1 Consultation	2 Development	3 Facilitation	4 Reporting	5 Review
The Action Plan task force uses priorities identified in the vulnerability assessment and gap analysis to determine the stakeholders to be consulted. Engagement and information sharing leads to development of shared goals. See: Raising awareness and engagement	The task force develops recommendations for regulatory and non-regulatory action, which are optimised through discussion with stakeholders. The task force should consider leveraging existing resources and coordination structures. See: Intervention options Appraising policy options	The task force facilitates the actions by securing funding and coordinating an operational plan. Actions should be refined in consultation with stakeholders. See: International networks to build local policy Working together to address the impacts of ocean acidification	Reporting structures are developed to ensure accountability and keep track of progress. The conditions and mechanisms of reporting are established.	Progress reviews are critical for maintaining engagement with stakeholders and momentum on the actions. The review process identifies changes that can be confirmed and refined in consultation with stakeholders.

Key to any **Action Plan** is the initial consultation and on-going engagement with stakeholders, since effective relationship-building is critical here. Communities, user groups, local experts, scientists, and stakeholders are contacted using appropriate communication media, and surveyed to assess issues, resources, and opportunities, and develop shared goals.

This consultation underpins the development of a task force or working group who assess existing efforts, infrastructure, knowledge gaps, and needs. The task force should consider leveraging existing coordination structures, and also traditional and novel marine resource management practices to add value and generate co-benefits. From this assessment, the task force produces recommendations for regulatory and non-regulatory action, which can identify the location and scale of action and the approaches and best practices to be used. These actions are then developed through dialogue with stakeholders.

The task force then facilitates each action by seeking and securing funding and coordinating an operational plan. This includes identifying how existing frameworks and management practises can incorporate these new actions. To ensure accountability and keep track of progress, reporting is included with regular review of progress, funding, and other support. Progress reviews and updates are critical for regular engagement and consultation with stakeholders, and for maintaining momentum on the action.

Ocean acidification **Action plans** can be applied at a variety of different spatial scales (local, regional, national), that reflect the issue to be addressed, stakeholder needs, and resources. For example, the action plan of a local or indigenous community will differ from that of a city (see Vancouver case study). Cross et al. (2019) illustrate the different pathways of *knowledge-to-action* at national, regional, and international scales. Finally, actions will have different components depending on their primary goal, e.g. education, research, monitoring, mitigation, adaptation, or international networking.

The Action Plan Toolkit: Building your Own Action Plan produced by the International Alliance to Combat Ocean Acidification (OA Alliance) identifies a number of actions for addressing ocean acidification corresponding to their five overarching goals:

Advance scientific understanding

Improve the understanding of ocean acidification globally and within the members' regions, including support for research and ocean acidification observations within their region.

Reduce causes of ocean acidification

Implement actions that will prevent or slow ocean acidification through reducing atmospheric emissions of CO_2, reducing inputs of land-based pollutants, and other measures.

Build adaptation and resiliency

Implement actions to assist ocean-dependent communities and industries, and marine ecosystems to adapt to increasing acidity in marine waters.

Expand public awareness

Engage policymakers, scientists and the public on the growing threat posed by ocean acidification, as well as local actions that may be taken to address ocean acidification.

Build sustained international support

Secure sustained funding, nationally and regionally, for ongoing, enhanced, and coordinated research and ocean acidification observation systems, to continue to inform governments and others about the increasing impacts of ocean acidification.

The Action Plan Toolkit: Building your Own Action Plan is a valuable source of ideas for actions that can be adapted to different spatial scales, issues and resources, and includes examples of actions that have been applied to each goal. Additional potential actions can be found in Cooley et al. (2016) and Turner and McIntosh (2019). Existing Action Plans at national, state, and local levels are available on the OA Alliance website.

CASE STUDY:
Vancouver's ocean acidification action plan

Vancouver is elevating ocean acidification in policy development.

Ocean acidification poses significant risk to the region's marine ecosystems and services

Vancouver sits along the Salish Sea, which is rich in biodiversity and provides cultural, environmental, and economic ecosystem services. The Salish Sea is naturally more acidic than the open ocean, which makes shellfish and fin fisheries highly vulnerable to ocean acidification. There have already been devastating impacts from acidification on shellfish in the Salish Sea. In 2014, a collapse of scallop stocks resulted in economic losses of $10 million and layoffs of 33%.

Vancouver implemented an action plan

Vancouver joined the OA Alliance in 2016 following the development of the Pacific Coast Collaborative in which British Colombia and the West Coast US states agreed to mitigate greenhouse gas emissions. Vancouver has now developed an ocean acidification Framework that builds on their greenhouse gas mitigation while leveraging other policy and strategies, including Climate Emergency Response, Climate Change Adaptation Strategy, Rain City Strategy, and Greenest City Action Plan.

Increased ocean acidification awareness and mitigation efforts

Vancouver raised ocean acidification awareness through public and stakeholder engagement. At the municipal government level, ocean acidification mitigation strategies were implemented through management of water quality and greenhouse gas emissions.

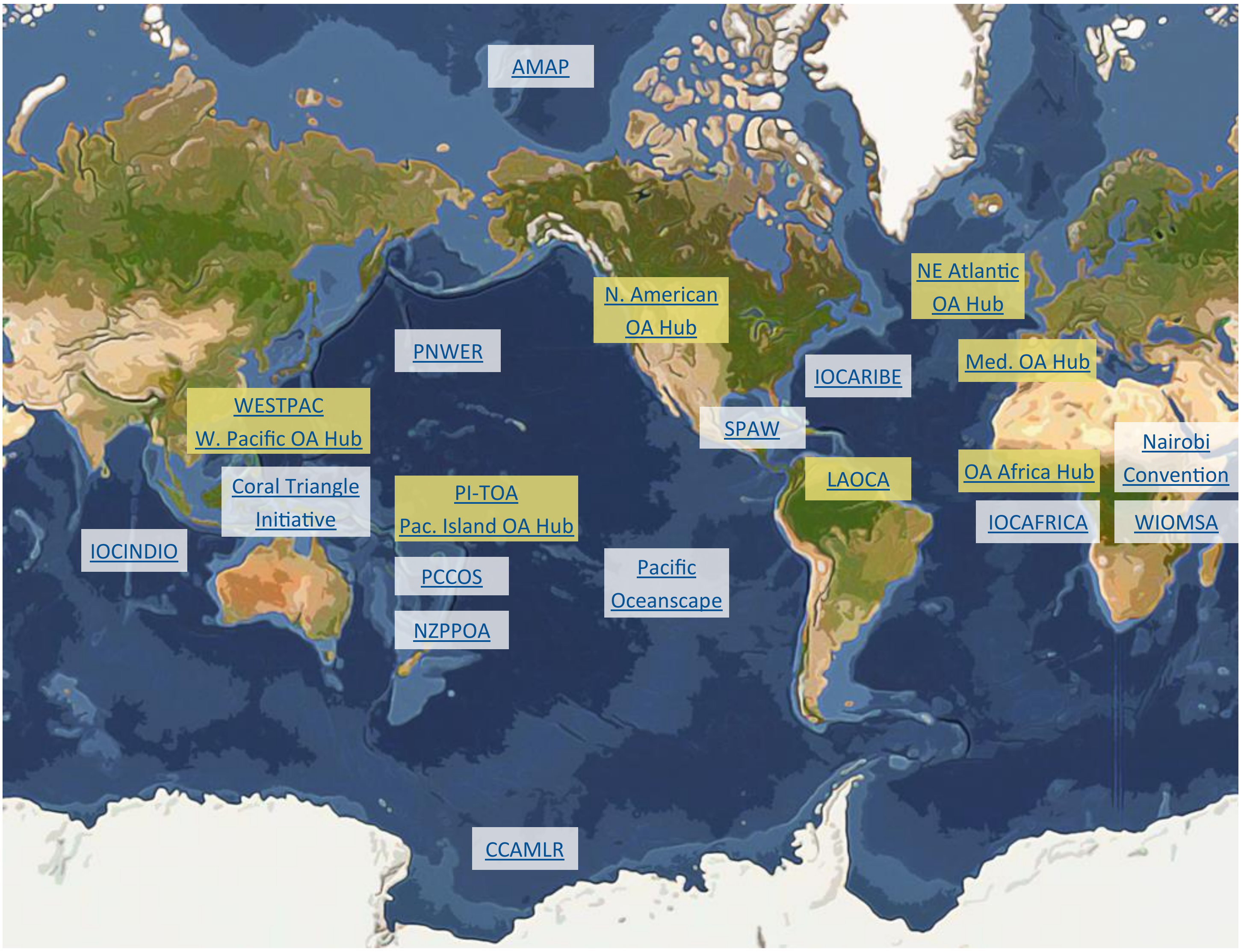
Most of the jurisdictional authority is at the provincial and federal levels, which remains a challenge to implementing broad-scale mitigation measures. However, Vancouver is currently on track to reduce their carbon emissions by 50% by 2030, directly mitigating ocean acidification on a global scale. Vancouver now aims to mainstream awareness through collaborative efforts between Musqueam, Squamish, Tsleil-Waututh, and across governmental departments to ensure consistent communication of the science and impacts.

Lead contact Angela Danyluk, Senior Sustainability Specialist, City of Vancouver, Angela.Danyluk@vancouver.ca

International networking to build local policy

International networks significantly increase the potential for leverage, funding, and knowledge sharing on ocean acidification. In addition, they enhance opportunities for activating responsible elements within government, engaging high-level political leadership, and integrating ocean acidification across policies, planning, and operations. There are a number of international ocean acidification knowledge-exchange networks, including the web-based Ocean Acidification Information Exchange (OAIE).

Regional networks are highlighted below, which can be used to identify potential regional networks for collaboration and interaction. Of particular relevance to ocean acidification are the regional hubs coordinated by GOA-ON. The GOA-ON hubs were established to foster communities of practice for the efficient collection of comparable and geographically distributed data to assess ocean acidification and its effects, and support adaptation tools such as model forecasts. Scientists, managers, and policymakers are encouraged to join their regional ocean acidification knowledge-exchange networks.



Regional networks with interest in ocean acidification, with GOA-ON hubs highlighted in yellow.

Appraising policy options

Although the science of ocean acidification is well established, there has been limited development of policy and legislation. For example, in Europe, there is considerable environmental and climate legislation, but little that includes ocean acidification (see review in Galdies et al., 2020). This reflects limited recognition of the issue of ocean acidification beyond the science, and so the need for greater communication and education. It also reflects the challenges of a global problem with local impacts, the different time and spatial scales of input and impact, and the limited jurisdictional capacity, particularly in the open ocean. Nevertheless, there are international frameworks, and also regional and national legislation, relevant to ocean acidification. The following table updates the information provided in The Ocean Foundation's Ocean Acidification Guidebook for Policymakers. The table illustrates the hierarchy from international to regional to national agreements, some of which are discussed in the following sections.

Selected existing international legislation and regional and sectorial agreements that can direct policy development at the national level
International governance and framework conventions
The 2015 Paris Agreement
Biodiversity Beyond National Jurisdiction (BBNJ, under negotiation)
Protocol to the Convention on the Prevention of Pollution by Dumping of Wastes and Other Matter of 1994 (London Protocol)
The Ramsar Convention
UN Convention on Biological Diversity (CBD)
UN Convention on the Law of the Sea (UNCLOS)
UN Decade of Ocean Science for Sustainable Development (2021–2030)
UN Framework Convention on Climate Change (UNFCCC)
UN Sustainable Development Goal (SDG) 14.3
Regional and sectoral agreements
The Cartagena Convention
Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)
Eastern Caribbean Regional Ocean Policy
EU Marine Strategy Framework Directive
HELCOM (Baltic Marine Environment Protection Commission)
Nairobi Convention
OSPAR Convention 1992
Pacific Oceanscape
Pacific Regional Environment Programme
Regional Fishery Management Organisations
National and state policy
Integration into existing and developing environmental, climate, ocean, and marine resource policy at national and sub-national scales

Appraising policy options: international

Examples of relevant international regulation include the UN Convention on the Law of the Sea (UNCLOS), a jurisdictional framework for states to regulate marine pollution, and the UN Framework Convention on Climate Change (UNFCCC), which has a primary goal of limiting greenhouse gas emissions (see the following table). Other relevant international legislation includes the Convention on Biological Diversity (CBD) which has developed reviews and led directives focused upon ocean acidification. These frameworks provide commitments and directives for guiding policy and regulation at regional and national levels. One example of this is the alignment of national objectives with UN SDGs. These are a universal set of goals, targets, and indicators that governments, businesses and organisations can use to frame their agendas. SDG 14.3 specifically focuses upon ocean acidification and provides a specific lever for developing ocean acidification policy at national level. There are several other SDGs that relate to ocean acidification, e.g. SDG 2, SDG 4, SDG 7, SDG11 and SDG 13.

Ultimately, the most effective approach to mitigating ocean acidification is to curb carbon emissions, and so integration into existing climate policy offers a potential pathway for addressing ocean acidification without the need for development of standalone policy. Although ocean acidification is not strictly climate change, this linkage to climate change policy and legislation generates leverage and provides access to associated resources and networks. Of course, developing new legislation specific to ocean acidification would be highly beneficial in addressing the unique issues and challenges of ocean acidification that are not covered, or are incompatible, with other environmental and climate responses and measures (Galdies et al., 2020). However, there are trade-offs between the investment required to generate new legislation versus the benefits of utilising existing regulations and their associated networks and structures. Consequently, one of the few examples of dedicated legislation is the USA's Federal Ocean Acidification Research and Monitoring Act (FOARAM, 2009), although the European Union recognises the threat of ocean acidification in regulations and frameworks addressing sustainable investment and climate change reporting.

Existing policy: **international**

Issue	Framework	Primary goal	Relevance to ocean acidification
Biodiversity	Biodiversity Beyond National Jurisdiction (BBNJ)	This is a UN process that seeks to arrive at a new international treaty to protect biodiversity and areas beyond national jurisdiction. This agreement for conservation and sustainable use of biodiversity will consider marine genetic resources, area-based management tools, impact assessments, capacity building, and technology transfer.	Pacific Small Island Developing States (PSIDS) have requested that ocean acidification be taken into account in the BBNJ.
Biodiversity	UN Convention on Biological Diversity (CBD)	Conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising from utilisation of genetic resources. Implements strategic goals known as "Aichi targets" to address underlying causes of biodiversity loss by mainstreaming biodiversity across government and society, reducing pressures on biodiversity, and promoting sustainable use.	The CBD has made significant contributions to improved understanding of ocean acidification, increasing adaptive capacity and awareness raising. Aichi Biodiversity Target 10 makes specific reference to ocean acidification: "By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimised, so as to maintain their integrity and functioning and links to other targets". Aichi Targets 8 and 11 are also relevant to ocean acidification.
Climate change	UN Framework Convention on Climate Change (UNFCCC) The primary instrument is the 2015 Paris Agreement.	International treaty system with protocols for limiting global greenhouse gas emissions. UNFCCC has a commitment and mandate to secure agreement on CO_2 emission reductions. The Paris Agreement aims to keep the global temperature increase less than 2 °C above - and preferably less than 1.5 °C above - pre-industrial levels. The Paris Agreement focuses on mitigation and adaptation, via Nationally Determined Contributions (NDCs). These national pledges include national emission reductions and implementation efforts. The Commonwealth Leader's Statement on Climate Action underlined the importance of "practical and swift action" to reinforce the outcomes of the 2015 Paris Climate Conference.	UNFCCC does not expressly mention protection of the marine environment, or ocean acidification and its relationship to CO_2. However, ocean acidification is accepted as an "adverse effects of climate change". A country's NDCs can include actions relating to ocean acidification, such as adaptation and building resilience. 14 NDCs make reference to ocean acidification (Gallo et al., 2017). Domestic legislation and regulation provides the platform for implementing national contributions.
Coastal protection	The Ramsar Convention on Wetlands of International Importance	An intergovernmental treaty for the conservation and sustainable use of wetlands, it deals with adaptation to climate change impacts on the coast.	Ocean acidification is a recognised threat, but there is no designated action. However, it does address coastal protection and adaptation to climate change impacts on the coast.

Existing policy: **international**

Issue	Framework	Primary goal	Relevance to ocean acidification
Marine protection	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention (1972) / London Protocol)	Limits marine pollution through regulation of dumping of waste materials into the sea. One of the first global conventions to protect the marine environment from human activities.	Can only regulate dumping at sea, so relevance to ocean acidification is limited as CO_2 entry into the oceans is not considered dumping. However, it does regulate deliberate activities, such as ocean fertilisation, which may increase CO_2 in the ocean.
Marine protection	UN Convention on the Law of the Sea (UNCLOS)	Overarching legal framework for the regulation of activities relating to ocean and seas. The only treaty at a global level obliging states to protect and preserve the marine environment by preventing, reducing, and controlling pollution of the marine environment from all sources.	Uptake of CO_2 by the ocean arguably falls under the jurisdiction of UNCLOS (Herr et al., 2014). UNCLOS has encouraged states, organisations, and institutions to urgently pursue research on ocean acidification and increase efforts to address levels of ocean acidity and its negative impact on vulnerable marine ecosystems, particularly coral reefs.
Sustainable development	UN Decade of Ocean Science for Sustainable Development (2021–2030)	A UNESCO-IOC resolution aimed at reversing the decline in ocean health and developing a common global framework to ensure ocean science supports countries in creating improved conditions for sustainable development of the ocean. It facilitates networks, supports developing countries, stimulates use of marine technology and observations.	Ocean acidification recognised as a major issue and one of most important research questions.
Sustainable development	UN Sustainable Development Goals (SDGs)	SDGs were adopted by UN member states as a universal call to action to end poverty, protect the planet and ensure peace and prosperity by 2030. There are 17 integrated SDGs, some of which include conservation and utilisation of the oceans, seas, and marine resources for sustainable development (SDG 14 Life under Water). SDGs are implemented and coordinated by the UN Development Agency.	SDG 14.3 seeks to "minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels". Its associated indicator SDG14.3.1 ("Average marine acidity (pH) measured at an agreed suite of representative sampling stations") encourages the adoption and compliance of standards at a national level, the collection of information from countries and regional organisations, and the estimation of global and regional aggregates. Other SDGs relevant to ocean acidification include SDG 13 (Climate), SDG 11 (Sustainable Cities); SDG 7 (Clean Energy); SDG 4 (Education); and SDG 2 (Zero Hunger).

Appraising policy options: regional

The implementation of international law and regulations in national and regional legislation is an important element in addressing ocean acidification (Herr et al., 2014). There is both potential and value in linking ocean acidification to existing and new policy relating to other environmental issues and broader sectorial concerns. This may enable greater leverage, co-benefits, and access to resources. For example, integration of ocean acidification into sectoral policy and legislation dealing with sustainability of regional seas and protection of marine ecosystems may add value, as reduction of other stressors via sustainable fisheries and management practices may indirectly generate resilience to ocean acidification. Fisheries management organisations and regulations operate in some regions, with agreements between relevant nations to govern and conserve specific ocean regions and their marine fauna and flora. Linking these with policy measures to address ocean acidification would be valuable (UN DESA Policy Brief #1). Other examples of legislation that could be utilised for ocean acidification include marine strategy frameworks and water quality regulations. Many countries, states, and local jurisdictions have the legal authority to control coastal pollutants. The implementation of strategies to limit the flow of nutrients and organic matter from rivers and catchments into coastal waters could assist management of coastal acidification (Billé et al., 2013). Regional Management Organisations, similar to RFMOs, also offer opportunities to collectively address aspects ocean acidification and climate change (Ringbom and Henriksen, 2017).

Existing policy: **regional**

Issue	Framework	Primary goal	Relevance to ocean acidification
Food security and sustainability	Regional Fisheries Management Organisations (RFMOs) There are 17 RFMOs.	International organisations formed by countries with fishing interests in an area. Some manage all fish stocks in a specific region, while others focus on particular highly-migratory species, such as tuna, across large geographical areas. RFMOs are mandated to sustainably manage fishery resources and adopt binding fisheries conservation and management measures.	Limited focus and activity on ocean acidification.
Marine protection	Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	Established in 1982 in response to an increase in commercial interest in krill as part of the Antarctic Treaty System. CCAMLR is a international convention with 26 members dedicated to conserving Antarctic marine living resources.	CCAMLR has a potential technical role in gathering information on the impacts of ocean acidification and providing additional arguments for adaptation measures, such as establishing marine protected areas (MPAs) as well as precautionary harvesting limits for Antarctic marine living resources. (Herr et al., 2014).
Marine protection	OSPAR Convention (1992)	Regulates international cooperation on environmental protection in the North-East Atlantic. Includes 15 signatory nations and representatives of the European Commission.	Investigating, monitoring, and assessing the rate and extent of ocean acidification and considering appropriate responses. OSPAR Coordinated Environmental Monitoring Programme (CEMP), received an additional appendix on ocean acidification in 2012.

Existing policy: **regional**

Issue	Framework	Primary goal	Relevance to ocean acidification
Marine protection and biodiversity	The Cartagena Convention	Regional legal agreement for the protection of the Caribbean Sea. Three technical agreements on Protocols on Oil Spills, Specially Protected Areas and Wildlife (SPAW), and Land Based Sources of Marine Pollution.	Works with The Ocean Foundation to address ocean acidification, including development and implementation of joint strategies and pilot projects in areas of mutual interest.
Marine protection and water quality	Regional Ocean Councils	Councils formed by representatives from regional states, provinces and territories. Facilitates across local to national level government agencies, regional organisations, and groups to address ocean and coastal issues at a regional scale.	Councils facilitate understanding of ocean acidification through supporting monitoring, research, education, and community outreach. They inform action plans for regional-scale policy (e.g. California, Oregon, Northeast Regional Ocean Council) and adaptation of terrestrial and freshwater policy to address coastal ocean acidification through clean water legislation (US 303d).

Appraising policy options: national

Examples of existing policy issues relevant to assets are shown below. These policy issues can be used to address ocean acidification by identifying and leveraging existing national or local policy.

	Policy issue						
Asset impacted	Biodiversity and protected areas	Water quality	Food security	Coastal protection and habitat	Cultural and customary practises	Livelihoods and economy	Climate change
	•	•	•	•	•	•	•
	•	•	•		•	•	•
	•	•		•	•	•	•
	•	•		•		•	•
	•	•		•	•	•	•

The Ocean Foundation's Ocean Acidification Guidebook for Policymakers is recommended, as it contains a detailed list of regional agreements and national legislation of relevance to ocean acidification. The Guidebook, together with information in the following table, can be used for the development of new policy or incorporation of ocean acidification into existing policy. Recommendations in the development of ocean acidification policy include:

Taking Inventory

- Review available resources, particularly monitoring capability.
- Carry out a vulnerability assessment and gap analysis.
- Review relevant policy options (international, regional, and national).
- Review international commitments, e.g. SDGs.
- Identify priorities.

Coordination

- Raise awareness of the threat, actions, and solutions to mitigate ocean acidification among policymakers and public.
- Ensure coordination across ministries, departments, and sectors, to enhance interaction and integration on marine issues. This is critical as ocean acidification is a multi-sectoral issue.
- Create a national inter-agency task force that promotes collaboration to aid coordination and implementation.

Action

- Incorporate ocean acidification into existing and developing environmental, climate, and marine resource plans and policies at regional and national scales.
- Integrate ocean acidification into national indicators, mitigation targets, and adaptation plans.
- Ensure monitoring and reporting inform decision making.
- Ensure explicit recognition and focus on ocean acidification in new or existing policy and legislation.
- Enable coherent, robust, and sustained reporting of ocean acidification.
- Consider incentivising actions that promote ocean acidification action and resilience.

Existing policy: **national**

Issue	Framework	Example	Relevance to ocean acidification
Biodiversity	National Biodiversity Strategies	The 2020 Biodiversity Goals and Targets for Canada were developed in response to the UN CBD and include four goals and nineteen targets.	Improving biodiversity requires action on ocean acidification. Biodiversity education is a lever for ocean acidification awareness and action.
		The Belize Climate Change Adaptation Policy encourages all government agencies to incorporate climate change in their activities and policies. One of the most important aspects is to create public awareness and education to support biodiversity conservation.	
Climate change	National Action Plans and National Adaptation Plans For further details of these and other Commonwealth country Climate Action plans see Scotford et al. (2017).	UK Climate Change Act (2008) includes a binding emissions reduction target and carbon budgets for each five-year period, establishment of a Committee on Climate Change to advise government, powers for introducing emissions trading schemes, and obligation for annual reporting. In 2019, the Act was updated to include a legally binding commitment to achieve net-zero emissions by 2050.	UK Climate Change Act (2008) refers to the actions needed to address ocean acidification since the latter is seen as one of the main risks arising from a changing climate.
		Fiji's National Adaptation Plan aims to address climate change through 160 adaptation measures identified through consultation with stakeholders.	Fiji's National Adaptation Plan identifies ocean acidification as a threat. Fiji's National Ocean Policy also identifies ocean acidification as a major threat that must be addressed to meet sustainable ocean management goals.
		Papua New Guinea Climate Change (Management Act) 2015 establishes a Climate Change and Development Authority (CCDA) to promote and manage "climate compatible development through climate change mitigation and adaptation activities".	
		Saint Lucia National Climate Change Adaptation Policy aims to pursue integrated adaptation actions to prepare for or respond to climate change impacts.	
Coastal protection and habitat	National Coastal Management Acts	South Africa National Environmental Management: Integrated Coastal Management Act 2008 incorporates climate change adaptation into coastal management processes.	Ocean acidification could be incorporated into Marine Spatial Planning policy, which is developing at both national and international levels.

Existing policy: **national**			
Issue	Framework	Example	Relevance to ocean acidification
Economics		The South African government strategic initiative, 'Operation Phakisa', aims to unlock and explore the full potential of the ocean's wealth to drive economic growth, create jobs, and alleviate poverty.	22 Marine protected areas designated in 2016 will reduce fishing and pollution pressures on these ecosystems, supporting resilience development.
General sustainability		Well-being of Future Generations (Wales) Act 2015 aims to carry out sustainable development and to pursue "well-being goals" including promoting a prosperous, low-carbon society, and developing ecological resilience and capacity to adapt to climate change (Scotford et al., 2017). Australian Environmental Protection and Biodiversity Conservation Act 1999 requires annual reporting of how activities accord with and promote ecologically sustainable development (Scotford et al., 2017).	Land-based approaches to sustainability and emissions reductions may have co-benefits for ocean acidification.
Ocean acidification	US Federal Ocean Acidification Research and Monitoring Act (2009)	Directs the US subcommittee on Ocean Science and Technology to create an Interagency Working Group on Ocean Acidification (IWG-OA), which coordinates ocean acidification activities across the Federal government.	Mandates for research and/or management of resources and ecosystems likely to be impacted by ocean acidification. Has established a research programme and funding (Billé et al., 2013). For details of individual US State legislation relating to ocean acidification see The Ocean Foundation Ocean Acidification Guidebook for Policymakers.
Oceans	National Ocean Policies	Many countries have National Ocean Policies to protect marine economic resources and ecosystems.	Solomon Islands National Ocean Policy notes the importance of considering climate change and identifies strategies to minimise or mitigate risks and threats (Turner and McIntosh, 2019).
Water quality	Clean Water Acts	US Clean Water Act (CWA) requires US states to establish water quality standards as basis for regulation.	The US Clean Water Act explicitly regulates marine pH. The California water quality control plan includes pH with a target that pH must not exceed by more than 0.2 units. States are mandated to list damaged waters and estimate maximum daily loads (Arce, 2016).

Working together to address the impacts of ocean acidification

The Commonwealth Blue Charter Action Group on Ocean Acidification has committed to sharing knowledge, experience, and best practice for understanding the impacts of ocean acidification. To address the social, environmental, and governance challenges, Action Group members must develop cross-Commonwealth connections to increase capacity, strengthen stakeholder engagement, and facilitate the development of national and international policy. This chapter identifies coordination and collaboration opportunities to help achieve these goals.

Partnerships within the Blue Charter Action Group on Ocean Acidification

Although ocean acidification is a global problem, nations must develop local responses to address the local impacts. The effectiveness of these responses will be enhanced if done in collaboration with other Action Group members. Many strategies for cross-country collaborations to address ocean acidification have been proposed and are summarised in the Executive Summary of the Fifteenth session of the IOC Sub-Commission for the Caribbean and Adjacent Regions, Mainstreaming Ocean Acidification into National Policies: A Handbook for Pacific Islands, Regional Action Plan on Ocean Acidification for Latin America and the Caribbean, and Review of the Scientific and Institutional Capacity of Small Island Developing States in Support of a Bottom-up Approach to Achieve Sustainable Development Goal 14 Targets. In addition, The Ocean Foundation's Ocean Acidification Guidebook for Policymakers summarises 18 regional agreements, networks, and convening bodies that are coordinating scientific research and data-sharing initiatives. While not all of these agreements explicitly address ocean acidification, they support a range of opportunities for capacity development and cross-country collaborations between governments, communities, stakeholders, and scientists.

The following table re-frames selected collaborations discussed in the above resources in the context of ocean acidification. For many of the collaborations, there is value in countries first going through the steps in the Path towards action, to identify priorities for action, available resources, and gaps. Depending on their local needs and assets, policymakers can then identify the most appropriate approaches to enhance their nation's own ocean acidification initiatives. For most countries, the most effective approach will involve both regional collaborations (e.g. monitoring) and stakeholder partnerships (e.g. protection of coral reefs). These efforts could be supported through the UN's The Small Island Developing States Partnership Toolbox, which provides information on building and maintaining "genuine and durable partnerships".

Opportunities for cross-country collaborations within the Commonwealth Blue Charter Action Group on Ocean Acidification

Coordinated evaluation of mitigation approaches

Countries must identify effective mitigation approaches to address local acidification, including restoring ecosystems, decreasing run-off, and supporting the restoration of mangroves and seagrass meadows. As with coordinated research efforts (below), coordination of the evaluation of mitigation approaches will allow Action Group members to compare the effectiveness of approaches across many regions and ecosystems. There are additional opportunities for knowledge and technology transfer, given the wide range of skills participants will bring to the partnership, e.g. mangrove mapping, water quality analysis, and stakeholder and community engagement experience.

Coordinated regional monitoring

Creating a sustained ocean acidification observing network will increase a nation's understanding of the spatial and temporal variability in ocean acidification parameters. While individual countries can increase their monitoring through programmes such as GOA-ON in a Box, the effectiveness of monitoring is enhanced when done on a regional scale and across a coordinated range of ecosystems and land-use types (see ApHRICA case study). A partnership-based approach to monitoring provides additional opportunities for technical support, shared monitoring equipment, and centralised water analysis. Tilbrook et al. considers aspects of regional monitoring and the role of GOA-ON regional hubs to address local needs and monitoring gaps.

Coordinated research efforts with a focus on high-priority species or ecosystems

A single experiment carried out under one condition will not provide a country with enough information to predict the impacts of ocean acidification and develop a response. However, coordinated experiments on similar species across several nations can provide information on biological thresholds and contribute to regional insight into the impacts of ocean acidification. To ensure a meaningful comparison of results across partner institutions, it is important to harmonise the experimental and data analysis methods.

Develop and implement models to improve regional forecasting

Downscaling global models and high-resolution regional models provide forecasting information based on a wide range of oceanographic, atmospheric, and ecosystem parameters. However, these models require expertise and computing power not available in all regions. By developing modelling-focused collaborations across Action Group countries, regions with limited modelling capacity will gain access to computing facilities and the experience needed to develop models independently in the future. For any modelling collaboration, these efforts will become increasingly impactful as modellers coordinate with monitoring programmes to ensure monitoring is done at the appropriate scale and quality to inform the models.

Support training courses and capacity-development workshops

Capacity-development workshops are an opportunity to bring together policymakers, educators, stakeholders, and scientists. There is a need for capacity-development workshops to address priorities identified in the Path towards action, including project proposal development, mitigation strategies, community-based monitoring, and the development of ocean literacy resources. Training courses have been created by a wide range of organisations, including the Blue Charter Secretariat, OA-ICC, The Ocean Foundation, PI-TOA, and could serve as a model for Action Group workshops.

CASE STUDY:
Regional monitoring in the Western Indian Ocean

The ApHRICA partnership is increasing regional understanding of the ecological and socioeconomic impacts of ocean acidification.

A public-private partnership in the South-West Indian Ocean and East Africa

The ApHRICA regional monitoring programme involves universities and institutions in Mauritius, Seychelles, Mozambique, South Africa, Tanzania, and Kenya. ApHRICA is a public-private partnership between The Ocean Foundation and US Department of State, which has received additional support from the Heising-Simons Foundation, Government of Sweden, Government of Mauritius, IAEA OA-ICC, and WIOMSA.

This monitoring partnership has led to a greater understanding of the threat of ocean acidification to coastal ecosystems and fisheries in the Western Indian Ocean. Baseline data has been collected at Flic en Flac and Albion (Mauritius) since 2017, and researchers are beginning to understand the diurnal and seasonal changes in pH. This data is informing biological experiments, while coordinated surveys of lagoons and the ocean are being used to detect areas of increased vulnerability and resilience for corals, shellfisheries, and marine calcifiers.

Building regional capacity while contributing to the global understanding of ocean acidification

The establishment of a regional ocean acidification network has allowed Western Indian Ocean researchers to organise training workshops tailored to their capacity needs. In addition, regional planning workshops can focus on local ocean acidification concerns and socioeconomic impacts. Through the ApHRICA partnership, the six East African member countries have contributed to a white paper for the Nairobi Convention *Science to Policy* meeting (February 2021) under WIOMSA and are designing experiments and collecting data for the GOA-ON portal in view of future joint regional publications.

Ensuring that the socioeconomic impacts of ocean acidification are considered in policy decisions is a priority for ApHRICA researchers. To better inform policy, where possible, biological, and chemistry experiments are conducted alongside monitoring efforts to understand the ecological and economic impacts of ocean acidification.

International networks and support

The ApHRICA partnership has taken advantage of the resources offered through GOA-ON's Pier2Peer mentoring programme. In addition, the monitoring partnership is enhanced by the Ocean Acidification Information Exchange (OAIE), which provides a platform for coordinating monitoring efforts, maintenance, and QA/QC material. The role of OAIE is expected to increase with the launch of an OAIE OA Africa Team on the platform, which is expected to include about 140 scientists from North, West, and East Africa.

Contacts

Associate Professor Roshan T. Ramessur, Chair East Africa, OA-Africa, University of Mauritius
ramessur@uom.ac.mu

The Ocean Foundation, Alexis Valauri-Orton
avalauriorton@oceanfdn.org

Partnerships between Commonwealth Blue Charter Action Groups

Although Blue Charter Action Groups are devoted to specific issues, each Action Group is working towards a larger goal of solving ocean-related problems and meeting commitments for sustainable ocean development. Partnerships between Action Groups can be leveraged to increase the impact of ocean acidification monitoring, policy, and response.

<table>
<tr>
<td colspan="2">Commonwealth Blue Charter
ACTION GROUPS

As of 1 January 2021</td>
<td>The <u>Clean Ocean Alliance Action Group</u> brings “together member countries, businesses and non-governmental organisations (NGOs) from across the Commonwealth to commit to action on plastics, share best practices, leverage funding and push for global action”
Champions: United Kingdom, Vanuatu</td>
</tr>
<tr>
<td>The <u>Coral Reef Protection and Restoration Action Group</u> “will highlight good practices in the restoration of coral reefs…It will be a platform to promote collaborative research, workshops and seminars, showcasing successful case studies among the Commonwealth.”
Champions: Australia, Belize, Mauritius</td>
<td>The <u>Mangrove Ecosystems and Livelihoods Action Group</u> focuses on “conservation and sustainable utilisation of mangroves” through legal frameworks, strengthening community partnerships, and economic valuations of mangroves’ contributions to livelihoods.
Champion: Sri Lanka</td>
<td>The <u>Marine Protected Areas (MPAs) Action Group</u> will “identify and develop innovative technical and financial approaches for the effective management of MPAs” through knowledge sharing, the promotion of good management practices, and the promotion of new and expanded MPAs.
Champion: Seychelles</td>
</tr>
<tr>
<td>The <u>Ocean Acidification Action Group</u> will “share knowledge, experience and best practice on the impact of ocean acidification and how to address it” while working towards increased technical capacity, the development of new cross-Commonwealth connections, facilitation of national and international policy, and increased public awareness.
Champion: New Zealand</td>
<td>The <u>Ocean and Climate Change Action Group</u> will “work with existing networks to improve ocean health through climate action. It will also look for financial mechanisms to enable a ‘blue carbon’ approach – restoring the ability of coastal ecosystems to store carbon in mangroves, coastal swamps and seagrass.”
Champion: Fiji</td>
<td>The <u>Ocean Observation Action Group</u> will work to advance the “accessibility of ocean observational data, knowledge and best practices among Commonwealth countries”, increase opportunities for ocean observations, support the integration of observational data into decisions, and address gender issues in ocean sciences.
Champion: Canada</td>
</tr>
<tr>
<td>The <u>Sustainable Aquaculture Action Group</u> “promotes the development of environmentally-compatible, financially-viable and socially-acceptable aquaculture,” including fish, plants, algae and shellfish.
Champion: Cyprus</td>
<td>The <u>Sustainable Blue Economy Action Group</u> is working towards “sustainable use of ocean resources for economic growth, improved livelihoods and ocean ecosystem health” by supporting economic empowerment, resilient communities, and the development of technology and economic instruments.
Champions: Antigua and Barbuda, Kenya</td>
<td>The <u>Sustainable Coastal Fisheries Action Group</u> will “support on-going fisheries programs, efforts and approaches to ensure sustainable coastal fisheries”, bringing benefit to present and future generations.
Champions: Kiribati, Maldives</td>
</tr>
</table>

Opportunities for collaboration between Blue Charter Action Groups

Co-location of monitoring sites

Co-locating biological and chemical monitoring will produce information useful for policymakers by linking chemical changes to biological responses. For example, including ocean acidification monitoring at mangrove, coral reef, and aquaculture restoration sites could provide information about baseline conditions and restoration effectiveness. Monitoring efforts can be further enhanced by working with the Ocean Observation Action group, to ensure the data is accessible (where appropriate) and relevant for decision makers. For more information, see the GOA-ON Implementation Strategy and Global Ocean Observing System 2030 Strategy.

Equity in ocean sciences

The proposed partnerships provide Action Groups with the opportunity to increase the participation of indigenous people, young people, and women in ocean sciences. When partnerships prioritise participation of underrepresented groups and support leadership opportunities, the programme will contribute to broader economic, social, and political goals. The Gender Equity in Ocean Sciences report, which provides specific recommendations and actions to increase gender equity, is part of Canada's commitment to gender equity in their role as Champion of the Blue Charter Action Group on Ocean Observation.

Integration of research, adaptation, and mitigation efforts

Given the inter-related nature of coastal ecosystems, coordinated efforts will enhance the effectiveness of the work of individual Action Groups. Specific examples where the Action Group on Ocean Acidification could work with other Action Groups include the restoration of mangroves and seagrass meadows to increase carbon sequestration and buffer local acidification (with the *Mangrove Ecosystems* and *Ocean and Climate Change* Action Groups), the expansion of marine protected areas to lessen the impact of ocean acidification by reducing other pressures, e.g. fishing (with the *Marine Protected Areas* Action Group), understanding the impacts of ocean acidification on commercial species to support sustainable aquaculture efforts (with the *Sustainable Aquaculture* Action Group), and understanding the local chemistry and ocean acidification impacts on target species to enhance restoration efforts for coral reefs (with the *Coral Reef Protection* and *Ocean Observations* Action Groups).

Ocean literacy

The changing oceans are creating social, economic, and environmental challenges. However, the long-term support for action on marine issues requires that the public becomes better informed about threats to our coasts and oceans. A joint effort on increasing ocean literacy would leverage the resources of all Action Groups and could build on available resources, including the IOC Capacity Development Strategy and UNESCO's Ocean Literacy for All: A toolkit. Additional national and regional strategies to incorporate culturally relevant ocean literacy curricula in formal education can build on Ocean Literacy for All: A toolkit and the IOC's rapidly expanding OceanTeacher Global Academy.

The following table of Action Group Membership can be used to identify potential partners across Action Groups and regions. Note: ••• indicates an Action Group Champion.

	Clean Ocean Alliance	Coral Reef Protection and Restoration	Mangrove Ecosystems and Livelihoods	Marine Protected Areas	Ocean Acidification	Ocean and Climate Change	Ocean Observation	Sustainable Aquaculture	Sustainable Blue Economy	Sustainable Coastal Fisheries
Antigua and Barbuda	•								•••	
Australia	•	•••	•				•			•
Bahamas		•	•	•		•		•	•	
Bangladesh	•		•			•		•	•	
Barbados	•	•		•	•	•	•	•		
Belize	•	•••		•						
Cameroon	•									
Canada	•					•	•••		•	
Cyprus								•••		
Dominica				•						
Fiji	•					•••		•		
Ghana	•			•						
Jamaica			•	•						
Kenya	•		•						•••	
Kiribati	•			•						•••
Malaysia								•		
Maldives	•									•••
Malta				•	•	•	•			•
Mauritius	•	•••						•		
Mozambique	•									
Namibia	•									
Nauru	•									
New Zealand	•				•••					
Nigeria	•		•							
Pakistan			•							
Rwanda	•									
Saint Lucia	•									
Samoa	•			•						
Seychelles	•			•••	•			•	•	
Sierra Leone	•									
Solomon Islands						•				
South Africa	•									
Sri Lanka	•	•	•••	•			•		•	•
St Kitts and Nevis				•					•	
St Vincent and the Grenadines	•					•			•	
The Gambia	•			•						
Tonga	•			•						
Trinidad and Tobago	•	•	•			•	•	•	•	
Tuvalu	•									
Uganda	•									
United Kingdom	•••	•	•	•	•	•				
Vanuatu	•••		•	•						
Zambia	•									

Building sustained relationships

The long-term success of international partnerships requires sustained relationships with support for regular communication and knowledge sharing. The following actions would support Action Group efforts to address ocean acidification, evaluate and implement intervention options, and share lessons learned.

Building sustained relationships

Convene Action Group meetings at regional and international events

Regional and international events provide an opportunity and ensure continued dialogue between Action Group members. Formalising these Action Group meetings as pre- or post-event workshops will help ensure ocean acidification remains a visible and high-priority issue at these events.

Coordinated pilot projects

As nations develop their own **Path towards action**, they will encounter gaps in knowledge that need to be addressed through pilot projects, e.g. the development of new mitigation approaches or stakeholder engagement strategies. Coordinating these pilot projects enhances efforts and will facilitate the development of the durable partnerships needed to achieve Action Group goals.

Create a knowledge exchange network for Action Group members

NOAA supports the Ocean Acidification Information Exchange (OAIE), a free platform to share information, response strategies, and lessons learned. The OAIE supports Region-based Teams (e.g. "Pacific Islands" and "OA-Africa") and Topic-based Teams (e.g. "Data Management" and "Policy & Management Strategies"). These Teams allow users to ask questions and access up-to-date information relevant to their interests and needs. The creation of an OAIE "Blue Charter Action Group on Ocean Acidification" Team would provide a platform for Members to share information, ideas, and resources relevant to the Action Group, while also providing access to expert advice through the global ocean acidification community.

Designate an "Ocean acidification ambassador" within each country

The "Ocean acidification ambassador" within each country would be responsible for coordinating ocean acidification activities and cross-Action Group collaborations. Designating an individual to fulfil this role avoids duplication of efforts and facilitates collaboration and capacity-building efforts.

"Virtual Coffee" meetings

Twice-yearly Virtual Coffee meetings between Action Group members will ensure opportunities for collaboration and the sharing of lessons learned are communicated in a timely manner.

Templates

This set of Templates with example text will help users collate and organise the information needed to develop a **Path towards action**. Users can use these Templates as an example to create their own tables or download blank, fillable versions of these templates from the Commonwealth Blue Charter Action Group on Ocean Acidification website.

Using the Templates

Path towards action

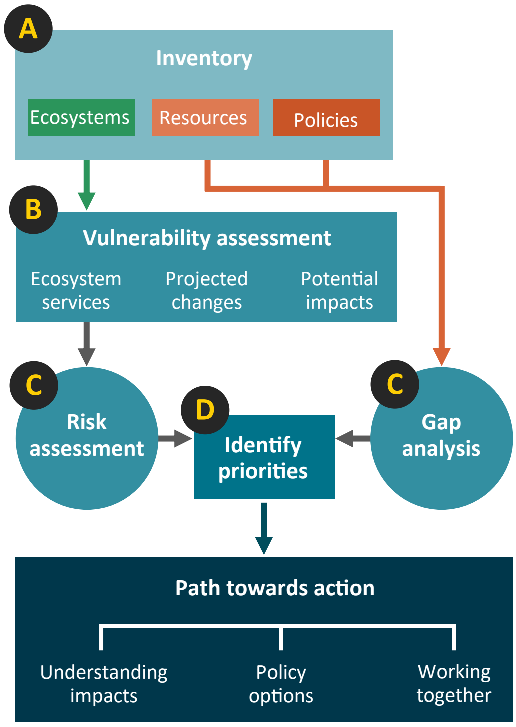
This Handbook provides a framework for developing region-specific actions and implementation plans based on the **Path towards action**. The **Path** provides a step-by-step guide to identifying the priorities for action that will inform the development of policy to address ocean acidification. The following Templates will help users collate and organise information based on the steps within the **Path towards actions**:

A An inventory of ecosystem types (Template 1), resources (Template 2, Template 3, and Template 4), and existing policy (Template 5) will assist in the identification of key resources, expertise, and infrastructure that can be adapted or leveraged to address ocean acidification.

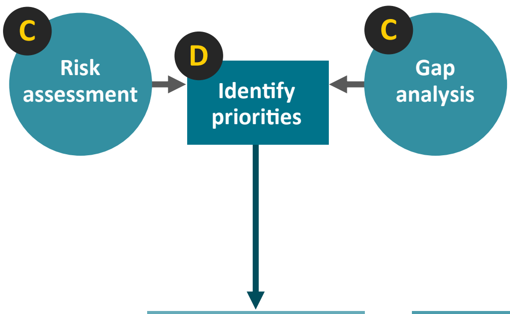
B A vulnerability assessment (Template 6) is used to identify potential impacts on key marine resources.

C A risk assessment (Template 7a and Template 7b) is used to estimate the adverse effects of ocean acidification on key resources. A gap analysis (Template 8a and Template 8b) is then used to identify potential actions and effectively allocate resources.

D Priorities for action are then identified by considering the risks of each impact scenario (Template 7b) and the cost and feasibility of potential actions (Template 8b).

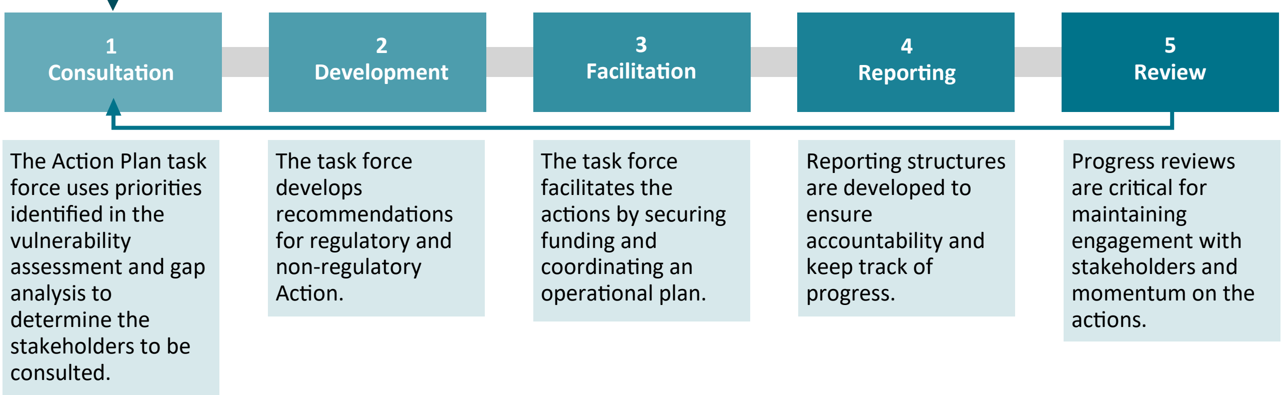


Developing an ocean acidification action plan



Identifying priorities for action is the first step in developing an action plan to address ocean acidification. This action plan requires a clear strategic vision and a roadmap of tractable actions. By starting this process with the **Path towards action**, potential actions are identified and relevant stakeholders can be engaged during the initial Consultation step.

Key components in the development of an action plan.



Taking inventory: ecosystem types

Template 1

Ecosystem type	Asset type	Location	Notes	Cross reference
Coral reef 1		e.g., name, latitude and longitude range, extent	Reef provides coastal protection Important for local fishing Culturally important	CR.1
Coral reef 2		e.g., name, latitude and longitude range, extent	Reef provides coastal protection Important for tourism, diving activities Culturally important Marine Protected Area University marine laboratory nearby	CR.2
Oyster beds		e.g., name, latitude and longitude range, extent	Shellfish gathering Culturally important	SB.1
Mangroves		e.g., name, latitude and longitude range, extent	Restoration as part of Blue Carbon project Important bird habitat	M.1
Aquaculture farm (marine)		e.g., name, latitude and longitude range, extent	Mussel farm, employs local people Takes water from bay for spat hatchery	A.1

Here, “Cross reference” refers to locations from the map-based ecosystem assessment. Use this example template as a guide to develop your own inventory of ecosystem types. Blank, fillable versions of all templates are available on-line.

Taking inventory: existing resources (infrastructure)

Template 2

Existing Infrastructure	Infrastructure relevant to ocean acidification		Infrastructure that can be leveraged		
	Chemical	Biological	Chemical	Biological	Other
University Marine Station Reef Monitoring Programme	Temperature Salinity Lab with alkalinity system	Calcification rates % coral cover Experimental facilities	Nutrient sampling programme Spectrometer		Monthly dive surveys Mooring with nutrient and PAR sensors
Local Council Coastal Monitoring	Temperature Salinity			Bacterial counts	
NGO Mangrove Restoration Project	Temperature Salinity		Oxygen	Mangrove health Mangrove cover	

Use this example template as a guide to develop your own inventory of existing resources (infrastructure). Blank, fillable versions of all templates are available on-line.

Taking inventory: existing resources (technology and expertise)

Template 3

Existing technology and expertise	
University	Chemistry lab, could prepare dye and buffer for pH measurements
Marine station	Diver surveys Citizen science programme Workshop for building and maintaining equipment
Research institute	Remote sensing expertise Climate modelling Data management expertise
Government department	Fishery survey cruises Community networks

Use this example template as a guide to develop your own inventory of existing resources (technology and expertise). Blank, fillable versions of all templates are available on-line.

Taking inventory: existing resources (funding)

Template 4

Existing funding sources		Budget
Government Climate Change Fund	Support to Climate Resilient Investment Pathways (SCRIPts) in the Pacific	$1 million
Research Funding Stream	Research programme to look at seagrass tolerance to pH and temperature changes	$50,000
Industry Fund	Joint aquaculture-university project on shellfish resilience.	$40,000 gov't funding matched with $40,000 industry funding

Use this example template as a guide to develop your own inventory of existing resources (funding). Blank, fillable versions of all templates are available on-line.

Taking inventory: existing policy

Template 5

Existing policy: frameworks, regulations, action plans, and treaties	
UN SDGs	Report towards SDG14.3 “Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels” Regulations addressing SDG 14.2 “By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans”
Climate Change Policy	Policy around greenhouse gas emission targets Transport Policy
Aichi Targets	Target 10 “By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimised, so as to maintain their integrity and functioning.”
Coastal Plan	Existing legislation or by-laws governing coastal use

Use this example template as a guide to develop your own inventory of existing policy. Blank, fillable versions of all templates are available on-line.

Vulnerability assessment

Template 6

Ecosystem type (cross reference)	Ecosystem services	Projected changes	Potential threats and impacts
Coral reef (CR.1)	Coastal protection	Decreased aragonite saturation, decreased calcification, impaired reef growth Change in species – decrease of stony coral, increase of soft coral Reef degradation will compromise protection of vulnerable coastline structures Coral bleaching also likely	Increased storm damage of coastal structures including seawalls, wharves, roads and buildings in Area X
	Local fishing	Reef habitat degradation will decrease or change fish stock (species and numbers)	Village Y gets fish for local consumption and sale at market Impact on number and type of fish caught, affecting food security and income
	Cultural importance	Ecosystem degradation	Local community experiences loss of cultural identity and historical connections due to degradation of coral reef
Coral reef (CR.2)	Coastal protection	see above	see above
	Tourism, diving activities	Degraded reef will compromise local businesses, income and employment	Area Z dependent on tourism for employment N people directly employed, $$$ contributed to local economy
	Cultural importance	see above	see above
Aquaculture farm, marine (A.1)	Economic importance	Mussel farm employs local people Takes water from bay for spat hatchery	Loss of income and employment

Use this example template as a guide to develop your own vulnerability assessment, including additional columns for Adaptive Capacity and Current Environmental Conditions if that information is available. Blank, fillable versions of all templates are available on-line.

Risk assessment - Part 1

Template 7a

A risk assessment matrix denotes the relative risk of each impact scenario. For each asset included in the vulnerability assessment (Template 6), **risk** is quantified by multiplying the **likelihood of each impact occurring** by the **consequence of each impact occurring** using the scale below:

Likelihood scale:

5 = Almost certain

4 = Likely

3 = Possible

2 = Unlikely

1 = Rare

Consequence scale:

5 = Catastrophic

4 = Major

3 = Moderate

2 = Minor

1 = Negligible

The relative **risk** is then calculated as **likelihood × consequence,** where

1 - 3 indicates low risk

4 - 6 indicates moderate risk

8 - 12 indicates high risk

15 - 25 indicates extreme risk

For example, an impact with a **likelihood** of 4 and a **consequence** of 3, gives a **risk** of 12 (4×3), which is high.

		Consequence				
		Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	Almost certain 5	Moderate 5	High 10	Extreme 15	Extreme 20	Extreme 25
	Likely 4	Moderate 4	High 8	High 12	Extreme 16	Extreme 20
	Possible 3	Low 3	Moderate 6	High 9	High 12	Extreme 15
	Unlikely 2	Low 2	Moderate 4	Moderate 6	High 8	High 10
	Rare 1	Low 1	Low 2	Low 3	Moderate 4	Moderate 5

Finally, individual risks evaluated in Template 7b can be ranked to aid in the development of mitigation strategies.

Risk assessment - Part 2

Template 7b

Ecosystem Type (cross reference)	Potential impacts	Likelihood scale 1 – 5	Consequence scale 1 – 5	Risk
Coral reef (CR.1)	Increased storm damage of coastal structures including seawalls, wharves, roads and buildings in Area X.	4	5	20
	Village Y gets fish for local consumption and sale at market. Impact on number and type of fish caught, affecting food security and income.	3	4	12
	Local community experiences loss of cultural identity and historical connections due to degradation of coral reef.	5	3	15
Coral reef (CR.2)	Area Z dependent on tourism for employment. N people will potentially lose their jobs, with a total loss of income of $$$.	3	2	6
	Urban development, storm runoff and freshwater inputs into lagoon lead to increasing nutrients and algal growth and additional stress on the reef.	4	3	12
Aquaculture farm, marine (A.1)	Ability to farm economically. Farm generates $$$$ of export earnings. Decrease in spat production, compromising this farm, and sale of juveniles to other farms.	3	3	9
	Farm provides employment for N people of Area W. %% layoffs possible with declining export.	**3**	**1**	**3**

Use this example template as a guide to develop your own risk assessment. Blank, fillable versions of all templates are available on-line.

Gap analysis - Part 1

Template 8a

A gap analysis helps to identify areas that are lacking information, which can then be used to identify priorities. Here, list the gaps in knowledge, capabilities and resources that were identified when compiling the inventories and the vulnerability assessment. Add notes as required to guide further actions.

Category	Inventory	Gaps	Notes
Current knowledge	Ecosystem Types	Areas of coastline not assessed Information held locally, need to collate Information scattered – charts and maps, reports, dive operators Coral reef survey last done 20 years ago, need to update	A rough indication will do for a start Contact local councils to get information Need system to retrieve and present information
	Ecosystem Services (CR.1)	Fisheries data exist across departments, private companies and local knowledge, need resources	Need to build partnership with fishing community to gain trust and foster cooperation and engagement
	Ecosystem Services (A.1)	Water quality management is not consistently meeting targets	Need to reassess targets and regulatory processes
	Policy	Information across many departments, need resources (time) to undertake inventory	Start with email to relevant Departments, asking what information is available
Current resources	Resources	No specific ocean acidification monitoring capability Limited lab equipment Research programme is conducting experiments on calcification rates, but data is not accessible Current level of public awareness and knowledge of ocean acidification is unknown	Need help with capacity building Contact science team and discuss Need to survey, create focus groups, public outreach and/or stakeholder engagement

Use this example template as a guide to develop your own gap analysis. Blank, fillable versions of all templates are available on-line.

Gap analysis - Part 2

Template 8b

Collate and itemise the gaps identified in Template 8a according to assets and capabilities. Begin by defining the current status for a given asset and capability and identifying the target that is wanted. Next, define the current capacity toward achieving the target and specify potential actions that can be taken. Include the potential economic impacts for the resource and the cost of implementing the potential actions. Lastly, rank the priority based on cost per impact or return.

Asset/ capability	Current status	Target status	capacity	Potential action	Economic risks	Cost	Priority
Coral reefs	Percent threatened unknown (potentially 40%)	5% threatened	Partial	Survey reefs where data is lacking Manage storm water and household pollution Re-seed retracted reef areas Create fishing exclusion zones	$3 million per year	$1-5 million	High
Fin fish stocks	Unknown (estimate: 50k tonnes per year)	100k tonnes per year	Adequate	Create data sharing from fishery stakeholders Develop protected marine areas to increase species abundance	$40 million per year	>$5 million	High
Coordinated regional network of monitoring stations	No monitoring stations	10 stations with central lab for analysis	Partial	Set up initiatives in each coastal jurisdiction to monitor conditions and assess the threats of ocean acidification Guide partnerships with local scientists	NA	$5 million	High
Coastal water quality	Intermittent algal blooms and failing test samples	Reduce nitrate and surface runoff	Adequate	Enforce existing regulatory measures to regulate water quality that affects enhanced coastal ocean acidification	$10 million per year	<$1 million	Low
Climate policy	Does not address ocean acidification	Include ocean acidification	Adequate	Integrate the threat of ocean acidification into existing and new climate change programs	$50 million per year	< $1 million	High
Public knowledge of ocean acidification	Unknown level of awareness	High awareness and engagement	Adequate	Survey public and launch education campaign on ocean acidification and its causes, raising public awareness and stakeholder engagement	Unknown	$1 million	Medium

Use this example template as a guide to develop your own gap analysis. Blank, fillable versions of all templates are available on-line.

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Key acronyms

BBNJ	Biodiversity Beyond National Jurisdiction
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCFAH	Commonwealth Climate Finance Access Hub
DESA	Department of Economic and Social Affairs (UN)
FAO	Food and Agriculture Organization (UN)
GCF	Green Climate Fund
GIS	Geographic Information System
GOA-ON	Global Ocean Acidification Observing Network
IAEA	International Atomic Energy Agency
IOC-UNESCO	International Oceanographic Commission of UNESCO
IOCAFRICA	IOC Sub-Commission for Africa and Adjacent Island States
IOCARIBE	IOC Sub-Commission for the Caribbean and Adjacent Region
IOCCP	International Ocean Carbon Coordination Project
IOCINDIO	IOC Regional Committee for the Central Indian Ocean
IPCC	Intergovernmental Panel on Climate Change
LAOCA	Latin-America Ocean Acidification Network
NGO	Non-governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NZPPOA	New Zealand Pacific Partnership on Ocean Acidification
OA	Ocean Acidification
OA-ICC	Ocean Acidification International Coordination Center (IAEA)
OSPAR	Oslo and Paris Conventions
PCCOS	Pacific Community Centre for Ocean Science
PNWER	Pacific Northwest Economic Region
SDG	Sustainable Development Goals
SOCAT	Surface Ocean CO_2 Atlas
SPAW	Protocol Concerning Specially Protected Areas and Wildlife
SPREP	Secretariat of the Pacific Region Environmental Programme
TBEP	Tampa Bay Estuary Program
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WESTPAC	West Pacific Hub of GOA-ON
WIOMSA	Western Indian Ocean Marine Science Association

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